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Southern Bluefin Tuna Inter-sessional Science 2015-16

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CSIRO

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The CSIRO and Department of Agriculture and Water Resources funded a related project on the implications of the cessation of the aerial survey in 2015.

The team of CSIRO scientists involved included:

Ann Preece

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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 2015/16 included:

- The regular scientific data exchange, evaluation of exceptional circumstances and indicators, review of progress in the CCSBT Scientific Research Program
- Participation and attendance at the September 2015 ESC and 2 day technical OMMP meetings, and consultation and preparation for webinars and meetings prior to the July 2015 Strategy and Fishery Management Working Group
- Preparation for running the Management Procedure (MP) in 2016 to set 2018-2020 TACs, preliminary planning for the MP review in 2017 and addressing requests for advice from the Commission, AFMA and stakeholders.

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

Key agreements were reached by the OMMP and ESC in 2015 on the future science needs of the management procedure, the scientific research program and the CCSBT work plan for the next several years. These recommendations were supported by the Commission. The primary outcomes from the work undertaken in this project are:

- The OMMP advised and the ESC and recommended to the Commission the need for a fishery independent recruitment index for use in the current and new MPs. The OMMP advised and ESC agreed that a CPUE-only MP would not provide acceptable rebuilding, performance given results of simulation tests (Anon 2015a).
- The 2015 ESC considered meta-rules and exceptional circumstances associated with four issues (see Davies et al, 2015a): 1) no aerial survey or recruitment index in 2015; 2) the identification, but uncertain quantification, of Un-Accounted Mortality (UAM); 3) the shift in Indonesian size/age data (2013-2015), and; 4) the potential that the aerial survey may not continue beyond 2016. Of these, 1 and 4 were resolved with agreements to resume the survey in 2016, and 2 and 3 remain unresolved and will be discussed further at the 2016 ESC.
- Preparation for running the MP in 2016 is underway with code changes completed (Hillary et al, 2015a) and preliminary examination of results using the data available to date.
- Recommendations for the Terms of Reference and issues of importance in the MP review scheduled for 2017 were incorporated into the outline and timeframe for development of a new MP and into the 2016 OMMP agenda (Davies et al, 2015a).

- The ESC recommendations from the review of the Scientific Research Program in 2015 have been adopted by the Extended Commission.
    - A pilot gene-tagging study (2016-2017) has commenced, to test the logistics of monitoring juvenile abundance using this method (Preece et al, 2015a).
    - The new close-kin genotyping method and analysis will be used to genotype the samples collected in 2015, but not the backlog as recommended by the ESC (Bravington et al, 2015a).
    - The CCSBT has continued to fund the collection of otoliths in Indonesia and collection of tissue samples for the close-kin study from juveniles and adults (Farley et al, 2015).
    - The collection of ovaries for maturity analysis, using a new histological method (see Farley et al (2013)), commenced in 2014 in Australia and by other CCSBT members, but the Australian collection has not yet reached the required sample size. CSIRO and AFMA are discussing opportunities to collect these samples. SBTMAC has listed this as high priority research in Dec 2015.

This SBT Inter-sessional Science 2015-16 project covered the planned priority items in the 2015 CCSBT work program, the AFMA SBT strategic plan, and the work up to June 2016 on the CSIRO components of the CCSBT 2016 data exchange. All the objectives of the project have been met.

Following from the scientific meetings, the Extended Commission has agreed to run the existing MP in 2016 to recommend the 2018-2020 TAC (subject to consideration of meta-rules in 2016), and to pursue development of a new Management Procedure. This agreement will benefit the Australian SBT fishery, given the potential disruption and uncertainty that would likely have ensued if the MP had been suspended.

Keywords
Southern bluefin tuna, Commission for the Conservation of Southern Bluefin Tuna, operating models, management procedure, exceptional circumstances

1 Background

Through the SBT Inter-sessional Science Project, CSIRO provides scientific support and advice to AFMA, ABARES, Department of Agriculture and Water Resources and Australian Industry, and participates in the Australian delegation to the CCSBT Extended Scientific Committee (ESC). The CCSBT ESC and inter-sessional science work schedule in 2015/16 included the regular 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, as well as preparation for running the Management Procedure (MP) in 2016 to set 2018-2020 TACs, and preliminary planning for the MP review in 2017.

In addition to the regular work plan and schedule of activities adopted as part of the management procedure, the 2014 meeting of the Extended Commission (EC) also requested:

1) Consideration of the process for implementation of new information on unaccounted mortalities in the management procedure,

2) Provide advice on the science items identified in the CCSBT performance review for the development of a CCSBT strategic plan and action plan, and,

3) Consider the management procedure work that will be required given the absence of the aerial survey abundance index in 2015 and potentially in 2016 and beyond.

The cessation of the aerial survey in 2015 meant that the data required for the index would not be available for use in the management procedure for that year. This had large implications for the work program and management of the fishery, which included the possibility that it would be considered “exceptional circumstances” under the meta-rules for the MP implementation, code changes would be required to accommodate the missing year and, if the index were no longer available into the future, a new MP would need to be developed and fully evaluated. The work to provide advice on the implications of cessation of the aerial survey for a special meeting of the Commission and at the 2015 ESC was supported separately through a short project with the Department of Agriculture and Water Resources (April-Sept, 2015).

2 Need

The CCSBT adopted a management procedure in 2011 that includes the monitoring, assessment and decision rule for TAC setting along with a schedule of events; annual evaluation of stock status and exceptional circumstances, TAC setting every 3 years, stock assessment every 3 years, MP review every 6 years. This schedule of events is part of the AFMA strategic research plan for the fishery.

The proposed work in this project, for the 2015-16 financial year, covers the annual CSIRO contributions to the scheduled events for the CCSBT ESC in 2015 and the preparatory work in early 2016 for the CCSBT ESC 2016 work plan. This includes the preparation for the 2016 MP TAC calculations. These items are identified as “essential” in the AFMA strategic research plan and in the CCSBT ESC work plans.

The MP TAC setting and stock assessment processes faced two challenges with the cessation of the scientific aerial survey in 2015, and potentially beyond, and from the possible impacts from sources of mortality that had not been accounted for in the original design and testing of the MP. This project addresses the second of these challenges and provides advice and processes for moving forward. Work on the first challenge is covered in a separate project to provide advice to the 2015 ESC, but there will be longer term work implications beyond 2015 ESC meeting, resulting from recommendations from that ESC meeting and decisions taken subsequently by the Commission, based on those recommendations e.g. development of a new management procedure.

This work program provides scientific advice and stock assessment advice to the SBTMAC and AFMA and covers the preparation and attendance at domestic and international meetings.

3 Objectives

Objectives of the project:

1. Prepare for and attend 2015 ESC and 2 day OMMP technical workshop (Sept 2015, Korea).
2. Provide data for CCSBT Data Exchange May 2016, contribute to updating operating model (OM) and management procedure (MP) data files, and provide advice on exceptional circumstances and the meta-rules process to the 2015 ESC.
3. Prepare for and attend OMMP meetings: June 2016 (USA).
4. Commence preparations for running the MP in 2016 for 2018-2020 TAC recommendations or prepare to provide alternative advice if MP cannot be run.
5. Commence discussion of requirements for the Management Procedure review in 2017.
6. Review Scientific Research Program activities.
7. Provide advice on process for dealing with unaccounted mortalities and MP and stock assessment implications.
8. Provide advice on science priorities prior to the CCSBT Strategy and Fisheries Management Working Group meeting, and to the ESC.

4 Results and Discussion

The project results are discussed for each objective below:

4.1 Objective 1: 2015 ESC and OMMP preparation

Prepare for and attend 2015 ESC and 2 day technical workshop (Sept 2015, Korea).

CSIRO prepared and presented a set of papers for the 2015 ESC and two day technical OMMP meeting (listed below) and participated in preparatory webinars and meetings prior to the Strategy and Fisheries Management Working Group. Paper writing was funded through specific contracts with AFMA, Department of Agriculture and Water Resources, and the CCSBT. Ann Preece, Campbell Davies and Rich Hillary, from CSIRO, attended the OMMP (30-31st August) and ESC (1-5th Sept) meetings, presented these papers, lead and participated in discussions, completed technical model changes and runs at the meetings, and rapporteured meeting reports.

CSIRO's 2015 ESC papers (Appendices 1-6):

- Davies C, Preece A, Hillary R. 2015a. Meta-rules for implementation of CCSBT Management Procedure and consideration of exceptional circumstances and 2017 scheduled review of MP. CCSBT-ESC/1509/12.
- Farley J, Eveson P, Clear N. 2015b. An update on Australian otolith collection activities, direct ageing and length at age keys for the Australian surface fishery. CCSBT-ESC/1509/13.
- Farley J, Davies C, Preece A. 2015c. Update on Scientific Research Program activities. CCSBT-ESC/1509/15.
- Farley J, Nugraha B, Proctor C, Preece A. 2015a. Update on the length and age distribution of SBT in the Indonesian longline catch. CCSBT-ESC/1509/14.
- Hillary R, Preece A, Davies C. 2015a. Technical changes in the MP to account for missing aerial survey data. CCSBT-OMMP/1508/4.
- Preece A, Hillary R, Davies C, Farley J, Eveson P. 2015b. Implications of cessation of the aerial survey for the MP and TAC setting. CCSBT-ESC/1509/09. Funded by the Department of Agriculture and Water Resources.

In addition CSIRO prepared 4 CCSBT funded papers on science research projects:

- Preece A, Eveson P, Davies C, Grewe P, Hillary R, Bravington M. 2015a. Report on gene-tagging design study. CCSBT-ESC/1509/18. Funded by the CCSBT.
- Preece A, Eveson P, Davies C, Grewe P, Hillary R, Bravington M. 2015c. Updated cost of pilot gene-tagging: Addendum to CCSBT-ESC/1509/18 Report on gene-tagging design study. CCSBT-ESC/1509/40. Funded by the CCSBT.
- Bravington M, Eveson P, Grewe P, Davies C. 2015. SBT Close-Kin Mark-Recapture: options for the medium term. CCSBT-ESC/1509/19. Funded by the CCSBT
- Anderson E, Waples R, Bravington M. 2015. Reviews of CCSBT-ESC/1509/19: "SBT CKMR: Options for the Medium Term". CCSBT-ESC/1509/36. Funded by the CCSBT.

Additional technical analysis on issues related to the value of the aerial survey as a fishery independent recruitment index and the performance of the management procedure, were undertaken by CSIRO during the OMMP meeting and considered in detail (Anon 2015b). These analysis had a substantial bearing on the advice of the OMMP to the ESC and the ESC recommendations to the Commission. These included the agreement by the ESC that a CPUE-only MP would not provide acceptable rebuilding performance, given the objectives of the CCSBT rebuilding plan, and that a fishery independent recruitment index was required in the current, and potential future management procedures.

4.2 Objective 2: 2015 consideration meta-rules, 2016 data exchange

Provide data for CCSBT Data Exchange May 2016, contribute to updating operating model (OM) and management procedure (MP) data files, and provide advice on exceptional circumstances and the meta-rules process to the 2015 ESC.

The CSIRO components of the CCSBT data exchange in 2016 are largely complete. The remaining items will be completed in June 2016. Data files are updated with available data (to date). Papers on data exchange items will be provided to the 2016 ESC, and discussion and consultation on these data were provided at SBT meetings held in Canberra in May, 2016.

Advice was provided to the 2015 ESC on the meta-rules process for implementation of the MP, and consideration of exceptional circumstances (Davies et al 2015a; Anon 2015a). The paper outlined the items for consideration as exceptional circumstances under the meta-rules for the MP in 2015: i) the missing 2015 aerial survey data point; ii) the identification, but uncertain quantification, of Un-Accounted Mortality (UAM); iii) the shift in Indonesian size/age data (2013-2015), and; iv) the potential that the aerial survey may not continue beyond 2016. Items 1 and 4 were resolved by changes to the MP code and recommendations and subsequent agreement by the Commission to conduct the aerial survey in 2016. The shift in Indonesian size and age data may be resolved with data recently provided by Indonesia to identify location of catches. Item 2, the UAM, remains an item for further progress in MP and stock assessment in 2016, as outlined under the objective below.

4.3 Objective 3: Preparation for 2016 OMMP

Prepare for and attend OMMP meetings: June 2016 (USA).

The CCSBT did not schedule the OMMP 2016 for June as expected, but instead attached a two day OMMP meeting to the ESC meeting in September 2016 in Taiwan. It was anticipated that the June OMMP meeting would be focussed on a number of technical issues associated with the OMs and preliminary runs of the MP in preparation for the 2016 ESC. The OMMP 2016 meeting terms of reference have substantially broadened given the agreements at the 2015 Extended Commission to include transition to a new MP.

The preparatory work anticipated for this objective has still been completed. It involved the preliminary runs of the MP and consultation with AFMA and ABARES on these results. Not all data are currently available (i.e. Japanese Longline CPUE) and hypotheses for these (i.e. dummy data for the MP) have been used in the preliminary examination of the likely MP outcomes and related advice to AFMA and ABARES. As soon as the longline CPUE data are available to the CCSBT, the data files will be updated and preliminary results will be discussed with AFMA and ABARES and inter-sessionally as required with members of the CCSBT and Advisory panel.

4.4 Objective 4: Preparation for 2016 MP TAC recommendations

Commence preparations for running the MP in 2016 for 2018-2020 TAC recommendations or prepare to provide alternative advice if MP cannot be run.

Preparation for running the MP in 2016 commenced prior to the 2015 ESC. The Strategy and Fisheries Management Working Group (Anon 2015c) agreed that a reduced aerial survey will be conducted 2016, which will provide the 2016 aerial survey data for use in the MP. Modifications have been made to the MP code to allow for the missing index in 2015 (Hillary at al 2015a) and these have now been incorporated into the stand-alone version of the software. Should the MP fail to provide TAC advice, because of exceptional circumstances or failure of the aerial survey for technical or logistical reasons, potential alternatives for providing TAC advice have been discussed (Davies et al 2015a).

4.5 Objective 5: Requirements for 2017 MP review

Commence discussion of requirements for the Management Procedure review in 2017.

The requirements for a review of the management procedure are discussed in Davies et al, 2015a, and the issues and potential terms of reference for the review are outlined. The review was scheduled for 2017 as part of the meta-rules for the MP, following completion of 3 TAC decisions (2011, 2013 and 2016). The timing of the review was based on several considerations, including, passing of sufficient time for i) several TAC decisions to be made by the Commission and a reasonable probability of observing a response in the stock, and ii) development and testing of alternative monitoring series to allow for an orderly transition from the agreed MP to a modified/new MP if required.

The decisions at the Extended Commission in 2015 to transition to a new MP will affect the focus of the review. Recommendations for the Terms of Reference and issues of importance in the 2017 MP review were incorporated into the outline and timeframe for development of a new MP and into the 2016 OMMP agenda (Davies et al, 2015a), and will inform the review work to accompany development of a new MP over the period 2016-2019.

4.6 Objective 6: CCSBT Scientific Research Program

Review Scientific Research Program activities.

The CCSBT Scientific Research Program was finalised at the 2014 ESC and included the following 5 components in the 2015 work plan:

4.6.1 Design study for a gene-tagging program

The gene-tagging design study was funded by the CCSBT in 2015 and a report was provided to the 2015 ESC (Preece et al, 2015 a, c). The report discusses and refines the experimental design most appropriate for a pilot gene-tagging program to estimate abundance of recruits (2yr olds), following the preliminary work in Preece et al (2013). A pilot study to test the feasibility and logistics for the simplest gene-tagging design was recommended, and has subsequently been agreed to at the ESC and funded by the CCSBT in 2016.

4.6.2 Design study and expert review of future close-kin mark-recapture approaches

The CCSBT funded a design study for the SBT close-kin mark recapture approaches for direct monitoring of the adult component of the SBT stock. The report by Bravington et al. (2015) proposes the use parent-offspring pairs and half-sibling-pairs in the analysis and a new more informative, robust and cheaper genotyping method. The report recommends the processing of the back-catalogue of close-kin samples. The methods were reviewed by independent, external experts, Dr Robin Waples, NOAA Seattle, USA and Dr Eric Anderson, NOAA Santa Cruz, USA. The reviews were provided in working paper CCSBT-ESC/0915/36 (Anderson et al, 2015). Funding for processing of the samples collected in 2015, using the new genotyping methods, has been granted by the CCSBT to ensure that the unprocessed back catalogue collection does not get any larger. Funding for the processing of the existing collection of samples (2006-2014), is currently being sought through a related FRDC/CSIRO/ASBTIA proposal (Davies, pers comm. 2016).

4.6.3 Ageing of Indonesian SBT otoliths

Farley et al. (2015a) provided an update of the length and age distribution of SBT in the Indonesian catch. The CCSBT funded ageing of the Indonesian otoliths in 2015. The Indonesian monitoring program has collected data and samples in 22 spawning seasons 1993/94 to 2014/15, and considerable change has occurred in the size and age distribution of SBT landed by the Indonesian longline fleet since monitoring began. It is not known whether the small/young SBT landed in recent years (2013-2015) were caught on or south of the SBT spawning ground, and whether they should be considered part of the SBT spawning population. The Indonesian age frequency data (from direct ageing) are used in the SBT operating models; and the fishery selectivity estimates from the operating models are used in projections and to test the management procedure. The Indonesian monitoring data are also an important input to the close-kin (CK) estimation model. The issue of whether or not the small fish in the size composition were caught on or off the spawning ground needs to be resolved at the 2016 ESC.

4.6.4 The continued collection and archiving of tissue samples for close-kin genetics

Farley et al. (2015a) provides an update on progress in the sampling program for close-kin tissue and otoliths. Tissue samples from juvenile and adult SBT for close-kin genetic analysis have been collected annually since 2006. In 2014, the CCSBT allocated funding to continue tissue sampling in Port Lincoln (1600 samples) and in Benoa (1609 samples) during the 2014/15 fishing season.

4.6.5 The collection of ovaries and otoliths for an independently estimated maturity ogive.

Farley et al. (2015c) provides an update on progress in the sampling program for ovaries and otoliths for maturity estimation, and requirements for the CCSBT maturity workshop. There remains uncertainty in the size and age of maturity for SBT and the functional form of the maturity schedule due to the lack of a targeted study of samples collected off the spawning ground in the non-spawning season. In 2014, a costed proposal for developing an independent estimate of the SBT maturity schedule (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 beyond. Samples (ovaries and otoliths) from 220 female SBT are required from statistical area 4 (Australia's east coast) during April to August. In 2014, Australian observers collected 19 ovary samples, and it was anticipated more samples would be collected in 2015, however this did not occur. Sample collection by other members (New Zealand, Taiwan, Japan and Korea) has occurred in other statistical areas. The SBTMAC agreed that this research was a 'High Priority' in December 2015 and that AFMA would discuss the collection with the AFMA observer section. There is currently no funding for collection of ovaries and otoliths or processing of the otoliths and histology. The workshop is currently scheduled for 2017.

In 2015, the ESC work plan listed a 3-day workshop to review otolith sampling design and age estimation/calibration as a priority for 2016. Indonesia's Research Institute for Tuna Fisheries was identified to host the workshop. The proposed aims are to: 1) Review otolith extraction, sectioning and reading methods including any recent age validation work, 2) Provide capacity building training for members who have not been involved in SBT age estimation, 3) Improve age estimation protocols and quality control procedures (checking precision and drift), 4) Update otolith reference set for among laboratory comparisons and determine a future quality control agenda, and 5) Revise the age determination manual with respect to methods related to reading otolith margins. This workshop is currently scheduled for 2017.

4.7 Objective 7: Unaccounted mortalities

Provide advice on process for dealing with unaccounted mortalities and MP and stock assessment implications.

Davies et al. (2015a) considers the implications for the management procedure and stock assessment of unaccounted mortalities (UAM), and a process for incorporating this uncertainty in future MP evaluation and tuning. The original MP design and testing assumed total removals were reported exactly and made no allowance was for UAM beyond implementation of the MP in 2011. Work completed by OMMP Working Group and ESC in 2014 indicated that plausible ranges of UAM can compromise the likely performance of the MP for stock rebuilding and future catches (Preece et al., 2014 and Anon 2014).

The ESC 2014 results indicated, for the scenarios examined, that the UAM was likely to have little impact on current stock status; but potentially substantial impacts on the performance of the MP and rebuilding of the SBT stock, if the unaccounted mortalities are occurring and continued into the future (Anon, 2014; Preece et al, 2014). The 2014 ESC could only use simple scenarios for the level and trajectory of potential UAM in the evaluation because there is very limited information or data on the specifics of the potential unaccounted mortalities available from the Commission and Compliance Committee. Limited new data became available in 2015, and access to data requested by the ESC is unresolved.

Incorporating implementation error in the MP TAC setting and testing is suggested as a method for accounting for the uncertainties associated with un-accounted mortalities in the MP (Davies et al, 2015a). Re-tuning with this additional error could also be considered in future testing of MPs. However, the limited new data available to specify the UAM scenarios constrains the ability of the ESC to provide robust advice on the implications for stock status and performance of the MP. The ESC has made a strong recommendation on the need to provide more specific estimates of the likely scale and nature of UAM so that this can be incorporated in their advice on TAC in 2016 and also in the stock assessment scheduled for 2017.

4.8 Objective 8: Science priorities advice to SFMWG and ESC

Provide advice on science priorities prior to the CCSBT Strategy and Fisheries Management Working Group (SFMWG) meeting, and to the ESC.

CSIRO participated in a series of Inter-departmental meetings, and planning and information discussions with ABARES and AFMA in preparation for the July 2015 SFMWG meeting and the ESC and OMMP meetings, to address the implications of cessation of the aerial survey in 2015 (Preece et al, 2015b). CSIRO also participated in technical inter-sessional web meetings with CCSBT member scientists to provide advice to the SFMWG on the logistics of running the aerial survey (Davies 2015b,) and implications of a reduced precision aerial survey (Hillary et al 2015b, Anon 2015d).

The SFMWG requested additional advice from the ESC on research priorities and costs and benefits of the current MP. Preece et al (2013b) outlined the role of the aerial survey in recruitment monitoring, the CCSBT operating models and the MP, and the costs and benefits of aerial survey data and alternative information on recruitment. Davies et al (2015a) outlined potential future work plan scenarios and costs and benefits for consideration at the 2015 ESC.

Research priorities for the ESC addressed the immediate need for continued operation of the current MP, resolving UAM, followed by an orderly transition to a new MP over the coming years (all have been identified as essential or high priorities by the ESC). Also included are data collection activities essential for the OM, data for future monitoring programs, and projects that are investigating cost-effective abundance estimation and monitoring methods.

The ESC provided firm advice for consideration by the Commission on the way forward. The components of the CCSBT scientific research program were discussed and the ESC recommended that the gene-tagging pilot study should commence in 2016, the backlog of close-kin samples should be processed in time for the 2017 reconditioning of the OM and stock assessment, and the maturity workshop and age validation work remain as high priority research.

The ESC work plan for 2016-2018 incorporates the decision by the Commission to transition to a new MP and priority scientific research activities. The Extended Commission subsequently funded the gene-tagging pilot project, 1 year of processing of close-kin samples but not the processing of the archived samples, and the maturity and ageing workshops have been re-scheduled for 2017.

Ann Preece and Campbell Davies attended the SBTRSC and SBTMAC in September 2015 and an SBTMAC teleconference in December 2015.

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, 2016) which is used to set the global TAC, and encompasses meta-rules that provide a timeframe and basis for review of data, methods, and MP performance. The management procedure provides for stability, certainty and sustainability of the Australian TAC, the benefits of which have been attested to by Industry, and assists in planning and scoping the future inter-sessional science work plans.

In 2015, through this project, CSIRO provided substantial input to the inter-sessional science webinars, 2015 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. Following from these scientific meetings, the Extended Commission has agreed to run the existing MP in 2016 to set the TAC (subject to consideration of meta-rules in 2016), and to pursue development of a new Management Procedure. The Extended Commission agreed that the new management procedure will use gene-tagging abundance estimates as the index of recruitment, even though this is a new technique and limited data will be available. The existing schedule of events for the MP remains in place, with a stock assessment in 2017 and MP-based recommendations for the 2021-2023 TAC block in 2019. This represents a substantial collective achievement and benefit to the Australian SBT fishery, given the potential disruption and uncertainty that would likely have ensued if the MP had been suspended.

Accounting for all sources of mortality remains an issue for scientific evaluation and performance of the MP in rebuilding the SBT stock, in addition to providing robust scientific advice on stock status. No substantial new information was provided in 2015, and the ESC will again address this issue in 2016 in the context of meta-rules for the MP, and TAC advice to the Commission. Incorporating an implementation error term has been recommended as one mechanism for incorporating this source of uncertainty directly in the MP and this will be further considered in preparation of the operating models for future stock assessment and Management Strategy Evaluation work.

The preparatory work for the 2017 review of the management procedure helped inform the steps required to transition to a new management procedure over the next several years and the ESC and Commissions consideration of future monitoring and research priorities. These have been included in the OMMP and ESC work plans and meeting agendas for 2016 and the Commissions new 3 year budget planning process.

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 2016. These research programs often have flow on effects for other Australian and International fisheries, potentially leading to improved global management of other stocks.

The benefits of work undertaken in this project are in government, industry and community confidence in the SBT rebuilding strategy and MP implementation program, and that the management of the fishery and process for setting the global TACs is based on the best scientific advice.

Government, managers, industry and stakeholders benefit directly from briefings, consultation and advice on the work prepared for the ESC and related meetings.

6 Conclusion

This SBT Inter-sessional Science 2015-16 project covered the planned priority items in the 2015 CCSBT work program, and the work up to June 2016 on the CSIRO components of the CCSBT 2016 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 2015 OMMP technical meeting and ESC meeting, and provided briefings, consultation and advice to AFMA, ABARES, Industry and SBTMAC.

Preparations for running the management procedure, scheduled to provide TAC advice in 2016, are underway, with changes to code to incorporate the missing aerial survey, and data files prepared as far as possible for preliminary runs (final data for the MP is due 15th June).

The Extended Commission has requested that the ESC transition to a new Management Procedure that will use gene-tagging data as the recruitment index. This brings forward and alters the normal MP review process. Development 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. The MP schedule of events involves TAC setting in 2016 using the existing MP, a full stock assessment in 2017, MP development 2016-2019 and TAC setting using a new MP in 2019 if the MP work has been completed in time.

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

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8 Appendices

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A.6 Preece A, Hillary R, Davies C, Farley J, Eveson P. 2015b. Implications of cessation of the aerial survey for the MP and TAC setting. CCSBT-ESC/1509/09. Funded by the CSIRO and Department of Agriculture and Water Resources.

Appendix A.1

Davies C, Preece A, Hillary R. 2015a.

Meta-rules for implementation of CCSBT Management Procedure and consideration of exceptional circumstances and 2017 scheduled review of MP.

CCSBT-ESC/1509/12.

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Meta-rules for implementation of CCSBT Management Procedure and consideration of exceptional circumstances and 2017 scheduled review of MP

Campbell Davies, Ann Preece and Richard Hillary

CCSBT-ESC/1509/12

Twentieth Meeting of the CCSBT Scientific Committee, 1 - 5 September 2015, Incheon, South Korea

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Contents

Abstract

The Meta-Rules for the CCSBT Management Procedure (MP) provide the agreed over-arching framework for the implementation of the Commission's MP. This framework includes the objectives and performance measures for the rebuilding of the stock; the detailed specification of the MP itself (monitoring series, analyses, harvest control rule and implementation); the schedule for TAC recommendations, periodic assessments of stock status, formal review of MP performance; and the process and criteria for identifying exceptional circumstances (i.e. circumstances/events outside the range for which the MP was tested during the Management Strategy Evaluation (MSE) phase of development).

This paper reviews the purpose and function of the Meta-rules in the implementation and review of the CCSBT MP, with a particular focus on: i) the identification of exceptional circumstances and the actions that may flow from this, ii) the events that have been identified, or may be identified, as exceptional circumstances by the ESC, and; iii) the issues that need to be considered in the context of the ESCs preparation for the first formal review of the performance of the MP against the Commission's objectives thus far (i.e. 2011-2015). This includes initial consideration of the recent requests from the 4th meeting of the Strategy and Fisheries Management Working Group (28-30 July 2015) and their potential implications for the current MP, TAC advice from the ESC and the ESC's short and medium term work program.

The 20th meeting of the ESC will consider whether the following events represent exceptional circumstances under the meta-rules for the MP: i) The missing 2015 aerial survey data point; ii) the identification, but uncertain quantification, of Un-Accounted Mortality (UAM); iii) the shift in Indonesian size/age data (2013-2015), and; iv) the potential that the aerial survey may not continue beyond 2016. In our view, the first two items constitute exceptional circumstances. The missing 2015 aerial survey data point can be accommodated within the random effects component of the existing MP harvest control rule, and hence, the MP can be used to recommend the 2018-2020 TAC in 2016, assuming the 2016 aerial survey index is available. The MP testing assumed total removals were reported exactly and no allowance was provided for UAM beyond 2011. Hence, in principle, UAM is exceptional circumstances and, in practice, the work completed by OMMP Working Group and ESC in 2014 indicated that plausible ranges of UAM can compromise the likely performance of the MP for stock rebuilding and future catches. The shift in Indonesian size/age data is yet to be fully considered by the ESC. However, CCSBT-ESC/1509/14 indicates a substantial change that has implications for the impact of the Indonesian fleet on the stock. It also has implications for the use of these data in the OM (for the 2017 reconditioning) and for Close-kin abundance estimation. Consideration of the potential for the aerial survey not to continue beyond 2016 is less straightforward in the context of exceptional circumstances, as it is a potential future event. However, were it to transpire, it would clearly represent exceptional circumstances as: i) it would not be possible to use the agreed MP to recommend future TACs, and; ii) there would be no recognised source of recruitment monitoring available to replace it. Such a situation would require the development of new recruitment indices, new MPs and full MSE testing at considerable addition cost and time before a robust MP could be used to

recommend TACs consistent with the Commissions objectives for minimising the risk of future declines and rebuilding the spawning stock.

The Meta-rules include a scheduled review of the MP in 2017, which will follow completion of 3 TAC decisions (2011; 2013 and 2016). The timing of the review was based on several considerations, including, passing of sufficient time for i) several TAC decisions to be made by the Commission and a reasonable probability of observing a response in the stock, and ii) development and testing of alternative monitoring series to allow for an orderly transition from the agreed MP to a modified/new MP if required. The recently reinstated CCSBT Scientific Research Plan was developed and prioritised with this focus and schedule in mind and the Commission and members have funded some of the work required to achieve these goals. This paper outlines some of the issues the ESC will need to consider at its 20th meeting in light of the decisions made by the Commission in 2015 and the requests from the July 2015 meeting of the SFMWG.

1 Introduction

The Management Procedure (MP) specifications and meta-rules for the CCSBT Management Procedure (Anon 2013, Attachment 10) provide the agreed, over-arching framework for the implementation of the Commission's MP. This framework includes the objectives and performance measures for the rebuilding of the stock; the detailed specification of the MP itself (monitoring series, analyses, harvest control rule and implementation); the schedule for TAC recommendations, period assessments of stock status and formal review of MP performance; and the process identifying exceptional circumstances (i.e. circumstances or events outside the range for which the MP was tested during the Management Strategy Evaluation (MSE) phase of development) that indicate that following the TAC recommendations of the MP may be highly risky or highly inappropriate.

This paper reviews the purpose and function of the Meta-rules in the implementation and review of the CCSBT MP, with a particular focus on: i) the identification of exceptional circumstances and the actions that may flow from this, ii) the events that have been identified, or may be identified, as exceptional circumstances by the ESC, and; iii) the issues that need to be considered in the context of the ESCs preparation for the first formal review of the performance of the MP against the Commission's objectives thus far (i.e. 2011-2015). This includes initial consideration of the recent requests from the 4th meeting of the Strategy and Fisheries Management Working Group (SFMWG, 28-30 July 2015) and the potential implications for the current MP, TAC advice from the ESC and the ESC's short and medium term work program.

It is structured into the following four sections:

1. MP specification and role of meta-rules
2. Exceptional circumstances
3. Initial considerations on TORs and process for 2017 MP review
4. Preliminary considerations on request for advice from SFMWG

2 MP specification and role of meta-rules

2.1 Meta-rules and MP implementation

"*Meta-rules can be thought of as "rules" which pre-specify what should happen in unlikely, exceptional, circumstances when application of the total allowable catch (TAC) generated by the management procedure (MP) is considered to be highly risky or highly inappropriate."*

In essence, the meta-rules are intended to guide scientists and managers in the event that situations arise that are outside the range for which the management procedure was tested and, therefore, there is some likelihood that the TACs recommended by the MP may not result in the rebuilding of the stock with the probability specified by the Commission.

The meta-rules process involves the following three steps:

1. Determining whether exceptional circumstances exist,
2. A "process for action" that examines the severity 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.

It also includes a schedule for review of 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 last assessment of stock status was completed in 2014. The first MP review is scheduled for 2017 (Anon. 2013, Attachment 10).

It is also worth noting, that while the simulation testing of the MP was done over a 40 year (projected) time horizon, the ESC did not have the expectation that the same MP would, necessarily, be used for the duration of the rebuilding period. The central consideration is that the total removals from the stock are consistent with the level of fishing mortality required to provide for the rebuilding, conditional on the perception of the status and productivity of the stock at the time of the MP testing and implementation.

In this context, the multiple frequency and "depth" of reviews specified in the Meta-rules provide a regular feedback mechanism to assess whether the MP is performing "as expected". That is, as we expected, given what we knew at the time.

It is also evident, from the CCSBT Scientific Research Plan recommended by the ESC in 2013 and adopted by the Commission, that appropriate consideration has been given to information and alternative monitoring series that are likely to a) improve the ESC's ability to assess stock status (Bravington and Davies 2012, Bravington 2014, Bravington et al 2015; Farley et al. 2015a) and, potentially, provide more accurate and/or cost-effective methods to monitor different components of the stock into the future (Harley et al 2008, Davies et al 2008; Basson and Davies 2008; Itoh and Takahashi 2014, Ping et al 2013, 2014; Preece et al 2013; Preece et al 2015).

3 Exceptional Circumstances

As noted above, exceptional circumstances are events, or observations, that are outside the range for which the management procedure was tested and, therefore, indicate that application of the total allowable catch (TAC) generated by the management procedure (MP) is considered to be highly risky or highly inappropriate.

The 20th meeting of the ESC will consider whether the following events represent exceptional circumstances under the meta-rules for the MP: i) The missing 2015 aerial survey; ii) the identification, but uncertain scale, of Un-Accounted Mortality (UAM) since the implementation of the MP and, potentially into the future; iii) the marked and unexpected shift in Indonesian size/age data (2013-2015), and; iv) the potential that the aerial survey may not continue beyond 2016.

In considering the potential for exceptional circumstances arising from these events, 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, 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 in the context of exceptional circumstances. However, the ESC will also discuss 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..

3.1 Cancellation of the 2015 Aerial survey

The absence of the aerial survey data in 2015 triggers exceptional circumstances because these data are essential to the operation of the adopted management procedure, and it generates logistical vulnerabilities to re-starting the aerial survey. The latter could mean it is no longer possible to operate the agreed MP and hence directly impact on the tested SBT rebuilding plan.

The ESC has undertaken, inter-sessionally, a technical evaluation of running the MP without the 2015 data point and for a reduced aerial survey in 2016 at the request of the Commission. The ESC has agreed that if there is aerial survey data in 2016, the MP can be used to recommend TACs in 2016.

The 2016 and 2017 TACs (set in 2013) would not need to be altered due to the absence of aerial survey in 2015, i.e. the severity of the exceptional circumstances is low, because the MP can be run in 2016 if there is a 2016 aerial survey. However, the absence of all recruitment monitoring information in 2015 is of concern, as are the other sources of exceptional circumstances. These are addressed individually below.

3.2 Lack of recruitment monitoring information

The lack of recruitment information in 2015 triggers exceptional circumstances. All recruitment monitoring programs ceased in 2015. There is no information on the level of recruitment to the youngest age classes (2-4 year olds) to inform the review of indicators or the most recent trends. These data would have been used as part of the annual assessment of whether the data used in the MP (and predicted likely values from the OM) are within or outside the bounds under which the MP was tested.

We consider the severity is “moderate”, given the recent trends in recruitment have been positive and above the historically low levels seen in the early-mid 2000s and 2012. However, if the ESC concludes that the aerial survey index is too variable or unreliable (i.e. as contended in CCSBT/ESC/0915/20), then this would also reflect on the recent trends from the OM, which are highly informed by the AS data. While we do not consider the latter to be the case (see Preece et al, 2015), it would also imply that the recruitment estimates from the OM are biased by the aerial survey index.

The actions that should be considered by the ESC are that new informative recruitment monitoring data need to be collected as soon as practical and a times series collated for use in OMs and future MPs. Actions on modifying TACs are not necessary, given that the MP can still be run effectively (assuming the 2016 survey index is available) and the Extended Commission has agreed to continue the survey for at least 2016.

3.3 Failure or cancellation of the aerial survey in 2016

Failure or cancellation of the aerial survey in 2016 will trigger exceptional circumstances in 2016 because the MP would not be able to be used to recommend 2018-2020 TACs. It would also mean i) a new management procedure would need to be developed and tested to continue the implementation of the rebuilding plan for the stock and ii) some form of ad hoc method for providing advice on TACs to the Commission would be required in lieu of new tested MP.

The ESC will need to develop specific principles and processes for action (as specified in the Meta-rules) to assess the implications for the 2017 TAC and develop an approach for how to advise on the setting of the 2018-2020 TACs. There will be no aerial survey information on recruitment in 2015 and 2016 and, at present, no other information on the strength of recent year classes. This would substantial limit the ESC’s ability assess changes to stock dynamics, and impacts of fishing operations, as required under the Meta-rules, particularly given that a large proportion of the global catch is on younger (1-4 yr) age classes (Preece et al 2015).

Inclusion of recruitment monitoring information in the MP has been considered important requirement by the ESC since 2008 and this will continue to be the case until the spawning stock has been rebuilt to a level that can maintain long-term average levels of recruitment. Currently there is no alternative recruitment monitoring series to replace the aerial survey (see Preece et al 2015) that could be used to develop and test a new MP before 2019. The timeframe for collection of sufficient new recruitment data to use in an MP may be in the order of 6-7 years. Should this scenario eventuate, we would consider this severe, as it would mean the current MP would be inoperable, there would be a lack of reliable recruitment monitoring and a substantial delay in best-practice management while developing both a new monitoring series and MP at a time when the stock status remains depleted.

In summary the actions that the ESC would need to consider under this scenario are:

1. Develop a new recruitment monitoring time-series for use in OM and MP.
2. Develop a new MP and complete full MSE testing, adoption and implementation.
3. Develop options for interim TAC advice, including, but not restricted to: maintaining status quo, TAC reductions given the uncertainty in recent recruitment, "risk equivalent" constant-catch projections for interim TAC information, acting with precaution (by, for example, adjusting the 2017 TAC downwards and/ or recommending conservative 2018-2020 TACs).

3.4 Indonesian selectivity changes

The last 3 years has seen a substantial shift in the length and age frequency of fish in the catches of Indonesian longline fishery (Farley et al, 2015b). As part of the 2014 reconditioning of the OMs, the selectivity constraints in the SBT operating models were relaxed to provide the flexibility to fit the shift in the data (Anon 2014a). It is unclear whether this change has arisen from a change in the age-structure on the spawning grounds, or if a proportion of the fish landed in Indonesia is being caught away from the spawning grounds.

In 2015 we do not consider this issue, on its own, to represent exceptional circumstances. However, the issue will be important to address directly in the next stock assessment (2017), as part of the MP review, and hence may trigger exceptional circumstances at that time.

It should be a high priority to determine the likely cause of this shift and, in the interim, gather as much ancillary information as possible. Attempts to resolve the catch location of the small fish, thus far, have not been successful. CDS data could potentially resolve the issue if they are available. Micro-constituent analysis of the otoliths of a subsample of small and large fish in each recent year may also shed some light on whether or not they are being caught on the spawning ground (see Clear et al 2014). The ESC will need to make recommendations and a work plan in consultation with Indonesia to resolve this uncertainty in 2016, so that the required changes in the OMs can be agreed prior to the 2017 stock assessment.

3.5 Un-Accounted Mortalities

As noted above, the design and simulation testing of the MP assumed that all removals from the stock were accounted for, i.e. the TAC was exact. In light of information provided to the ESC and the request from the Commission in 2013, the ESC evaluated the impacts of scenarios for potential UAM from a variety of sources as part of 2014 the assessment of stock status and the implications for the rebuilding plan (Anon 2014). The results indicated, for the scenarios examined, that the UAM was likely to have little impact on current stock status; but substantial potential impacts on the performance of the MP and rebuilding of the SBT stock, if the unaccounted mortalities are occurring and continued into the future. The ESC could only use simple scenarios for the level and trajectory of potential UAM scenarios in the evaluation because there is very limited information or data on the specifics of the potential unaccounted mortalities.

In 2014 the ESC agreed that the scenarios considered for potential unaccounted mortalities, if they were in fact occurring, triggered exceptional circumstances but that no urgent management action on TAC setting was required, at that time. Resolving the veracity of the current set of scenarios and provision of more detailed data is urgent and essential for accurate assessment of these impacts on the stock and MP performance. Hence, the ESC advised the Extended Commission to continue to follow the MP but, as a matter of urgency, to take steps to quantify all sources of unaccounted SBT mortality.

Attachment 5 of the ESC report (Anon 2014) identifies initiatives (data collection and analysis) that could be undertaken to improve estimation of unaccounted mortalities. The ESC encouraged all countries to make their CDS data and information on market monitoring available to facilitate and improve analyses. Reduced uncertainty on the scale and nature (size composition, area/season of capture) of UAM prior to the next scheduled MP and assessment would enable the ESC to provide a more meaningfully assessment of the impact on the stock and MP performance.

In terms of potential UAM from non-member fleets, there is no additional information from the Compliance Committee or Extended Commission. The Extended Commission recommended a market review be undertaken and this is work is being commissioned by the secretariat.

There are two papers for the 2015 ESC that have attempted to quantify potential levels of non-member UAM in the Pacific and Indian oceans by indirect methods (CCSBT-ESC/1509/21 and CCSBT-ESC/1509/10). These papers indentified potential for low-levels of non-member catches in the Indian and Pacific Oceans, noting there were substantial uncertainties and assumptions made in these analyses.

In terms of potential UAM from member fleets (Attachment 5, ESC 2014 report), national reports and papers provide some updated information (such as: CCSBT-ESC/1509/32-rev1; CCSBT-ESC/1509/BGD01).

In considering all the potential sources of unaccounted mortality and unresolved access to data since the 2014 evaluation of the impacts of UAM on the MP, the ESC should consider principles and process for action on TACs. Incorporating implementation error in the MP TAC setting and testing. Re-tuning with this additional error could also be considered in future, with the MP review in 2017 being the most obvious next opportnuity.

3.6 Summary of review of potential meta-rules outcomes

The absence of the 2015 aerial survey data, no other recruitment information in 2015, UAM and Indonesian selectivity changes are all likely to be considered exceptional circumstances because of their impacts on the input data for the MP (Aerial Survey), the ESC's ability to monitor stock status (Aerial Survey and Indonesian fleet), changes in fishery operations (in the case of Indonesian fleet) or because of their impacts on the performance of the MP and rebuilding of the stock (UAM).

Each of these was assessed individually in terms of the principles and processes for action regarding recommendations for alteration of the 2016 and 2017 TACs that were set in 2013.

The lack of an aerial survey point in 2015 combined with no other recruitment information, results in increased uncertainty around the strength of the most recent year classes, which also constitute a substantial proportion of total removals. The ESC should discuss whether more precautionary TACs are needed in the absence of robust recruitment monitoring.

The marked shift in the Indonesian size/age distribution does not currently suggest that there should be changes to the TAC, but the uncertainty in the mechanism causing this shift needs to be resolved; agreement on actions to resolve this need to be made at the 2015 ESC, so that appropriate changes can be made to the OM and data preparation to incorporate these data correctly in the 2017 stock assessment and MP review work.

The limited new data available on UAM scenarios constrains the ability of the ESC to provide robust advice on the implications for stock status and performance of the MP. This lack of progress suggests that the ESC may need to revisit the basis of its 2014 ESC advice on this issue. The Extended Commission agreed to a work plan related to UAM, which should be considered as part of this issue, and in formulating the ESC 2015 advice to the EC.

The 2015 ESC will also need to consider the extent to which the co-occurrence of these events means that their combined impacts may be more severe, in the context of the meta-rules, than when they are assessed individually.. While we have reviewed the detail of each issue/event separately, the combination of them occurring simultaneously warrants explicit consideration by the ESC and advice to the EC.

4 Initial considerations on the TORs and preparation for 2017 MP Review

The CCSBT MP was designed to:

- Reduce the risk of further declines in SSB
- Reduce the risk of further very low recruitments
- Rebuild the SSB with a high probability (~0.7) to >20% by 2035
- Use aerial survey data series as a fisheries independent input to provide early index of recruitment and mitigate against uncertainties associated with the CPUE series.

Given these objectives and inputs, reasonable ToRs for the 2017 MP review might include:

1. Review of data, including
   - Input data series to the MP. This should include a review of data collection, reliability, costs, standardisation and potential alternative data sources.
   - Review of the data predicted by the OM versus those observed in the monitoring series.
   - Review of alternative indices and new information on population and fishery dynamics
2. Review of observed MP performance for stock rebuilding, including for example
   - Estimated SSB in 2017 and projected 5yr trend from the OM
   - Estimated average recruitment and 5yr trend from the OM
   - Estimated period to achieve Pr(>0.2 SSB_0) = 0.7., currently 2035
   - Updated Close-kin estimate of abundance and trend in spawning potential

For the purposes of the review, it may be worth giving some consideration to the likely performance of the MP relative to some plausible alternatives, such as, 3 yr risk-equivalent constant catch projections or constant catch projections at F=MSY, purely for comparative purposes.

3. Review of grid and other key assumptions used in in testing and tuning.
   - M, h and B_0 interaction.
   - Re-estimate of $R_{0.}$
   - Form and values of natural mortality schedule.
   - Initial consideration on Performance measures and MP for beyond rebuilding target.
   - Given the outcome of the above, is re-tuning of the MP warranted.
4. Timetable, priority and funding arrangements for future ESC MP work program.

5 Preliminary considerations on request for advice from SFMWG

The 4th meeting of the Strategy and Fisheries Management Working Group (Anon 2015) made the following additional requests for advice from the ESC:

- ESC's relative research priorities for 2016 to 2018 inclusive, noting that the research budget is limited;
- Costs and benefits of continuing with the current MP, including conducting the aerial survey from 2017 to 2019; and
- Preliminary consideration of alternatives to the current MP approach, including an indication of their relative costs and benefits, if possible.

In addition, the SFMWG, requested that the ESC provide as much advice as possible on the relative merits of the alternatives to our current approach to the MP. This should consider questions in relation to the suitability (e.g. data quality and cost effectiveness) of developing an MP with recruitment information from sources other than the aerial survey (e.g. gene tagging, trolling survey, CPUE from young age classes etc.) or only with long-line CPUE. This will assist the EC to make a decision in relation to continuation of the aerial survey and the current MP beyond 2016. It was noted that unaccounted SBT mortalities was another issue that would need to be considered in a review of the MP and its application. Preece et al 2015 (CCSBT-ESC/1509/9) considers potential alternative sources of information on recruitment, influence and fit of the aerial survey data in the SBT OM, and costs and benefits of historical and future aerial survey data in the MP. The unresolved issue of UAM is considered directly in the section above and in future research priorities below.

5.1 Future work program scenarios, costs and benefits

To address these requests we outlined 5 alternative future work programs that incorporate combinations of aerial survey, SRP projects and MP review activities, in the context of the meta-rules, and used this framework to identify priorities and schedules SRP activities:

Option 1 - Default: The AS proceeds in 2016 and beyond, gene-tagging (GT) trial commences (conditional on GT design study outcomes, Preece et al, 2015 (CCSBT-ESC/1509/18)), MP review 2017, new MP developed for implementation.

Option 2 - AS 2016 only, GT trial commences, MP review/development, potential exceptional circumstances and TAC review in 2016/2017; no MP for TAC setting for 2019.

Option 3 - AS 2016 only, members work on CPUE recruitment series, MP review/development, potential exceptional circumstances and TAC review in 2016/2017; no MP for TAC setting for 2019.

Option 4 - No AS 2016, Exceptional circumstances, no MP to set 2018-2020.

5.1.1 **Option 1:**

This is the default option agreed by the Commission when adopting the management procedure and meta-rules process in 2011 and the SRP in 2013 and 2014 (Anon 2014): The AS proceeds in 2016 and beyond, GT trial commences, MP review 2017, new MP developed for implementation.

- AS continues: As an essential data source for the MP the aerial survey data should continue to be collected until a review of the MP and a timetable for a new MP is developed and the ESC agrees that the AS data are no longer needed. This implies that the Aerial survey should continue in 2016 and Jan-Mar 2017, at least, as the MP is scheduled for review in Sept 2017.
- GT trial commences. The SRP for 2014-2018 was finalised in 2014, and the 3 year work plan included a gene-tagging design study (completed) and a pilot study to commence in 2016, subject to outcomes of the design study. The data from gene-tagging should provide estimates of absolute abundance of juveniles, and could potentially replace the aerial survey for recruitment monitoring and potentially be used in future MP's (Preece et al, 2015).
- MP review in 2017. The review of the MP in 2017 would evaluate the performance of the current MP. In considering the data inputs to the MP, the aerial survey and CPUE data would be reviewed and if the ESC recommends that a new MP should be developed, then the agreed process is that a timetable of activities to develop, collect required data, test and implement the MP will be developed. This timetable should indicate whether or not the aerial survey data are still required and when it can stop being collected, because aerial survey data will be needed for the 2019 MP calculations if a new MP is not in place in that amount of time.
- Development of a new MP. If following the review of the MP the ESC agrees to develop a new MP then work can proceed as scheduled in the agreed timetable. The costs and time for development for the current MP were substantial. If the decision is made in 2017, it is very unlikely that a fully tested and agreed MP could be implemented in time for the 2019 TAC setting, using the new MP in 2022 may be a more realistic timeframe.

The Option 1 combination of future activities does not breach the agreed management procedure schedule of events and therefore would not trigger exceptional circumstances under the meta-rules processes. The SRP priorities agreed in 2016 would be maintained, and the development of a recruitment monitoring program based on gene-tagging could be considered as a data input for a new MP. Costs will involve; Annual AS, GT design study, and potential annual GT for recruitment monitoring, costs of MP review, significant costs for MP development, including costs of other data collection activities, OMMP meetings, special meeting of the Commission, and Advisory Panel and consultant advice. There would be no TAC reductions based on this plan, however other sources of exceptional circumstances, for example the unresolved unaccounted mortalities issue, will still need to be evaluated.

5.1.2 **Option 2.**

Option 2 involves conducting the aerial survey in 2016 but not beyond, commencing the GT trial, cancellation of the MP review, development of a new MP, potential exceptional circumstances and TAC review in 2016 and 2017, no MP for TAC setting for 2019.

- Aerial survey in 2016 only. If the aerial survey is only conducted in 2016 and there are no plans for continuation, then the MP can be used to set TACs in 2016 (for 2018-2020), but the MP will then be unusable.
- Commence GT trial. As above.
- Cancellation of MP review. The adopted MP and rebuilding plan will have been abandoned with the cessation of the aerial survey after 2016, and therefore there will be no need for an MP review.
- New MP development. A new MP will need to be urgently developed and the data sources required for use in it will need to be collected. It may not be possible to develop a new MP before 2019. Timeframes and costs are discussed above.
- Potential exceptional circumstances and TAC review. The cancellation of the AS in 2015 will potentially trigger exceptional circumstances and need for TAC review, given the lack of recruitment monitoring information and data for the MP. The cancellation of the AS after 2016 will also trigger exceptional circumstances because this leads to the cessation of the adopted MP and SBT rebuilding plan. The ESC will need to discuss the implications of these exceptional circumstances in providing the recommendation for the current 2016 and 2017 TACs and the yet to be determined 2018-2020 TAC block.
- No MP for 2019 TAC setting. There may be no replacement MP in place to set TACs in 2019.

Option 2 involves the complete loss of the adopted MP, and requires development of a new MP. Costs will involve costs for the AS 2016 only, GT design study and potential future ongoing monitoring costs, significant costs of development of a new MP (including OMMP meeting, commission meetings, advisory panel expertise). An additional cost of this approach is that there will also be potential TAC losses from exceptional circumstances considerations and precautionary management in the absence of an agreed MP (Preece et al 2015).

5.1.3 **Option 3.**

Option 3 involves running the AS in 2016 only, no GT trial, members work on CPUE recruitment series, cancellation of MP review, MP development, potential exceptional circumstances and TAC review in 2016/2017, no MP for TAC setting for 2019.

- AS in 2016 only. As above in option 2. This leads to the adopted MP being unusable.
- No GT trial. Delays in developing new and informative methods for recruitment monitoring.
- Members work on CPUE recruitment series. Some initial advice has been provided on the feasibility and reliability problems of using CPUE data for recruitment monitoring (Preece et al, 2015). It is unclear how these will be addressed and the implications for any future MP.
- No MP review. As above in option 2, no need for review given that the MP no longer functioning.
- New MP development. As above.
- Potential exceptional circumstances and TAC review. As above.
- No MP for 2019 TAC setting. As above, there may be no replacement MP in place to set TACs in 2019.

Option 3 is similar to option 2 and also involves the complete loss of the adopted MP. There are cost savings from delaying or not conducting the gene-tagging and future recruitment monitoring via GT, but additional costs in developing and reviewing alternative recruitment indices.

5.1.4 **Option 4**

Option 4 involves no AS in 2016, exceptional circumstances triggered, no MP to set 2018-2020 or beyond.

- No aerial survey in 2016. This means the adopted MP is unusable, and there is no MP and SBT rebuilding plan.
- Exceptional circumstances would be triggered, with potential precautionary adjustments to TACs that have already been set.
- No MP to set 2018-2020 TACs. There would be no MP based method for setting the 2018-2020 TACs and non-MP based methods would need to be considered and agreed.

Option 4 involves immediate cancellation of the adopted MP. Costs would be for development of non-MP based advice for setting TACs in 2016, plus costs of development of a new MP. This scenario is likely to require additional ESC/OMMP meetings and resources, and possible special meetings of the Commission. An additional cost of this approach is that the TACs developed without a rebuilding plan are likely to be lower than current given the need to be precautionary and the current depleted state of the stock.

5.2 Research priorities

Priorities for CCSBT funding are suggested below, based on the high priority activities identified in the three-year SRP outlined at the 2014 ESC (Anon 2014, Tables 2A and 2B). We have not included here the member country obligations to collect and collate data on their fleets and catches. The catch characterisation, size sampling, observer programs and other essential and high priority monitoring, member research projects and ESC preparation work is already undertaken and funded by members and is not included in this list. Should any of these items need to be considered for CCSBT funding, then members will need to make that clear and add it to the list for consideration of SRP priorities.

The list below is in suggested priority order and immediate need for continuing operation of the current MP, resolving UAM, and an orderly transition to a new MP over the coming years (all have been identified as essential or high priorities by the ESC) for discussion at the ESC. The prioritisation is based on necessity for running the MP, resolving uncertainties that affect performance of the MP, data essential for the OM, data for future monitoring programs, projects that are investigating cost-effective abundance estimation and monitoring methods. The priorities and scheduling, and the level of likely increase in performance and robustness of the MP, needs to be part of an active dialogue with the Extended Commission on a regular basis.

1. Scientific aerial survey. Essential data for implementing the MP (2014 ESC Report, Table 2A). Data should continue to be collected until a new MP is developed and implemented, or exceptional circumstances will occur (as discussed above). Cost effective relative to the costs of

development of new MPs, and potential TAC reductions in the absence of an MP and rebuilding plan.

2. Research and monitoring for resolving UAM. A high priority given the relevance to the performance of the management procedure and OM. The 2014 ESC advised that, as a matter of urgency, steps should be taken to quantify all sources of unaccounted SBT mortality. The 2014 EC directed the ESC to undertake research in this area and agreed to a timeline. Resolving this issue also requires consideration and information from the Compliance Committee. In the absence of data, the ESC will need to discuss the implications for exceptional circumstances, or inclusion of implementation error in the MP and in MSE testing and tuning the MP.
3. Indonesian otolith collection, ageing and archiving. Essential data for the age frequency of Indonesian catch in the OM, for including the close-kin data in the OM, and for the independent assessment of spawning abundance using the close-kin method (e.g. Hillary et al 2012). Normally, this would be the member’s responsibility, however this is an area of identified capacity development for Indonesia.
4. Close kin sample collection. High priority for the close-kin genetics monitoring of spawning abundance. Collection costs are small relative to the value of the data for the OM.
5. Resolution of the Indonesian small fish issue. This is a high priority for resolution before the 2017 full stock assessment. This is needed to resolve potential changes in size/age at maturity and/or which fish are caught on the spawning ground, for use in close-kin abundance estimation. Costs may be nil if Indonesia can provide data to resolve the issue.
6. Gene-tagging pilot study and consideration of ongoing monitoring. High priority for development of cost-effective fishery independent recruitment monitoring program. Data for use in OM and potential future MPs.
7. Close-kin genotyping for spawning stock abundance estimation. High priority for close-kin data for inclusion in OM, the next full stock assessment is scheduled for 2017, and for independent assessment of spawning biomass.
8. Age validation workshop. Remains a high priority for ensuring scientists undertaking ageing are consistent in their estimates, to resolve issues regarding ageing fish caught in the winter and to discuss spatial distribution of sampling in terms of potential future use of the direct age data in SBT OMs.
9. Maturity workshop. Remains a medium priority for defining spawning abundance in the OM and close-kin abundance estimates. Scheduling could occur after the next full stock assessment depending on the method of CK used (see Bravington et al 2015).

We note that the Extended Commission budget is not unlimited and there is the need to fund other activities, including those central to the operation of the MP, in addition to those identified by the ESC for under the CCSBT SRP.

The role of the ESC is to advise the EC on the activities, and their relative priority, required to maintain a robust, precautionary scientific basis for rebuilding the stock, through the current MP, consistent with the EC’s objectives, and being able to report with appropriate confidence on progress against the rebuilding plan. The latter requires periodic estimates of the spawning stock and, while the spawning stock remains depleted, trends in recent recruitment. The proposed prioritisation is provided to promote discussion at the ESC and EC on the budget and schedule of tasks for the SRP in light of the potential trade-offs in uncertainty about stock status, rebuilding and ability to assess the performance of the MP and likely future levels of catch. We also consider it worth considering that items which may not be directly funded by the EC, through SRP, may still be progressed by collaboration between members and co-operating non-members, as has been undertaken previously for the development of monitoring and assessment approaches.

6 Summary and Recommendations

1. CCSBT MP should continue in current form through to, at least, 2017. This is the most cost-effective option in the context of the operational cost invested in MP development, testing and implementation and in terms of value of likely foregone catches and rebuilding.

2. EC should consider results of analyses presented to ESC 20, in particular the relative value of information versus the costs of monitoring and the risks to rebuilding and level and stability of future catches.

3. The decision not to fund the 2015 AS and not to confirm funding beyond 2016 has materially weakened the AS (logistically). Given this, a priority must be put on developing and securing ongoing funding from the Commission for robust estimates of recruitment. This will remain an essential priority until such time that the spawning stock is rebuilt to a level that can maintain long-term average levels of recruitment.

4. The changing nature of the SBT fisheries mean that it is highly desirable to base long-term monitoring of the stock for assessment and MP purposes on consistent, transparent monitoring methods which all members have confidence in. The ESC has identified a number of approaches that have the potential to meet these criteria and initiated design studies. We strongly urge all members and the ESC to actively participate in the development of these approaches so that they may be appropriately tested, refined and implemented as soon as practical.

5. We do not consider that fisheries dependent (i.e. CPUE) indices of recruitment are appropriate for monitoring recruitment of SBT. As previously noted by the ESC, they are subject to unquantifiable uncertainties due to the market anomalies, historical and future changes in spatial and temporal coverage, which are very difficult to address satisfactorily through standardisation, and, unknown biases due to changes in targeting and other behavioural factors.

6. The current MP should continue to be implemented until such time that an orderly transition can be made to a new MP that has been simulation tested and shown to have a high probability of meeting the objectives of the ECs rebuilding program.

7. The recommended priorities for the CCSBT Scientific Research Program are based on necessity for running the MP, resolving uncertainties that affect performance of the MP, data essential for the OM, data for future monitoring programs, projects that are investigating cost-effective abundance estimation and monitoring methods. As these projects have been identified as high[1] priorities, their scheduling and funding should be part of an active and regular dialogue with the Extended Commission.

[1] With the exception of the Maturity workshop, which was ranked as medium.

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Appendix A.2

Farley J, Eveson P, Clear N. 2015b.

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

CCSBT-ESC/1509/13.

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

Jessica Farley, Paige Eveson, Naomi Clear

CCSBT-ESC/1509/13

Twentieth Meeting of the CCSBT Scientific Committee, 1 - 5 September 2015, Incheon, South Korea

Contents

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Executive summary

This report provides an update on the direct age estimation and age distribution of SBT in the Australian SBT surface (purse-seine) fishery in the 2013/14 fishing season, and the archiving of SBT otolith sampled in Australia in the 2014/15 fishing season.

Age was estimated for 99 SBT in 2013/14 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 sampling the catch. 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. The proportion at age estimates from this method suggest that in the 2013/14 season there was a higher proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Moreover, the mean length of age 2-4 fish was estimated to be higher in 2013/14 than in past seasons, most notably for age 3.

Otoliths from 133 SBT were sampled from in Australian in 2014/15. The fish sampled were between 61 and 128cm fork length (FL) with a mode around 100-115 cm FL.

1 Introduction

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

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

Since the 2002 fishing season, Australia has been obliged to provide annual length-at-age estimates for the surface 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 new inter-laboratory comparison of direct ageing methods.

In this paper we update the information given in Farley et al. (2014) by extending the direct ageing series and estimates of proportion-at-age of the surface fishery to include the 2013/14 fishing season. We also provide an update on the otolith sampling for the 2014/15 season.

2 Methods

2.1 Direct ageing for 2013/14

Of the 146 otoliths collected from the Australian surface fishery in the 2013/14 season (see Farley et al., 2014), 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 61-128 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). All otoliths were embedded by FAS in clear casting polyester resin. 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 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

A subset of 20 otoliths was read once by a secondary otolith reader (from CSIRO) who was trained in SBT otolith reading in 1996 and has read SBT otoliths routinely since that time. All readings were conducted without reference to the size of the fish, date of capture, otolith weight or to previous readings. The precision of readings was assessed using the coefficient of variation (CV) (Chang, 1982; Campana et al., 1995).

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.

2.2 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 (Morton & Bravington 2003, see Table 2). This is especially true for fisheries that catch young fast-growing fish, such as the Australian SBT surface fishery, where length is quite informative about age. As an alternative to the ALK, Morton and Bravington (2003) developed a parametric method which makes more efficient use of the information in both the length frequency and direct age data. The basis for the method is maximization of the following log-likelihood within each year:

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

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

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

Previously we applied the standard ALK method and the method of Morton and Bravington (hereafter referred to as the M&B method) to the age-length and length-frequency data from the Australian surface fishery in seasons 2001/02 through 2012/13 (see Farley et al., 2014). Here we update the analysis to include data from the 2013/14 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

[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.

Basson et al. (2005). Specifically, if T is the number of tow cages in a particular season, c_i is the number of fish in tow cage i, m_i is the total number of fish sampled from tow cage i, and m_{il} is the number of fish of length l in the sample from tow cage i, then we estimate π_l, the frequency of fish of length l over all tow cages, to be

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

where

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

and

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

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

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

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

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

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

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

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

2.3 Otolith sampling and archiving 2014/15

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

[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.

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).

3 Results and Discussion

3.1 Direct ageing for 2012/13

A final age estimate was given for 99 of the 100 SBT selected for ageing. Ages ranged from 1-5 years and the length to age relationship is given in Fig. 1. The coefficient of variation between readings was 2.85%. When successive readings of otoliths differed, they were only by ±1 (n=12) indicating a good level of precision. For these fish, a final age was obtained by re-examining the otolith with the knowledge of the previous two age estimates as recommended by Anon. (2002). The percent agreement between readers was 75% and 100% were within +/-1. The CV was 5.86%.

Table 2 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.

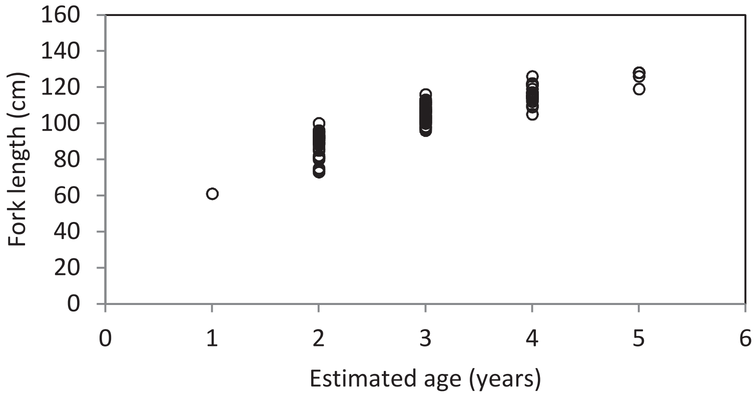

Figure 1. Length at age for SBT caught in the Australian surface fishery in the 2013/14 fishing season (n=99).

Table 2. Age-length-key for the 2013/14 fishing seasons for the Australian surface fishery. The lower length of each 5cm length bin is given in the first column and ages are shown across the top.

	AGE					
LENGTH	1	2	3	4	5	TOTAL
60	1					1
65						0
70		2				2
75		1				1
80		4				4
85		6				6
90		12				12
95		4	4			8
100		1	13			14
105			13	2		15
110			8	6		14
115			1	10	1	12
120				5	0	5
125				1	4	5
Total	1	13	42	20	7	99

3.2 Age distribution of the surface fishery 2001/02 to 2013/14

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 2. 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, for the 2013/14 season, the proportion of fish estimated to be age 2 is much greater using the standard ALK (56%) and the M&B method with unknown growth (72%) than the M&B method with known growth (20%). Likewise, the proportion of age 3 fish is estimated to be much smaller with the ALK (37%) and M&B method with unknown growth (22%) than the M&B method with known growth (78%).

The M&B method with unknown growth produces estimates that fit the length data very closely for all seasons (Fig. 3), 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. 4). 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. 5).

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 more accurate. For the 2013/14 season, estimates from this method suggest there was a larger proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Furthermore, the mean length-at-age estimates are higher than in past seasons, most notably for age 3 (Fig. 5).

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 often estimated to be very close to the mean length for age 3 (Fig. 3; Fig. 5). It is possible to impose tighter bounds on the mean length at age parameters, but doing so simply results in the age 4 estimates falling on the lower bound, so it is not a very satisfactory solution. A possibility for future consideration is to incorporate *a prior* distributions on the mean length at age parameters—this would provide an intermediate approach to the known and unknown growth methods currently available.

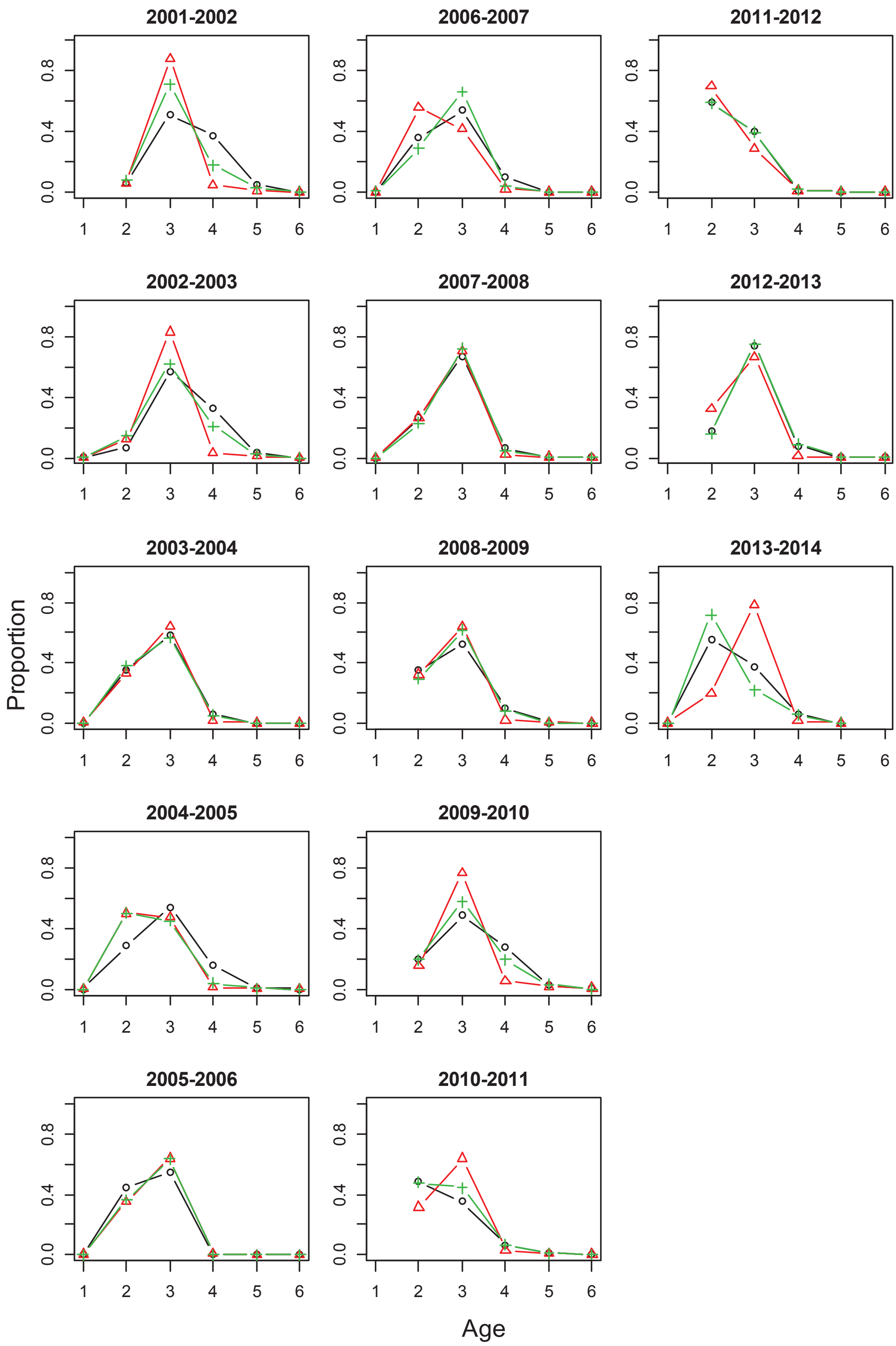

Figure 2. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

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 2013/14 season, the CV of the estimates for ages 2 to 4 are 2%, 9% and 23% respectively. In general, the proportion at age estimates are quite precise for ages 2 and 3 (CVs < ~10%), but less so for age 4 and 5 (ranging from 14% to 39%) since these older age classes have less data available. As discussed in Farley et al. (2012), the 2010/11 season was an exception with much higher CVs for the age 2 and 3 estimates than in previous seasons due to a contrast between the direct age data and length-frequency data for fish of ages 2 and 3 in this season.

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).

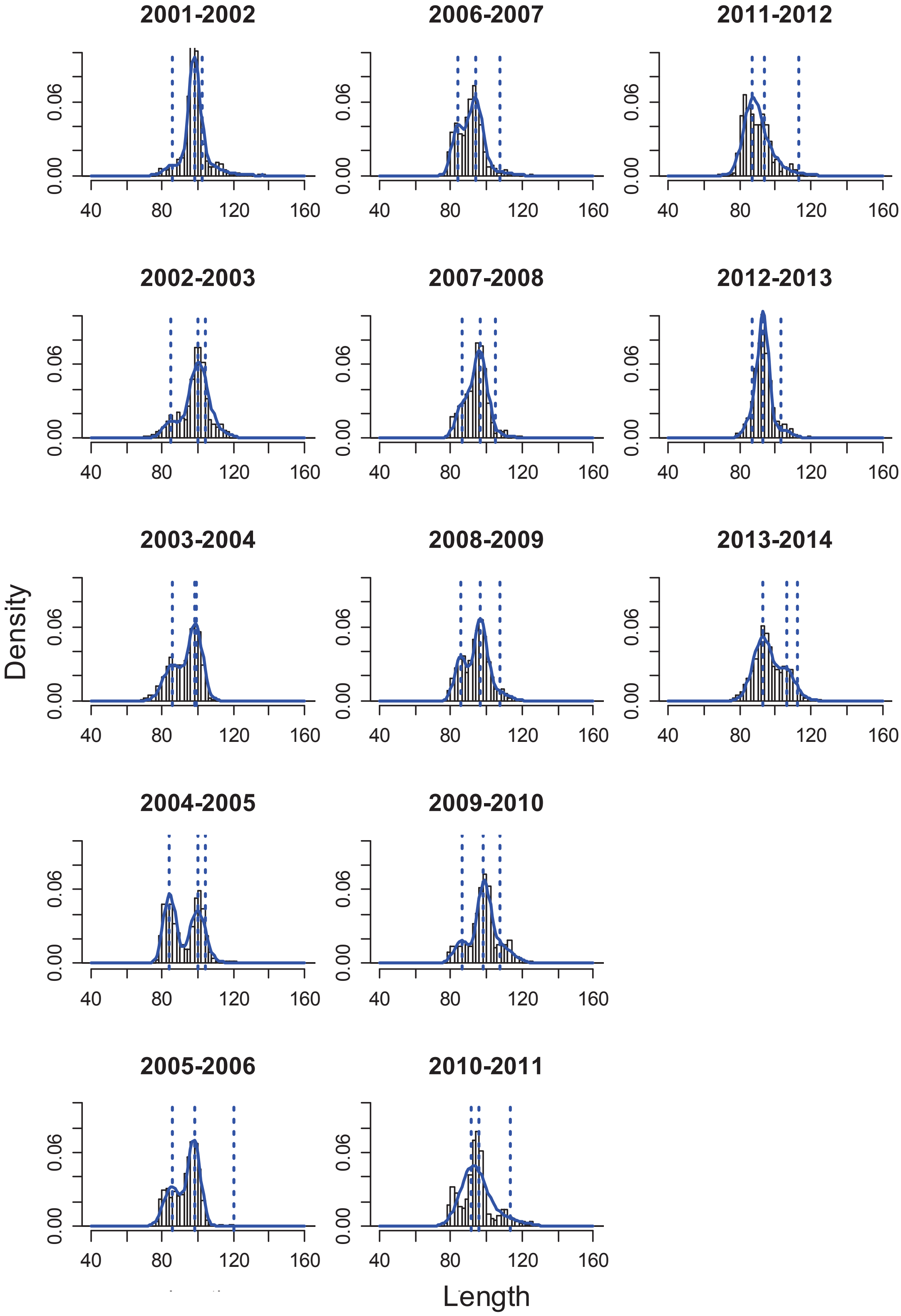

Figure 3. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

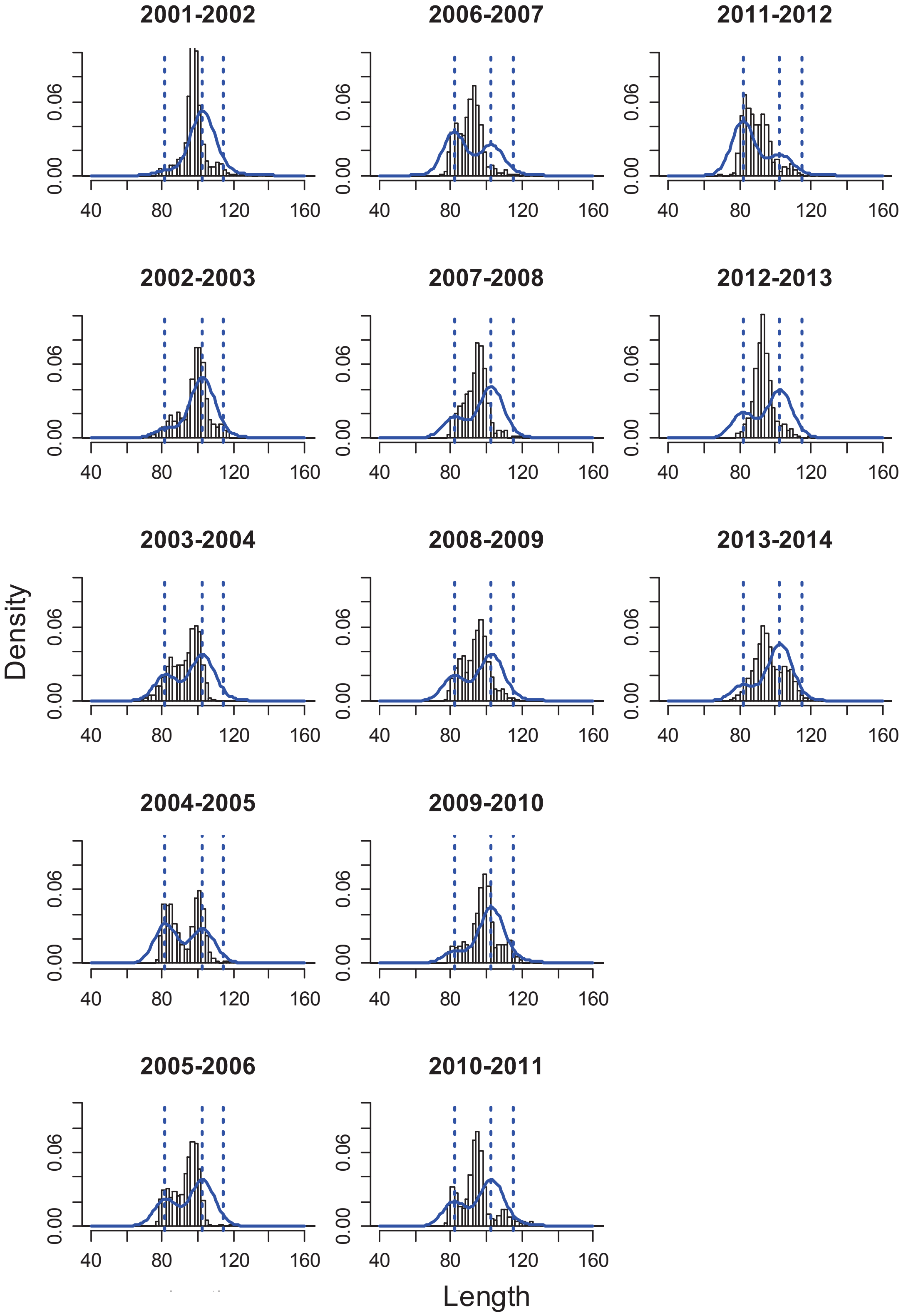

Figure 4. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

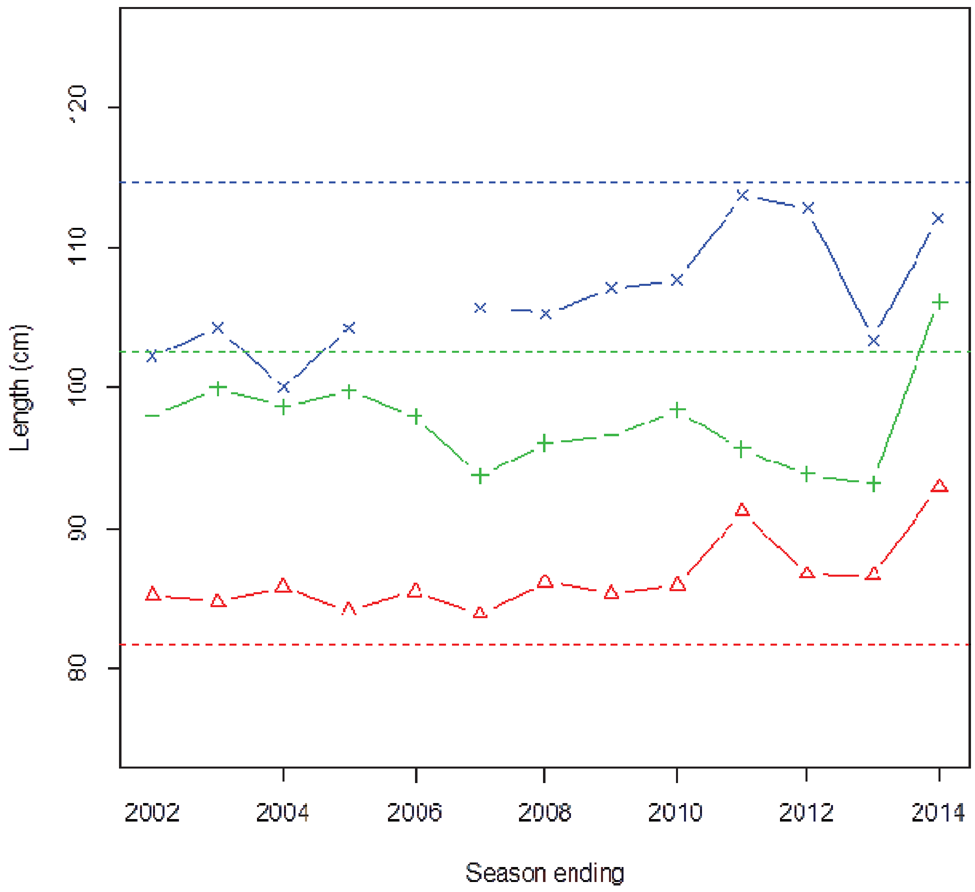

Figure 5. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show 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).

3.3 Otolith sampling and archiving 2014/15

In 2014/15, a total of 133 sets of otolith were collected from the Australia surface fishery. The SBT sampled were between 61 and 128cm fork length (FL) with a mode around 100-115 cm FL (Fig. 6).

As noted in previous reports to the Scientific Committee, (Farley et al., 2014), it is clear that the current sampling protocol does not provide either a fixed number of otoliths from each length class nor has it provided representative samples of otoliths from all length classes in proportion to their abundance in the catch from the surface fishery. In previous seasons, this has often resulted in an apparent disproportionate number of large fish sampled compared to the size distribution of SBT from the surface fishery (based on CCSBT CatchAtLength data). The exact reason for the disparity is unclear, but could be the result of selection biases in the choice of dead fish to retain for otolith sampling or due to size related differences in towing and early farming related mortality rates. It could also be due to biases in the estimated size distributions of fish in the tow cages. The resulting age-length keys have "missing rows" where there are no or very few age estimates for the smaller length classes. The missing rows could lead to highly uncertain (less robust) age-length-keys and highlights the issue of representative otolith sampling for the fishery. It is unknown if sufficient fish were sampled within each length class to estimate the age distribution of the surface fishery catch in the 2013/14 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

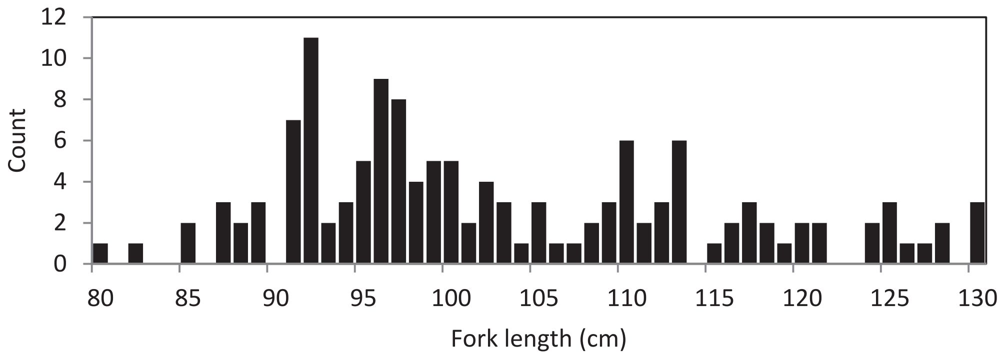

Figure 6. Length frequency of SBT with otoliths sampled from the Australian surface fishery in 2014/15 (n=133).

4 Summary

The proportion at age estimates from the M&B method with unknown growth suggest that in the 2013/14 season there was a higher proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Furthermore, the mean length at age estimates for ages 2-4 are higher in 2013/14 than in past seasons, most notably for age 3.

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.

5 References

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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.

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

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

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

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

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

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

[#] 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

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

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Appendix A.3

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Update on Scientific Research Program activities.

CCSBT-ESC/1509/15.

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Update on Scientific Research Program activities

Jessica Farley, Campbell Davies, Ann Preece

CCSBT-ESC/1509/15

Twentieth Meeting of the CCSBT Scientific Committee, 1 - 5 September 2015, Incheon, South Korea

Contents

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Executive Summary

In 2013, the Extended Scientific Committee (ESC) developed a new Scientific Research Plan for southern bluefin tuna (SBT). The SRP was updated in 2014 and several items were identified as high priority in the 2015 work plan including the continued collection and archiving of tissue samples for close-kin genetics, and the collection of ovaries and otoliths for an independently estimated maturity ogive. In addition, the work plan for 2016 included a workshop on otolith-based ageing to be held in conjunction with a workshop on maturity estimation.

Here we provide an update on progress in the sampling program for close-kin tissue and ovaries and otoliths for maturity estimation, and requirements for the ageing and maturity workshops. The dates for these workshops have not yet been set hence it would be useful if the ESC could advise on the most appropriate timing for these workshops, if they are to proceed in 2016.

Introduction

In 2013, the ESC developed a new Scientific Research Plan (SRP) for SBT. The SRP was updated in 2014, with a range of activities identified as essential and several items identified as high priority for 2015 (Anon 2014). The high priority items included:

1) Design study for a gene-tagging program,
2) Design study and expert review of future close-kin mark-recapture approaches,
3) Ageing of Indonesian SBT otoliths,
4) Continued collection and archiving of tissue samples for close-kin genetics (in Australia and Indonesia), and
5) Sampling ovaries and otoliths for an independently estimated maturity ogive.

In addition, the ESC work plan identified a second workshop on otolith-based ageing in conjunction with a maturity estimation workshop as high priorities for 2016 (Anon 2014). The ESC will also reconsider potential research using otolith microchemistry and electronic tagging to understand within season spawning behaviour and skipped spawning behaviour in adult SBT (Table 2B in Attachment 10 of Anon 2014).

The gene-tagging design study, review of future close-kin mark-recapture approaches, and ageing of Indonesian otoliths were funded by CCSBT in 2015, and reports are provided for ESC consideration (see CCSBT-ESC/1509/14; 18; 19).

In this paper we provide an update on progress in the sampling program for close-kin tissue and ovaries and otoliths for maturity estimation, and requirements for the ageing and maturity workshops.

1 Tissue sampling for close kin

In 2013, the project to obtain a fishery-independent estimate of spawning biomass of SBT using close-kin genetic techniques was successfully completed (Bravington et al. 2014). The project analysed tissue samples collected from juvenile and adult SBT in 2006 to 2010. Since then, tissue sampling has been ongoing with approximately 3200 (1600 juveniles and 1600 adults) samples collected and archived annually.

In 2015, the CCSBT allocated funding to continue tissue sampling in Port Lincoln and Benoa during the 2014/15 fishing season.

Sampling of adult SBT occurred between September 2014 and April 2015 at the Port of Benoa, Bali, using the existing Indonesia-CSIRO SBT catch monitoring system for the longline fishery (see Proctor et al., 2006). Muscle tissue was collected and frozen by a trained sampler using protocols provided by CSIRO. Tissue was obtained from 1609 fish ranging from 117 to 201 cm FL. Sex was identified for all fish based on residual gonad tissue. The frozen tissue samples are stored at RIMF in Muara Baru (North Jakarta) and will be transported to Hobart for archiving as soon as possible.

Sampling of juvenile SBT began in July 2015 and is still in progress at tuna processors in Port Lincoln. Muscle tissue was collected and frozen by Protec Marine Pty Ltd according to protocols provided by CSIRO. Tissue has been obtained from 1600 SBT ranging from 103 to 109 cm fork length (FL) (age 3 fish). Once the sampling is complete, the tissue will be transported to the CSIRO in Hobart.

The samples are stored in consecutively labelled boxes with 100 positions (10 by 10) in each box (A01 through J10). Individual sample are given a unique identification label (e.g., SbPL2014_Bx01_A01) and placed in either -80 or -20°C for long term storage. Where possible, boxes are stored together as a year class.

2 Ovary and otolith sampling for maturity

There remains uncertainty about the size and age that SBT mature and the functional form of the maturity schedule. Up until 2013, the SBT operating model (OM) used a "knife-edge" maturity relationship, which specified that 0-9 yr olds made no contribution to the spawning biomass or reproductive output of the population and 10+ yr olds all contribute in proportion to their weight. In 2013, the method was updated to use the currently available estimates of maturity and additional information provided by the close-kin estimate to give a spawning potential by age (Anon 2013a). It was acknowledged, however, that there was no independent estimate of a maturity schedule for SBT (Anon 2013b). In 2014, a costed proposal for developing one (Farley et al., 2014) was supported by the ESC, and sample collection for maturity was listed as a high priority in the work plan for 2015 and ongoing. Table 1 shows the draft sampling plan proposed by Farley et al. (2014)

Table 1. Design for collaborative ovary/otolith sampling program by CCSBT statistical area. Sampling of females only from April to August.

STASTICAL AREA	CCSBT MEMBER	NO. OF FEMALES TO SAMPLE
Area 4	Australia, Japan	220
Area 5	Japan	220
Area 6	New Zealand	220
Area 7	Japan	220
Area 8/14	Japan, Taiwan, Korea	220
Area 9	Japan, Korea	220
Total		1320

In addition to the above sampling program, it was proposed that the collection of ovaries from small SBT by Indonesia would provide the opportunity to confirm if all SBT caught in the Indonesian fishery are mature (and actively spawning) or not. Farley et al. (2015) shows that in 2012/13 to 2014/15 the size frequencies of SBT in the Indonesian longline catch has a new mode of relatively small/young fish (<155 cm FL, <10 years) that had not been previously observed. It is not known if these fish were caught on, or south of, the spawning ground. If they were caught on the spawning ground, then information on their maturity status would be important in relation to the current project.

In 2014, Australian observers collected 19 ovary samples preserved in 10% formalin (134-190 cm FL). It is anticipated that additional samples will be collected over the next month if observers are deployed onto longline fishing vessels on Australia's southeast coast. Where possible, otoliths will be collected from sampled fish in port using the "drill and hole-saw" method (Anon 2002) which does not affecting the external condition or quality of the fish. In 2015, New Zealand collected 122 ovary samples, preserved in formalin, from Area 6.

3 Age estimation workshop – 2016

In 2002, the CCSBT led the development of standardised direct ageing methods for SBT among member nations (see Anon 2002). It is recognised, however, that there is a need to regularly examine the precision and bias of age estimates between readers and among laboratories to maintain a consistent level of precision and minimise the potential for systematic biases in ageing estimates. In 2015, the ESC work plan listed a 3-day workshop to review otolith sampling design and age estimation/calibration as a priority for 2016. Indonesia's Research Institute for Tuna Fisheries was identified to host the workshop.

Potential issues for consideration are:

- Ageing errors and difficulties identified during the calibration exercise,
- Standardising otolith margin interpretation and converting counts to age estimates,
- The level of acceptable ageing error,
- Future research requirements.

Proposed aims are to:

- Review otolith extraction, sectioning and reading methods including any recent age validation work,
- Provide capacity building training for members who have not been involved in SBT age estimation,
- Improve age estimation protocols and quality control procedures (checking precision and drift),
- Update otolith reference set for among laboratory comparisons and determine a future quality control agenda,
- Revise the age determination manual with respect to methods related to reading otolith margins.

Prior to the workshop, it is recommended that an inter-laboratory otolith exchange exercise be undertaken. The main objective of the calibration exercise would be to estimate precision and relative bias in readings from scientists at CCSBT member laboratories, and to ensure that the precision/bias levels are within acceptable limits. This is an area for potential collaboration among tuna RFMOs give the interest in bluefin tunas in particular, but also the tropical tunas.

4 Maturity estimation workshop – 2016

In 2015, the ESC work plan listed a 3-day workshop to discuss and finalise maturity criteria for SBT as a priority for 2016. It was suggested that this workshop be held in conjunction with the ageing workshop (above) at Indonesia's Research Institute for Tuna Fisheries to reduce costs by some participants.

Proposed aims are to:

- Develop standardised histology classification criteria for ovaries,
- Provide capacity building training for members who have not been involved in maturity estimation,
- Finalise maturity classification for SBT,
- Initiate analysis of the results to estimate the maturity schedule of SBT,
- Discuss future research requirements,
- Develop a manual with the classification scheme for future maturity work by members; this manual may be applicable to other tuna species and the respective tuna RFMOs.

Prior to the workshop, it is recommended that histological sections are prepared for all ovary material collected, and that an inter-laboratory histology interpretation exchange exercise be undertaken. It is recognised that ovary classification may vary between researchers due to the semi-quantitative approaches used, so the purpose of the exchange exercise would be to allow all laboratories to examine and classify the ovaries prior to discussion at the workshop.

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Appendix A.4

Farley J, Nugraha B, Proctor C, Preece A. 2015a.

Update on the length and age distribution of SBT in the Indonesian longline catch.

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Update on the length and age distribution of SBT in the Indonesian longline catch

Jessica Farley[1], Budi Nugraha[2], Craig Proctor, Ann Preece

CCSBT-ESC/1509/14

Twentieth Meeting of the CCSBT Scientific Committee, 1 - 5 September 2015, Incheon, South Korea

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Contents

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Executive summary

This paper updates previous analyses of SBT length and age data from the Indonesian longline fishery operating out of the port of Benoa, Bali. Length-frequency data are presented for 22 spawning seasons (1993/94 to 2014/15) and age frequencies for 20 seasons (1993/94 to 2013/14, but excluding 1995/96). As noted in previous reports to CCSBT-ESC, considerable change has occurred in the size and age distribution of SBT landed by the Indonesian longline fleet since monitoring began. In summary:

- There was a change in the size and age distribution of SBT caught in the early 2000s when the proportion of small/young fish (155-165 cm/10-15 years) increased markedly. The young fish can be tracked through the age distribution of subsequent years suggesting a pulse of recruitment to the spawning population. A second recruitment pulse of fish is apparent in the mid-2000s.
- In the last three spawning seasons (2012/13 to 2014/15), the length and age frequencies showed a new mode of very small/young fish in the catch (140-155 cm/7-10 years). The proportion of fish aged <10 years increased from 5.8% in 2011/12 to 37.0% in 2012/13 and 22.5% in 2013/14 (the last year we have direct age data for). It is not known whether the small/young SBT landed in recent years were caught on or south of the SBT spawning ground, and whether they can be considered part of the SBT spawning population.
- It is important that we understand where the small fish are being caught because of how these data are used in the SBT operating model. The Indonesian age frequency (from direct ageing) are used in the SBT operating model and the fishery selectivity estimates from the operating models are used in projections and used to test the management procedure. Substantial changes in selectivity in a fishery could trigger exceptional circumstances under the SBT Management Procedure (MP) meta-rules process, because the MP has not been tested under these conditions. If the small fish are coming from further south, then these data may need to be assigned to a different fishery within the SBT OM fishery definitions. Information from the Catch Documentation Scheme may be able to provide information on fishing location.
- The Indonesian monitoring data are also used in the current close-kin (CK) estimation framework. It is assumed that all catches come from the spawning grounds. Hence, these recent changes will influence how these data can be used in the future in the CK abundance estimation.

1 Introduction

Southern bluefin tuna spawn from September to April in an area between Indonesia and the northwest coast of Australia (Farley and Davis, 1998). An Indonesian-based longline fishery operates on this spawning ground year-round targeting yellowfin and bigeye tuna, with a bycatch of SBT. Obtaining an accurate estimate of the size and age composition of SBT landed by the Indonesian longline fishery is vital for population modelling and stock assessments, and to monitor changes in the spawning population over time.

Since the early 1990s, the size and age structure of the SBT spawning population has been monitored through a series of collaborative research programs between CSIRO, Indonesia's Research Centre for Capture Fisheries (RCCF) and Research Institute for Marine Fisheries (RIMF), the Indian Ocean Tuna Commission (IOTC), and Japan's Overseas Fishery Cooperation Foundation (OFCF). The program monitors the catch of SBT by Indonesia's longline fleet operating on the SBT spawning ground in the north-east Indian Ocean. Initially, the program collected data on SBT landed at the port of Benoa in Bali, but in 2002 this was expanded to include the ports of Muara Baru (Jakarta) and Cilacap (south coast Central Java), and to comply with IOTC protocols. The majority of targeted SBT sampling, however, still occurs at Benoa, as this is the port where the bulk of SBT are landed.

The collection of such large quantities of length frequency data, and the development of validated methods to directly age SBT using the otoliths sampled, have allowed us to accurately estimate the age composition of the Indonesian catch. These data have shown that the parental stock of SBT has undergone substantial changes since monitoring began; the greatest change being a shift in the mode of SBT caught from 18-22 years in the mid-1990s to 12-15 years in the early-2000s.

In the mid-2000s, at least one Benoa-based fishing company (Processor A) was identified as having shifted their operations to target SBT south of the SBT spawning ground (Andamari et al., 2005; Proctor et al., 2006; Farley et al., 2007). A greater proportion of the catch landed at Processor A comprised small (<165 cm FL) fish compared to the other processors. SBT of these sizes are consistent with historic Japanese catch data for vessels operating on the staging ('Oki') fishing ground to the south of the spawning ground (Shingu, 1978).

In 2012/13 and 2013/14, the size distribution of SBT landed in Bali also showed a greater proportion of small fish (<150 cm FL) in the landed catch compared to previous seasons (Farley et al., 2014), suggesting that some vessels may have operated south of the spawning ground. Unfortunately, the catch locations of the sampled fish are unknown.

In this paper we update the information given in Farley et al. (2014) by including the most recent length and age data available for the Indonesian fishery. Length frequency data are presented up to the 2014/15 season and age frequency data up to the 2013/14 season.

2 Methods

As in previous years, targeted sampling of SBT occurred at the Port of Benoa using the existing monitoring system (e.g. see Proctor et al., 2006). Length measurements were obtained for 3433 SBT in the 2014/15 spawning season and otoliths were collected from 1346 fish (Table 1).

Direct ageing of a subsample of 500 otoliths was undertaken for fish sampled in the 2013/14 spawning seasons (Table 1). Otoliths were selected based on size of fish (length stratified sampling scheme rather than random sampling) to obtain as many age estimates from length classes where sample sizes were small. Length stratified sampling is the best way of obtaining sufficient age estimates from length classes where sample sizes are small, while providing enough estimates for each season. Otoliths were sent to Fish Ageing Services Pty Ltd (FAS) for sectioning and reading using the techniques described in Anon. (2002). The otolith reader has at least 10 years experience reading SBT otoliths.

Each otolith was read twice by the primary otolith reader (FAS) and then a final age estimate was given to 473 fish. All readings were conducted without reference to the size of the fish, date of capture, or to previous readings. The precision of readings was assessed using the coefficient of variation (CV) (Chang, 1982; Campana et al., 1995).

To determine the age structure of the Indonesian catch of SBT in the 2013/14 season, an age-length key was developed using the sample of aged fish. The age-length-key gives the proportion of fish at age in each 5-cm length class, which enabled us to infer the age-frequency distribution of the catch from the length-frequency distribution obtained through the monitoring. This method has been used to estimate the age distribution of the Indonesian catch since the mid-1990s, apart from 2011/12 when no direct age estimates were available. For that season, an ALK was developed using direct age data for the two preceding spawning seasons and applied to the 2011/12 length frequency data.

3 Results

3.1 Length distribution

Figure 1 shows the length frequency distributions for SBT caught by the Indonesian longline fishery by spawning season (note that 8 fish between 100 and 129 cm FL were also sampled in 2013/14 but are not shown). The data are separated into those caught on and those caught just south of the spawning ground in the 2003/04 to 2006/07 seasons (see Farley et al., 2007) as SBT caught south of the spawning ground are not considered part of the spawning population.

As noted in previous reports to CCSBT-ESC, considerable change has occurred in the size distribution of SBT caught on the spawning ground since monitoring began. In the mid- and late-1990s, the majority of SBT caught were between 165 and 190 cm FL with a median length of ~180 cm (Figure 1). In the early-2000s, the relative proportion of small SBT (155-165 cm FL) in the catch increased (Figure 2). The mean size of SBT caught declined from 188.1 to 166.8 cm between 1993/94 and 2002/03, and remained between 168.3 and 171.0 cm until 2011/12 (Table 1).

In the last three spawning seasons (2012/13 to 2014/15), the length frequencies indicate a new mode of very small fish between 140 and 155 cm FL in the catch. In these seasons, the relative abundance of fish <155 cm was between 32.9% and 35.3% compared to much lower levels of 0 to 12.4% in the previous seasons (Figure 2). This change in the size distribution is reflected in a decrease in the mean size of SBT in the catch to ~162 cm FL (Table 1; Figure 3).

Investigations were initiated to determine whether the small SBT sampled recently were caught on or off the SBT spawning ground. In early May 2014, tuna fishing industry in Benoa participated in a workshop[3] at which a presentation was given highlighting the importance of catch location information to enable a better understanding of the increase in smaller fish in the landings. Follow-up discussions at the Benoa office[4] with responsibility for monitoring of fishing vessel activity revealed that VMS is available for some of the Benoa longline fleet and may provide validation of catch location information for the smaller SBT, should such information be provided by individual fishing companies.

3.2 Direct age estimation and age distribution

A final age was available for 473 of the 500 otoliths selected from the 2014/15 spawning season. Fish ranged in size from 135-211 cm LCF and age estimates ranged from 6 to 36 years. The coefficient of variation between readings was 2.99%. When successive readings of otoliths differed, 95.3% were only by ±2 (n=463), again indicating a good level of precision.

[3] Workshop "Monitoring and Evaluation of Enumerator and Observer Acitivties in Port of Benoa, Bali", 5 May 2014, held at office of Asosiasi Tuna Longline Indonesia, Benoa.

[4] Pelabuhan Perikanan Nusantara Pengambengan – Benoa Office, a regional office under Directorate General of Capture Fisheries.

Figure 4 shows the estimated age structure of the Indonesian catch by spawning season. As reported previously, the age composition of the catch has also changed over time. There was a change in the age distribution of SBT caught in the early 2000s when the proportion of young fish aged 10-15 years increased markedly. These young fish can be tracked through the age distribution of subsequent years suggesting a pulse of recruitment to the spawning population. A second recruitment pulse of young fish occurred in the mid-2000s (see Farley et al. 2014).

In 2012/13 and 2013-14, however, there was a substantial increase in the catch of very young SBT (7-10 years) (Fig. 4). The proportion of fish aged <10 years increased from 5.8% in 2011/12 to 37.0% in 2012/13 and 22.5% in 2013/14 (Fig. 5). As expected, the mean age of SBT sampled decreased from 15-16 to 13-14 years (Table 1; Fig. 6). The mean age of SBT >20 years has also decreased since the mid-2000s.

Table 1. Number of length measurements and age estimates for SBT by spawning season.

SPAWNING SEASON	FORK LENGTH (CM)			OTOLITHS	AGE (YEARS)	
	N	MEAN	RANGE	*N*	*N*[1]	MEAN
1993/94	676	188.1	161-207	0	0	NA
1994/95	1610	180.7	147-221	549	486	21.2
1995/96	1107	178.9	149-216	225	50	NA
1996/97	1615	179.6	146-218	602	475	20.8
1997/98	1577	176.4	143-214	519	485	19.8
1998/99	936	179.9	145-210	660	474	20.7
1999/00	786	177.4	150-216	533	498	19.5
2000/01	762	174.2	140-210	720	481	16.9
2001/02	821	169.5	147-223	715	489	14.8
2002/03	1385	166.8	134-229	1502	488	14.5
2003/04	1279	168.5	145-215	1283	494	15.2
2004/05	1580	170.1	89-205	1523	493	15.3
2005/06	1182	169.2	122-201	1180	486	14.4
2006/07	1586	168.3	134-202	1586	491	15.1
2007/08	1693	169.5	145-203	1709	485	16.7
2008/09	1704	171.0	143-219	1697	479	15.6
2009/10	1583	168.5	141-204	1538	488	15.3
2010/11	1015	170.4	142-198	1009	481	16.8
2011/12	565	169.4	136-212	543	*NA*	16.0
2012/13	1381	162.1	135-211	1373	474	13.2
2013/14	1810	161.8	100-204	1637	473	13.9
2014/15	3443	161.4	95-225	1346	NA	NA
Total	30096			22449	8770	*Total*

[1] A random sub-sample of 500 are selected for ageing, apart from the 2011/12 season where an ALK based on data from the previous two seasons was used.

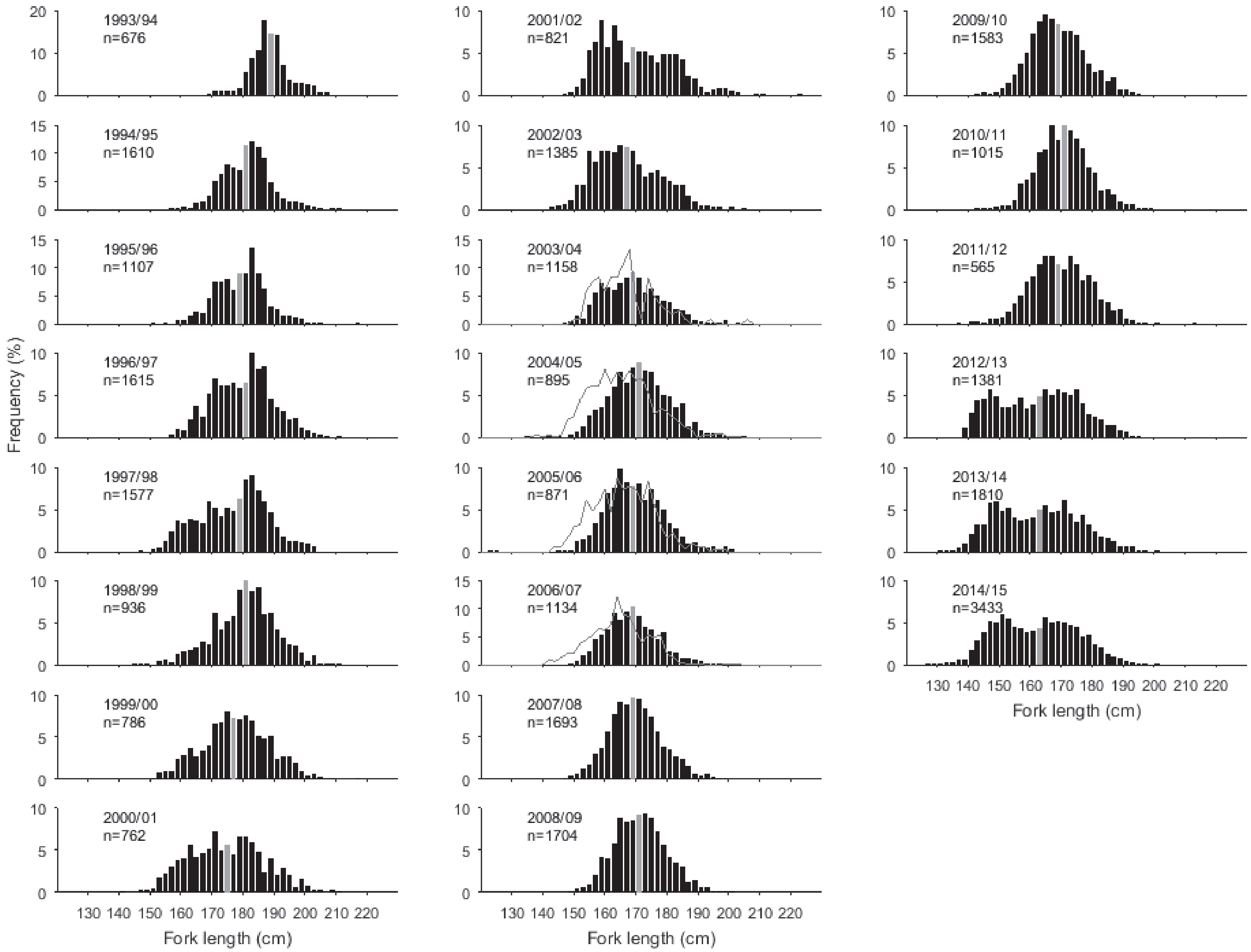

Figure 1. Length frequency (2 cm intervals) of SBT caught by the Indonesian longline fishery (bars) by spawning season. The grey bar shows the median size class. For comparison, the length distribution of SBT thought to be caught south of the spawning ground (Processor A) is shown for the 2003/04 (n=121), 2004/05 (n=685), 2005/06 (n=311) and 2006/07 (n=452) seasons (grey line) (see Farley et al., 2007).

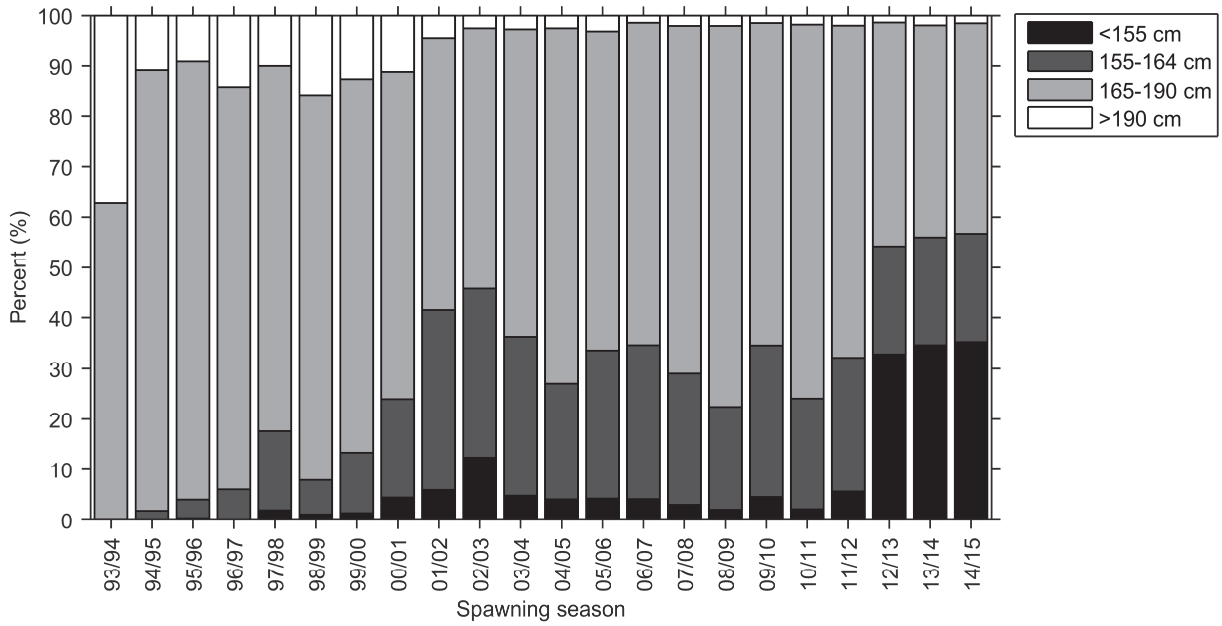

Figure 2. Proportion of SBT caught by the Indonesian longline fishery by size class. Data from Processor A in 2003/04 to 2006/07 are excluded.

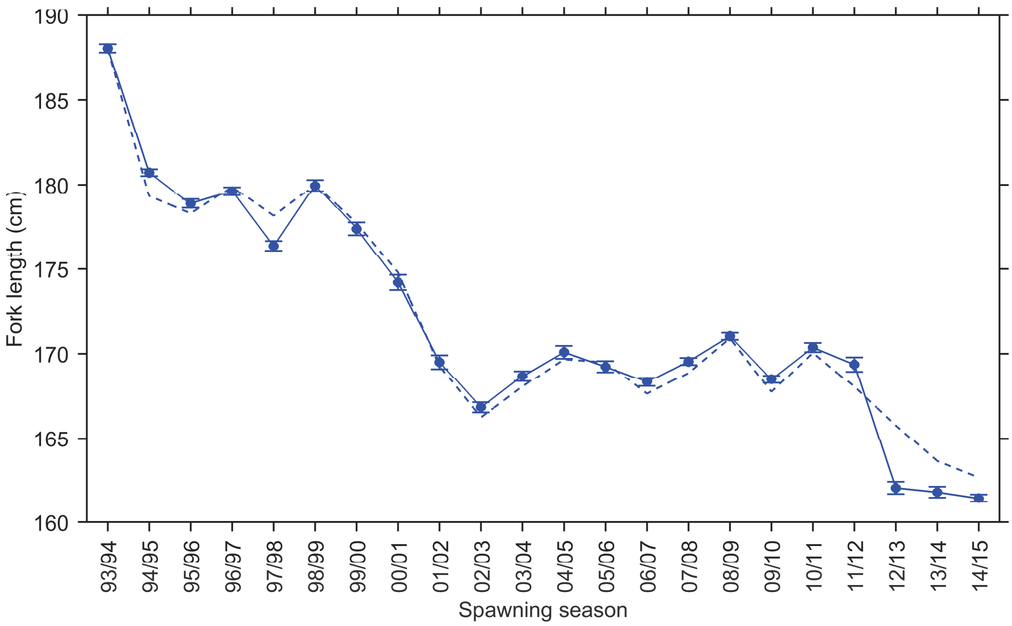

Figure 3. Mean length (+/- 95% CI) of SBT landed by the Indonesian longline fishery by season. Data from Processor A in 2003/04 to 2006/07 are excluded. Dashed line is the mean length of SBT caught in December to May only.

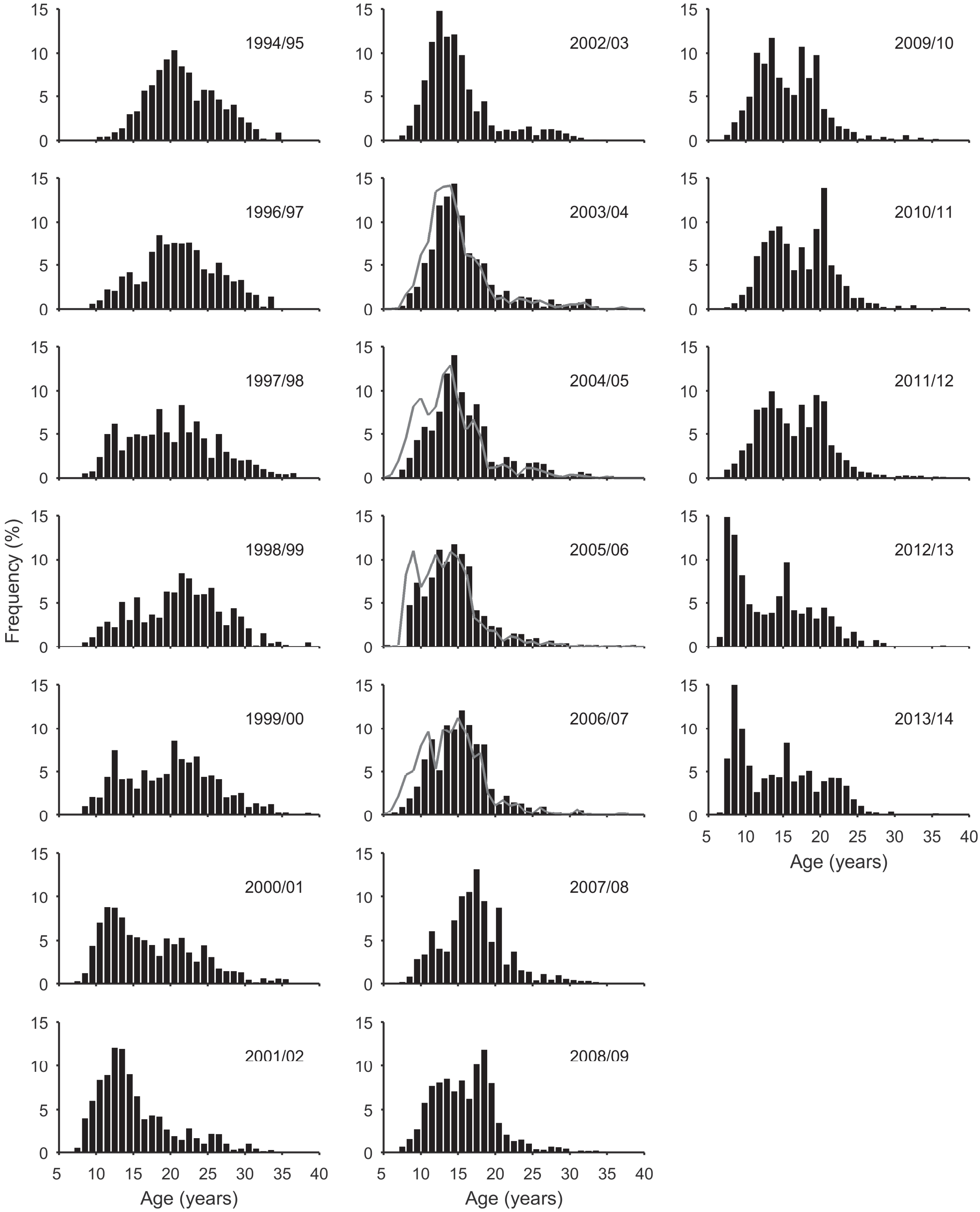

Figure 4. Age frequency distribution of SBT in the Indonesian catch on the spawning ground by spawning season estimated using age-length keys from our sub-samples of aged fish and length frequency data obtained through the Indonesian monitoring program. There was no direct ageing of the 2012–13 otoliths; age frequency is based on the age-length key from the previous two seasons and 2012–13 length frequency data. For comparison, the age distribution of SBT caught south of the spawning ground (Processor A) is shown for the 2003/04, 2004/05, 2005/06 and 2006/07 seasons (grey line).

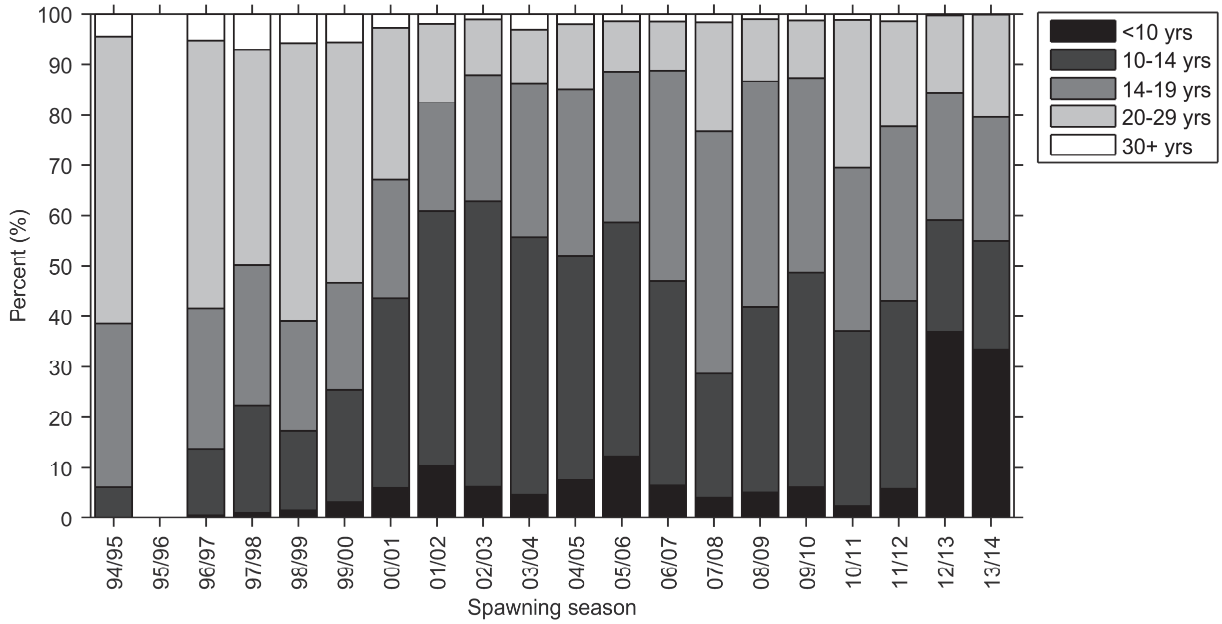

Figure 5. Estimated proportion of SBT by age class in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season.

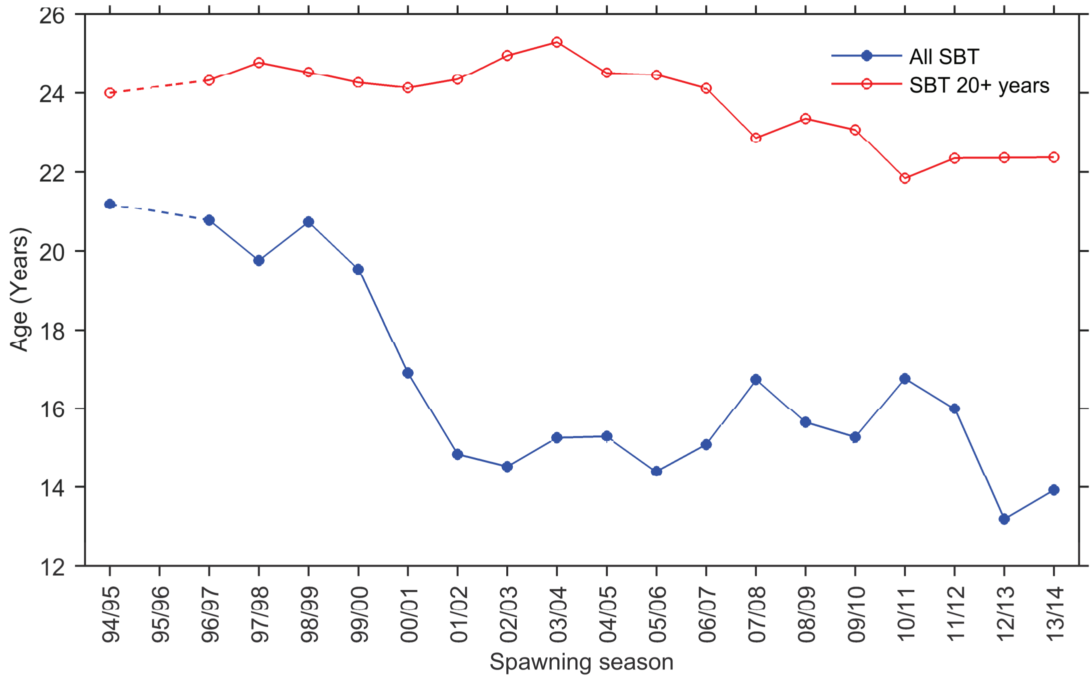

Figure 6. Estimated mean age of SBT in the Indonesian catch. Data from Processor A for 2003/04 to 2006/07 are excluded. Note there are no age data for the 1995/96 season.

4 Summary

We present the length and age distribution of the Indonesian longline catch from the mid-1990s through to the 2013/14 and 2012/13 spawning seasons respectively. In each season, apart from 2011/12, an age-length-key (ALK) was developed using age estimates obtained from that season. Length frequency data were then applied to the ALK to estimate the age distribution of the catch. In 2011/12, however, no direct age estimates were available. For that season, an ALK was developed using direct age data for the two preceding spawning seasons and applied to the 2011/12 length frequency data.

The size and age composition of the SBT in the Indonesian catch has changed over time. There was a change in the early 2000s when the proportion of young (<15 years) fish increased in the catch, which can be tracked through subsequent years (Farley et al., 2014). A second pulse of young fish is apparent in the mid-2000s.

Over the last three spawning seasons, a relatively large proportion of SBT landed were very small/young (<155 cm FL/10 years old) compared to previous seasons. Investigations have been initiated to determine whether the small SBT landed were caught on or south of the SBT spawning ground, and whether they can be considered part of the SBT spawning population. Unfortunately, the catch locations of the sampled fish are currently unknown.

It is important that we understand where the small fish are being caught because of how these data are used in the SBT operating model. The Indonesian age frequency (from direct aging) are used in the SBT operating model and the fishery selectivity estimates from the operating models are used in projections and used to test the management procedure. Substantial changes in selectivity in a fishery could trigger exceptional circumstances under the SBT MP meta-rules process, because the MP has not been tested under these conditions. If the small fish are coming from further south, then these data may need to be assigned to a different fishery within the SBT OM fishery definitions (Anon 2014). Information from the Catch Documentation Scheme may be able to provide information on fishing location.

The Indonesian monitoring data are also used in the current close-kin (CK) estimation framework. It is assumed that all catches come from the spawning grounds. Hence, these recent changes will influence how these data can be used in the future in the CK abundance estimation.

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Appendix A.5

Hillary R, Preece A, Davies C. 2015a.

Technical changes in the MP to account for missing aerial survey data.

CCSBT-OMMP/1508/4.

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Technical changes in the MP to account for missing aerial survey data

Rich Hillary, Ann Preece, Campbell Davies

CCSBT-OMMP/1509/4
Prepared for the 6th CCSBT Operating Model and Management Procedure meeting held in Incheon, Korea 30th–31st of August 2015.

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Contents

Abstract

Given the absence of an aerial survey in 2015, and the fact that this is one of the two input indices to the Bali MP, this paper details how this missing data point is dealt in an updated version of the MP code. The methodology is simple, and is the same approach as used to deal with the missing 2000–2004 data that is already a key feature of the existing aerial survey index. The underlying harvest control rule and MP parameters do not change, so this minor alteration simply needs noting in the already existing MP description text, and the code simply needs updating with the revised version.

1 Background

This paper details the technical changes required in the existing MP code to accommodate the fact that the 2015 aerial survey was not undertaken. We do not focus on whether or not the missing data point triggers exceptional circumstances but only on how it can be dealt with in the MP code itself and in the SBT OM version of the MP.

2 Missing 2015 aerial survey datum in the MP

From a purely technical perspective, it is quite simple to deal with missing data in the Bali MP. Indeed, we already do deal with missing data as the aerial survey index, while spanning the 1993–2014 period, is already missing data in the years 2000–2004. The state-space relative abundance delay-difference model in the Bali MP (see Attachment 10 in [1]), fitted to both the aerial survey and the CPUE data, predicts values of both indices even if they are absent in some years. The only change required in the code is to tell the code not to expect any aerial survey data in 2015. The same change is applied to both the standalone Bali MP code (used to calculate the TAC) and the version of the MP that is called by the SBT OM when performing projections. The OM is free to simulate the survey in 2015 (and this in itself is useful) but the code has been altered so that, even if it is simulated, it is ignored in the estimation process.

What will actually happen in the estimation part of the MP is that, in the absence of direct data on the juvenile biomass (from the aerial survey) in a given year, the main determinant of the estimate will be the prior, which shrinks the estimate to the long-term average relative recruitment. There *could* be some information in the CPUE in later years, but not historically, and given the CPUE always lags the aerial survey in this regard it is not going to be an issue in either our simulations for this year or the next TAC decision, if the MP is used.

The final point to make is that there are **no** changes required in the harvest control rule in the Bali MP as a result of missing data. The mathematical form and parameter values and specifications of the HCR stay exactly as they were adopted in 2011 [1].

3 Acknowledgements

This work was funded by AFMA, the Department of Agriculture and CSIRO's Oceans and Atmosphere flagship.

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[1] Anonymous. (2011) Report of the Sixteenth Meeting of the Scientific Committee of the CCSBT in Bali, Indonesia. *CCSBT*.

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Appendix A.6

Preece A, Hillary R, Davies C, Farley J, Eveson P. 2015b.

Implications of cessation of the aerial survey for the MP and TAC setting.

CCSBT-ESC/1509/09.

Funded by CSIRO and the Department of Agriculture and Water Resources.

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Implications of cessation of the aerial survey for the MP and TAC setting

Ann Preece, Richard Hillary, Campbell Davies, Jessica Farley and Paige Eveson

CCSBT-ESC/1509/09

Twentieth Meeting of the CCSBT Scientific Committee, 1 - 5 September 2015, Incheon, South Korea

Acknowledgments

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Contents

Abstract

The aerial survey index of juvenile abundance provides essential fishery independent information on recruitment for the CCSBT management procedure (MP) and meta-rules processes. These include review of fishery and stock indicators, assessments of stock status, TAC recommendations, MP reviews and a process for dealing with exceptional circumstances (Anon. 2013).

The SBT aerial survey was cancelled in 2015 following funding discussions at the Commission (Anon 2014a). The Commission has requested advice on the implications of cessation of the aerial survey in 2015 and potentially in 2016 and beyond. Some aspects of this were considered by the ESC in informal inter-sessional webinars, and a report was provided to the SFMWG meeting (Anon, 2015a). This paper provides advice on the implications of cancelling the aerial survey for the MP schedule of activities, including future TAC setting, an evaluation of the costs and benefits of the aerial survey data and potential alternative sources of information on recruitment.

The aerial survey index is used in several processes which are part of the MP schedule of events as set out in the meta-rules adopted in 2011 (Anon 2013);

1. **Recruitment monitoring:** The aerial survey index is used in the annual indicator based review of the stock and consideration of exceptional circumstances. Recruitment monitoring and detecting and responding to periods of low recruitments, and the associated risks of further decline in SSB, has been a high priority for the Commission. A large percentage of the catch of SBT is on the juvenile component of the stock. The lack of information on recruitment may trigger exceptional circumstances in 2015.
2. **Operating models for stock assessments and Management Strategy Evaluation:** The index is integrated into the CCSBT operating models as a relative abundance index for three combined age classes (ages 2-4). The operating models are used for periodic (3 years) assessment of the status of the stock, management strategy evaluation of MPs, and will be used as a central part of the review of the MP scheduled for 2017. In 2005, *"…The ESC Chair noted that considerable work had been carried out recently to validate the aerial survey and that this had resulted in higher levels of confidence in the survey outcomes. The external panel suggested that the aerial survey outcomes may now be at the stage where they could be included in the tuning of the operating model*" (Anon 2005). Analysis of the consistency and variability of the survey in the current operating models, indicates that (i) the survey is consistent with the estimated recruitment information in all the other data sources and priors, (ii) the survey can act to ameliorate spurious estimates of year-class strength driven by issues common to fishery dependent CPUE indices, and (iii) when actively including the survey in the estimation procedure there is a better and more consistent fit to the data in the resulting operating model trajectories.
3. **Management procedure to recommend TACs:** The aerial survey index is one of two data series, and the only fishery independent data, used in the MP decision rule adopted by the CCSBT for recommending TACs. In 2008, the ESC agreed that candidate MPs must include the aerial survey to provide an earlier signal of year class strength. The inclusion of the aerial

survey in the MP development was also due to the concern of relying on an MP using CPUE only, given unresolved uncertainties in the historical time-series. Complete cessation of the aerial survey would mean that the adopted MP could no longer be used, and a new MP would need to be developed. This would trigger exceptional circumstances. Alternative recruitment information that could be considered in the development of future MPs is discussed, although there are currently no robust alternative quantitative indexes. There would be substantial time and costs associated with developing, testing performance, agreeing and implementing a new MP.

We estimate the aerial survey related component of the TAC increases that have been adopted by the Commission between 2012 and 2017 and, if converted to a monetary value, would cover the cost of the aerial survey multiple times over. The same estimates have been made for potential future TAC increases under the MP, should it continue to be used to set TACs in 2016. The component of these that can be attributed to the aerial survey exceed the costs of the aerial survey by an order of magnitude.

Adoption of the first management procedure in a tuna RFMO set the benchmark for tuna Commissions, and provided a scientific basis for continued fishing of SBT and rebuilding of a depleted stock. Cessation of the aerial survey beyond 2016 would mean the Commission would cease to have a scientifically tested, explicitly precautionary, rebuilding plan for the SBT stock. It would also mean under-utilising substantial investments in research and monitoring to develop the current MP and potentially foregoing large future catches that would otherwise have been possible under the agreed MP.

1 Introduction

The southern bluefin tuna (SBT) line transect scientific aerial survey was cancelled in 2015 following funding decisions at the Extended Commission (Anon 2014a). The index of relative juvenile abundance from the aerial survey provides essential information on recruitment for the CCSBT management procedure (MP) and meta-rules processes, which include review of fishery and stock indicators, assessments of stock status, TAC setting recommendations, MP reviews and a process for dealing with exceptional circumstances (Anon. 2013).

The scientific aerial survey of SBT is conducted in the Great Australian Bight (GAB) and commenced in 1993, prior to the formal constitution of the CCSBT. It was developed as part of the NRIFSF (Japan) and CSIRO (Australia) Recruitment Monitoring Program, to provide a relative abundance estimate of juvenile SBT, following concern regarding the status of the stock and declines in recruitment (Cowling et al, 2002). This concern remains, with the SBT stock estimated to be approximately 9% of initial biomass levels (Anon 2014b) and consistent evidence of recent low year classes still to move into the spawning population.

The aerial survey index is used in several components of the management procedure schedule of events as set out in the meta-rules adopted in 2011 (Anon 2013; see CCSBT-ESC/1509/12 for further details);

1. Recruitment monitoring: The aerial survey index is used in the annual indicator-based review of the stock and consideration of exceptional circumstances.
2. Operating models for stock assessments and management strategy evaluation: The index is an input data series for the CCSBT operating models and integrated as an index of relative abundance across three age classes (ages 2-4). The operating models are used for assessment of the status of the stock every three years, management strategy evaluation of management procedures, and will be central to the scheduled review of the MP in 2017.
3. Management procedure decision rule to recommend TACs: The aerial survey data is one of two data series, and the only fishery independent data, used in the Management Procedure decision rule adopted by the CCSBT for recommending TACs.

The Extended Commission has requested advice on the implications of cessation of the aerial survey in 2015 and potentially in 2016 and beyond (Anon 2014a). Some aspects of this were considered by the ESC in informal inter-sessional webinars, and a report was provided for consideration at the CCSBT’s Strategy and Fisheries Management Working Group (SFMWG) meeting (Anon, 2015b). This paper provides advice on the implications of cancelling the aerial survey for the management procedure schedule of activities including future TAC setting (see also Davies et al, 2015 (CCSBT-ESC/1509/12)), an evaluation of the costs and benefits of the aerial survey data and potential alternative sources of information on recruitment.

2 Role of the aerial survey in recruitment monitoring and CCSBT operating model and MP

The scientific aerial survey has been conducted in the Great Australian Bight since 1993. Data collected in the survey are used to estimate a relative abundance index for juvenile SBT for the years 1993-2000 and 2005-2014. The survey was suspended in 2001 because of problems in finding trained spotters and spotter-pilots. The suspension allowed for a review of the survey design, data analysis and effectiveness of the survey in detecting changes in abundance to be conducted, and it concluded that the scientific aerial survey provides a suitable indicator of SBT abundance in the GAB (Bravington 2003). An ad-hoc survey design was trialled in 2002-2004 but did not provide a reliable index of abundance (Farley et al, 2004). Thus, the full scientific aerial survey recommenced in 2005 (Bravington et al. 2005), and continued each year through 2014. The survey was not conducted in 2015.

New analysis methods were developed in 2005 (Bravington et al. 2005), and have subsequently been refined to provide a robust index of juvenile abundance (along with confidence intervals) across all survey years (Eveson et al. 2008). Methods were also developed to incorporate calibration factors for single spotters in the planes (Eveson et al 2011).

In 2004, the estimates of recruitment from the stock assessment and the independent aerial survey estimates (1993-2000) were compared and found to be consistent (Bravington et al, 2004). The Recruitment Monitoring Workshop noted "… *that there was no evidence for inconsistency, such as might be caused by variations in the proportion of juveniles entering the GAB. However, the data do not rule out low levels of inter-annual variability* "(Hobday, 2005).

The fishery-independent index of abundance from the aerial survey has historically been used as a fishery independent means for monitoring recruitment. Since 2009 it has been incorporated into three elements of the management procedure and meta-rules processes; 1) recruitment monitoring and evaluating stock indicators, 2) operating models for stock assessments, management strategy evaluation and MP review, and 3) the management procedure decision rule to recommend TACs.

2.1 Recruitment monitoring:

The aerial survey index is one of the recruitment monitoring data sets used in the annual indicator-based review of stock status and evaluation of exceptional circumstances under the MP meta-rules. In 2015 all current recruitment monitoring ceased (i.e. the aerial survey, the trolling survey, the commercial spotting index (SAPUE)). Consequently there are no data in 2015 to evaluate recent changes in recruitment.

The aerial survey index is the longest of the recruitment monitoring times series that have been collected. Other recruitment monitoring programs undertaken in the past include the acoustic survey in the years 1996-2006 and trolling survey 2006-2014 (Itoh and Tokuda, 2014), the SAPUE commercial spotting index from the GAB from 2002-2014 (Farley et al. 2014), and tagging programs in years 2001-2007 and for previous periods in the 1990's and 1960's (Polacheck et al, 2004). No alternative recruitment monitoring methods are currently available (discussed further below). The number of one year olds spotted in the GAB in the 2014 aerial survey was low compared with recent high years (Eveson et al, 2014), and the 2014 trolling index declined from 2013 (Itoh and Takahashi, 2014), which may have resulted in a low aerial survey abundance estimate in 2015, had the survey proceeded. **The lack of information on recruitment may trigger exceptional circumstances in 2015.**

Avoiding periods of low recruitment, and the associated risks of further decline in spawning stock biomass (SSB), has been a high priority for the Commission (e.g. Anon, 2001, 2005, 2008, 2011, 2014) and the rationale for the large investment in recruitment monitoring. The 2009 reduction in quota reflected the Commissions concern about both stock status and the historically low levels of recent recruitment in the early 2000's. The ESC reflected this concern in the design of the MP, with stronger reductions in catches in response to declines in recruitment than increases in response to signals of rebuilding, and focusing on robustness tests associated with this.

A large percentage of the catch of SBT is on the juvenile component of the stock. Approximately 50% of the total SBT catch (in weight) is aged 0-4 years old, and 76% of the catch in numbers (averaged over the last 10 years) is juveniles (ages 0-4). In the longline 1 fishery (LL1), which includes all the Japanese longline catch used in the CPUE calculations, the proportion of the catch that is juveniles (ages 0-4) ranges from 15 to 45% in numbers and 6 to 18% in weight (over the last decade)[1].

The ESC has noted previously the importance of recruitment monitoring and development of indicators that are fishery independent and unaffected by the over-catch scenarios (Anon 2008). Noting the depleted state of the SBT stock, and the substantial time-lags between initial recruitment and a) the first reliable observations from the longline fisheries (~5 yr old), and b) maturation (8-10 years on average), it is essential that abundance of juveniles is monitored to provide information about potential low year classes as early as possible.

2.2 Operating models:

The aerial survey index series is integrated into the SBT operating models as a relative abundance estimate across three age classes (ages 2-4). In 2005, the ESC noted the increasing importance of recruitment indices, and the recent contribution of information from tagging work and aerial surveys. "*The ESC Chair noted that considerable work had been carried out recently to validate the aerial survey and that this had resulted in higher levels of confidence in the survey outcomes. The external panel suggested that the aerial survey outcomes may now be at the stage where they could be included in the tuning of the operating model*" (Anon 2005.

In 2008, the ESC agreed to incorporate the aerial survey time series in the operating model (OM) in light of the series of historical low recruitments, the lag between recruitment and occurrence in the longline CPUE, the depleted state of the stock and the unquantified uncertainties in the longline CPUE series resulting from the unreported catches (Anon, 2008). In the review of the

[1] Note these calculations are from the MP CAA calculated by the secretariat(SEC_ManagementProcedureData_5213.xls, 2014)

2000's Scientific Research Program (SRP), it was recommended that research and monitoring should be aimed at reducing reliance on CPUE (e.g. Itoh et al 2007, Davies et al. 2007).

There are currently no alternative data series that provide direct information on recruitment of 2-4 year olds in the OM. The 2007 CPUE modelling group and SAG noted that the nature of the purse seine fishery meant that CPUE was not useful as an index of abundance (Anon 2007 (see Att. 4 Extract of 2nd CPUE modelling workshop report)). While the troll survey index is included in the annual review of indicators of stock status, it has not been incorporated into the reference set of OMs due to questions that remain over the survey design used to obtain the trolling index (Anon 2008). The SAPUE data are not included because the index is fishery dependent and developed from commercial operations that change each year to cover different areas and times.

The reference set of OMs are used for assessment of the status of the stock every 3 years, and are the models used in management strategy evaluation of the MP decision rules and review of the MP. The next stock assessment and the MP review are scheduled to be conducted in 2017. Sustained levels of higher recruitment estimated from the SBT operating models will be the first indications that the rebuilding of the SBT stock is occurring, and higher recruitments are central to the rebuilding the spawning stock.

2.3 Management procedure:

The aerial survey index is one of two data sources used in the MP adopted by the CCSBT; the other being the average of two standardised CPUE series from the Japanese longline fleet (Anon 2013, Attachment 10). The aerial survey data are the only fishery independent data used in the MP.

The management procedure has been designed to use the aerial survey data (recruitment information) and Japanese longline CPUE data (biomass changes), in a model that calculates changes to the TAC. The most recent aerial survey data points (the last 5 years) provide information on whether or not recent recruitment is above the historical low levels in the series. The MP reacts strongly to low recruitments by recommending reductions in catches, and reacts conservatively to higher recruitments by increasing TAC slowly; in this way the MP is explicitly precautionary and reflects the Extended Commission's desire to have a low probability of further stock declines and a high probability of meeting their rebuilding objective.

In 2008, the ESC agreed that candidate MPs must include the aerial survey data to provide an earlier signal of year class strength (than longline CPUE on its own). The inclusion of the aerial survey index in the MP development was also due to the concern of relying on an MP using only CPUE and/or catch composition data, given unresolved uncertainties in the historical time-series for the longline fleet, recent changes in the LL1 fleet (due to changes in management and economic drivers) and potential for future changes. The MP which had been developed prior to the revelation of market anomalies was abandoned in 2006; " *… the ESC agreed that it was not possible to proceed with the current MP and that urgent consideration of a short-term "interim MP", incorporating indicators unaffected by the catch anomalies was required*" (Anon 2006). Various robustness tests used in the process of selection of a new MP were specifically aimed at testing its ability to cope with postulated scenarios about the uncertainties in CPUE.

3 Fit and Influence of aerial survey

3.1 Fit of OM to aerial survey data

We have examined the influence of the aerial survey and its consistency with other data sets included in the OM. The “reliability” of the aerial survey is examined in the predicted versus observed plots that are routinely produced when the OM is reconditioned (e.g. Hillary et al 2014).

Figure 1 shows the predicted vs. observed aerial survey plots for two scenarios: (i) where the aerial survey data are fitted with an assumed process error SD of 0.22; and (ii) where the process error SD is set at 10 so the data are effectively ignored (although for graphical purposes the Probability Interval (PI) in the graph are plotted assuming the same SD of 0.22 as the default settings). Clearly, apart from the most recent years of 2013 and 2014, there is not much difference between the two plots. This can be interpreted in two contrasting ways:

1. The aerial survey data have little influence on the estimated trends in juvenile biomass in the OM
2. The aerial survey is consistent with the recruitment information in the other data sets in the OM (CPUE, catch composition, tagging) where they overlap.

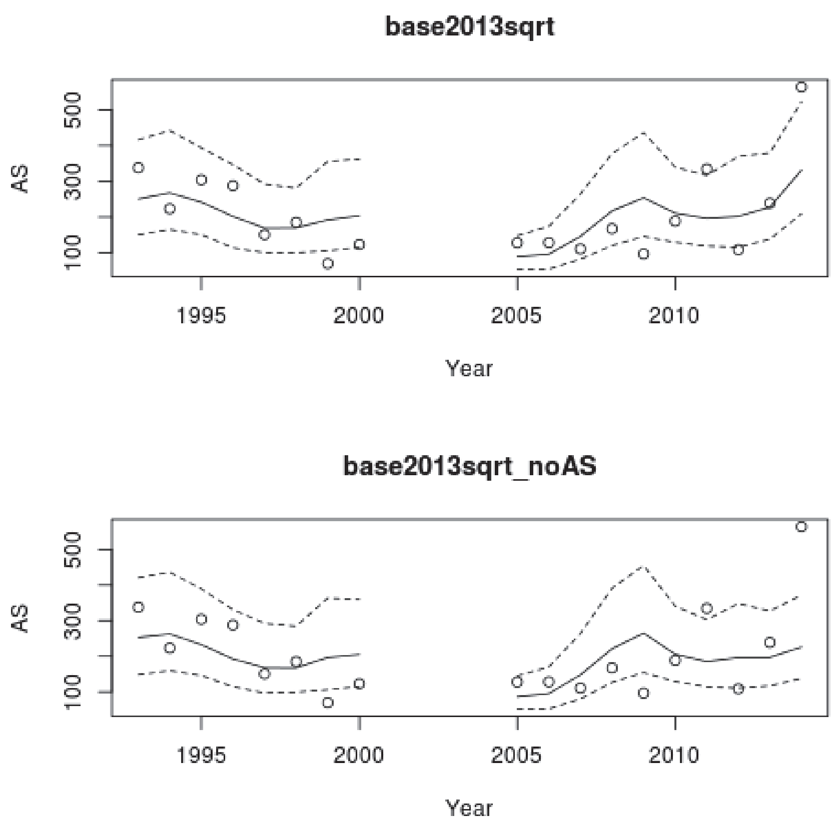

Figure 1 Predicted versus observed aerial survey data when fitted in the OM (top) and not fitted in the OM (bottom)

The plot in Figure 1 only really tells us that on average the survey is consistent with the trend in the OM and is almost always found within the probability bounds we assume in the likelihood (i.e. given the observation and assumed process error levels and structure). What it does not tell us is if - for each of the grid samples - actively fitting to the survey data results in a noticeably more consistent trend between the OM and the survey index. In an attempt to differentiate among these two candidate explanations, we estimated the correlation between the OM predicted aerial survey and the actual survey observations, for each grid sample. Figure 2 shows the estimated correlation, summarised across all 2,000 grid samples, between the OM and the survey estimates, when the aerial survey is actively fitted in the OM, or not.

Clearly, when the survey data are actively fitted in the OM there is a significantly higher correlation (very precise and around 63%) than when the index is effectively ignored (much more variable and around 36%). Improving the fit to the 2013 and 2014 data points would not account for this increase and consistency of correlation between the OM and the survey estimates; when actively fitting to the survey the result is a much more consistent relationship across all grid samples between the OM and the survey.

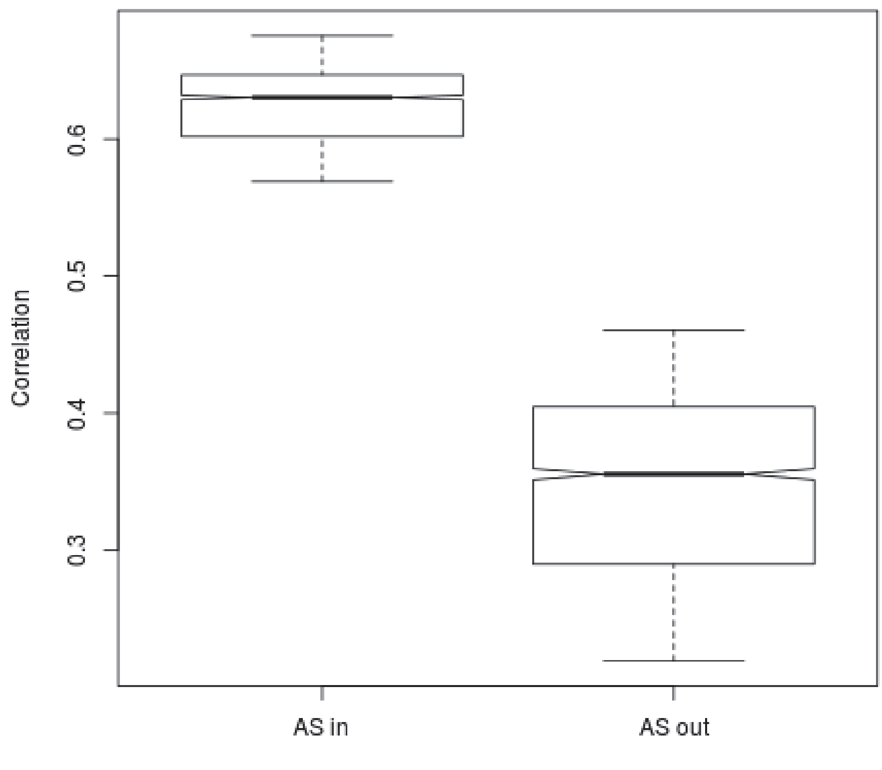

Figure 2 Correlation between the OM-predicted survey index and the observed index for each grid sample from the OM, with the aerial survey included (left) or excluded (right).

3.2 Influence of aerial survey on estimates of year class strength

In addition, we examined how the estimates of year-class strength differ when the survey is either included, or excluded from the fitting procedure. Figure 3 shows the estimated abundance of individual year-classes (age 0yrs) for the years covered in the survey (1991-present). Overall, there is a strong consistency of estimates from 1991-2004 with little apparent difference, regardless of whether the aerial survey is included, or not, in the fit. Beyond 2004, 2005 and 2006 are estimated to be smaller year-classes with the aerial survey included; 2007-2010 estimates are slightly (but not significantly) higher with the survey included and 2011 and 2012 are significantly higher, with auto-correlation keeping the estimates higher in 2013 and 2014 (in the absence of any data).

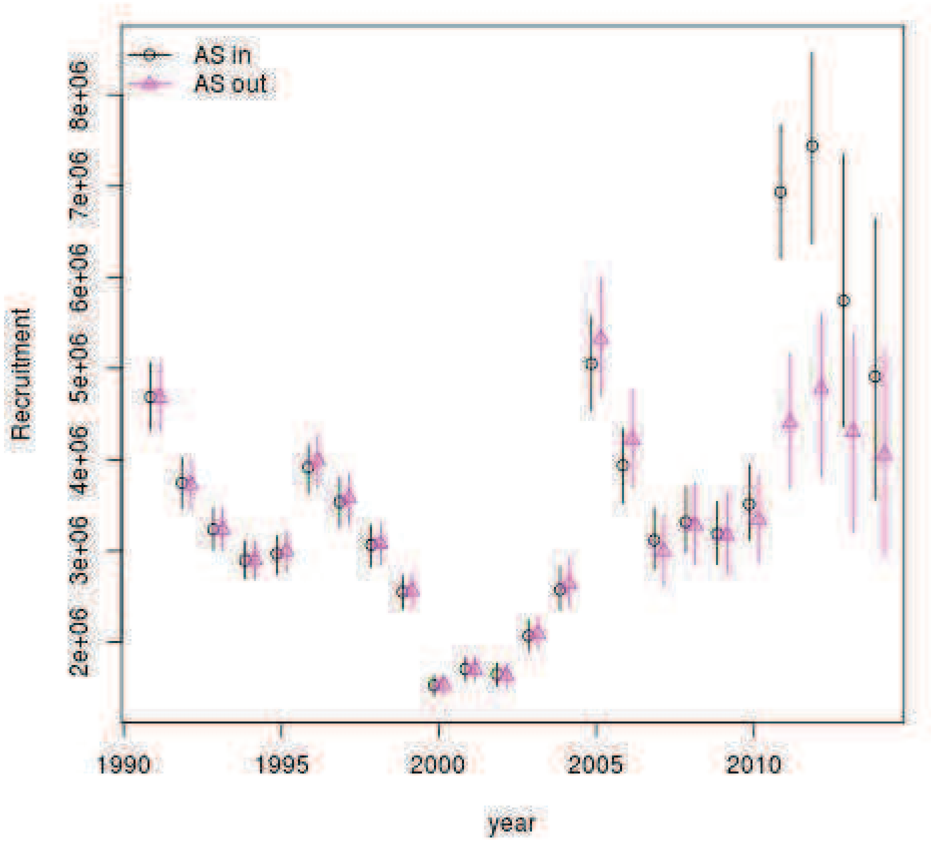

Figure 3 The estimated abundance of individual year-classes (age 0yrs) for the years covered in the survey (1991-present), when the survey is either included (black circles), or excluded (pink triangles) from the fitting procedure.

The general consistency up until 2010, following which the aerial survey is the only information on year-class strength, is to be expected given the strength of correlation demonstrated in Figure 2. The fact that 2005 and 2006 are estimated to be smaller year-classes is interesting given 2005 was used as an example of why the aerial survey is not a reliable abundance index in (CCSBT-ESC/1509/20). Both visual analyses of the nominal CPUE-at-age (OMMP3) and OM-specific estimates (Anon. 2014) indicate a general increase in catchability in the LL CPUE data from 2008 onwards. Given catchability is fixed in the reference set of OMs (with a small linear increase over time), such an increase in catchability would manifest as higher than expected estimates of year-class strength, in the absence of other data to inform the estimation. There is no systematic lack of fit to the 2005 year class in the survey as suggested in CCSBT-ESC/1509/20 (see years 2007, 2008 and 2009 in Figure 3 when this cohort is observed in the survey) but the survey does not reflect as strong an increase as predicted by the CPUE and, therefore, tempers the increase in year-class strength in 2005 and 2006.

We contend these results demonstrate the benefits of fishery independent monitoring, particularly for recruitment. The aerial survey data clearly improves the estimates of year class strength in the OM and acts to constrain the OM estimating anomalously large changes in year-class strength driven by issues such as catchability shifts in the CPUE index. As to whether the notably higher recruitments estimated in 2011 and 2012 will be observed in the other data sets, remains to be seen, but again, these cannot be assumed to be evidence, or otherwise, of the survey's reliability until these data are available to include in analyses such as those presented here. It would be incorrect, and against experience in this and other fisheries, to assume that the fishery dependent data are accurate and, or, sufficient, in the absence of a basis for formal comparison.

The analysis above shows three things: (i) the aerial survey is consistent with the estimated recruitment information in all the other data sources and priors, (ii) the survey can act to ameliorate estimates of year-class strength driven by issues common to fishery dependent CPUE indices, and (iii) when actively including the survey in the estimation procedure we see a better and more consistent fit to the data in the resulting OM trajectories. These results are consistent with the ESC's previous views that, in the absence of a rigorously designed and tested alternative, the survey is indeed both a reliable and important index of average recruitment to the juvenile part of the SBT stock.

4 Requests from the Commission

4.1 2014 Commission request

> "Members expressed concern that the lack of aerial survey data in future will affect the Management Procedure (MP). The EC requested the ESC to consider the implications of this for the Management Procedure process and advise how best to run or re-tune the MP in the event that no aerial survey data is available for 2015 and potentially also 2016 and beyond." (Anon. 2014. Report of the Twenty First Annual Meeting of the Commission, 13-16 October 2014, Auckland, New Zealand).

4.2 ESC agreements

The ESC addressed some of these issues inter-sessionally and provided an informal report for consideration by the SFMWG meeting (Anon 2015a (CCSBT–SFM/1507/09)). The key agreements and recommendations from the ESC informal webinars were:

1. The MP is a central component of the SBT rebuilding plan. The aerial survey provides fishery-independent information on recruitment that has been critical in the CCSBT Operating Model, for development and testing of MPs and for periodic assessments of stock status. The aerial survey index, on its own, is also an important indicator of year class strength and trend in recruitment.
2. Given that the SBT stock is estimated to be depleted, and a substantial proportion of the catch is taken from the juvenile and sub-adult components of the stock, continued recruitment monitoring is essential for early warning of possible low recruitments in the future.
3. All other recruitment monitoring programs ceased in 2015 or earlier (i.e. trolling, SAPUE and the aerial survey were all cancelled in 2015).
4. A reduced 2016 aerial survey, within the range of options proposed, would allow continued operation of the MP and other uses of the survey (e.g., indicator and stock assessment). Without the 2016 aerial survey data, the MP could not operate and exceptional circumstances would likely be triggered.
5. If the aerial survey is discontinued a new MP will need to be developed, which will take considerable time and funding to complete. In the interim, the CCSBT will be without a tested and agreed rebuilding plan.

Recommendation:

1. The aerial survey for 2016 should proceed to allow the use of the MP for setting the 2018-2020 TAC in 2016.

4.3 SFMWG agreements and requests

The SFMWG met in late July and discussed funding arrangements for the aerial survey. The meeting agreed to fund a reduced aerial survey in 2016, but there was no commitment to funding the aerial survey in 2017-2019 for use in the MP in 2019 for the next 3-year block of TAC (Anon, 2015b).

The SFMWG requested the ESC provide additional advice, and two of those requests are covered here; 1) provide advice on costs and benefits of continuing with the current MP and conducting the aerial survey in 2017 to 2019, 2) provide advice on alternative recruitment information for use in new MPs. The other requests (research priorities, alternative MPs and costs, MP review and meta-rules) are dealt with in the meta-rules and management procedure review paper (Davies et al, 2015).

5 Implications of cancelling the aerial survey

5.1 Implications for recruitment monitoring

The aerial survey index is the only continuous (to 2014), long-term, fishery independent recruitment monitoring data set used in the annual indicator based review of the stock and evaluation of exceptional circumstances. Other recruitment indicators are used in a qualitative manner given the uncertainties associated with them.

Exceptional circumstances may be triggered by the absence of the 2015 data point. If the 2016 aerials survey fails to cover enough transects or does not proceed, then exceptional circumstances will be triggered in 2016. The ESC would use the agreed meta-rules process for action to assess implications for current and future TACs and make appropriate recommendations to the Commission.

5.2 Implications for the operating models

The aerial survey index is used directly in the CCSBT operating models, which are used for the assessment of stock status, and in MP evaluation and review. As noted above, the aerial survey data in principle directly inform the estimates of the most recent recruits in the operating models, and there is little additional data available in the models to inform these estimates. There is a need for information on juveniles in the operating models/stock assessment models to provide information on recent recruitment and early warning of low recruitment. The next stock assessment and review of the MP is planned for 2017. Inter-sessional work for this review would need to commence in 2016. The operating models are also used to check that the MP is operating as expected in the TAC setting years (i.e. 2016).

5.3 Implications for the MP

The next TAC calculation for SBT is scheduled for 2016 where the full time-series of aerial survey and CPUE indices will be used to recommend the TACs for 2018-2020. Following this, the next TAC setting decision is in 2019, using data up to and including 2019, to set the TAC for 2021-2023. Under the meta-rules the first formal review of the MP is scheduled for 2017.

The aerial survey data are considered “essential” input data to the SBT management procedure (Anon, 2013 ESC report Att10); these data are also “essential” for current management of the stock, the SBT rebuilding plan and setting the global TAC.

The lack of an aerial survey index data point in 2015 may trigger exceptional circumstances under the meta-rules process for the MP (CCSBT-ESC/1509/12). The ESC is yet to review and agree on a method for accounting for missing data in the aerial survey time series in the MP. Inter-sessional work involved modifying the MP code to run models missing the 2015 index (Hillary et al 2015a). These code changes will need to be considered and adopted by the OMMP working group and ESC prior to use in 2016. Missing data in the most recent 5 years in the aerial survey will be particularly influential as they have the greatest impact on whether or not recommended TACs increase, stay the same, or decrease, in the short term.

Complete cessation of the aerial survey would mean that the adopted MP could no longer be used. A new MP would need to be developed. There would be substantial time and costs associated with developing, testing performance, agreeing and implementing a new MP. The last MP took more than 4 years to develop, and there were substantial costs for the main developers (primarily Australian and Japanese scientists), plus the costs of OMMP meetings, Advisory Panel contributions, and ESC work and special Commission meetings for review and adoption of the MP (Hillary et al 2015b).

The MP review process, scheduled for 2017, was intended to assess performance of the adopted MP (relative to the Commission's interim rebuilding objectives), consider plausible alternatives that may be transitioned to in the future, and alternative data series that could be obtained (e.g. close-kin). The MP and meta-rules include a transition process in the event that a new MP is to be developed; the adopted MP should continue to be used to set TACs while a new MP is developed to provide for the orderly and precautionary rebuilding of the stock (Anon. 2013). Collection of data for the current MP should only cease when a new MP, including required data series, has been developed, tested and is ready to be (or has been) implemented. This underlying rationale is reflected in the SRP workplan developed by the ESC and adopted by the Commission in 2013 (Anon 2013).

Adoption of the first management procedure in a tuna RFMO set the benchmark for tuna Commissions, and provided a scientific basis for continued fishing of SBT and rebuilding of a depleted stock. The most recent performance review (Garcia and Koehler, 2014) notes the implementation of the MP, and the scientific foundation for decision making and rebuilding the SBT stock, and considers that the related actions from the 2008 performance review are now successfully completed. Cessation of the aerial survey beyond 2016 would mean the Commission would cease to have a scientifically tested, explicitly precautionary, rebuilding plan for the SBT stock. It would also mean under-utilising substantial investments in research and monitoring to develop the current MP and potentially foregoing large future catches that would otherwise have been possible under the agreed MP.

5.4 Logistic implications and reduced aerial survey design

The implications of not conducting the aerial survey in 2015 are both technical and logistic. The logistics issues are that specialist expertise are required to run the aerial survey. In particular, tuna spotters who have been calibrated into the aerial survey, and who have provided consistency in the last 10 years of the survey, may no longer be available in 2016. This logistic vulnerability has increased in recent years, with the loss of experienced pilots and spotters from the Industry, and was planned to be addressed in 2015 with the use of 2 planes and calibration of a new spotter. Ideally, this would have been done over multiple years to provide as precise calibration as possible. This was not possible given the cancellation of the 2015 aerial survey.

The SFMWG meeting agreed to fund the 2016 aerial survey in a reduced format, with 1 plane flying for 3 months and a second plane flying for 4 weeks covering half of January and half of February. Restarting the aerial survey in 2016 in this format is still uncertain because the calibrated spotter may not be available for a 1 year contract and therefore only 1 plane with a new spotter and an experienced spotter pilot (asked to return from retirement) would potentially be available. The logistical and timing issues related to attempting to re-start the aerial survey in 2016 are addressed in Davies (2015b), presented at an informal ESC webinar held in March and are also addressed in the informal report of the ESC for the SFMWG meeting (Anon, 2015a).

5.4.1 An aerial survey every second year and re-tuning

At the time of cancellation of the 2015 aerial survey it was suggested that the aerial survey could potentially be run every other year, but the logistics are not feasible (see Davies 2015b and CCSBT–SFM/1507/09). The expertise required is highly specialised, and it's unlikely that those specialists will be available for a 3 month work project every second year. The key points to note are that there is currently 1 spotter calibrated into the aerial survey, and new spotters can't just be added in without calibration. Importantly, an aerial survey "every-other-year" would be a new management procedure that would need to be fully evaluated. The adopted MP was not designed for data every other year, and therefore an MP of this form would need to be specified and would require full MSE testing of performance prior to use for setting TACs. This would be an extensive additional item for the ESC to consider and potentially add to the existing work program.

Re-tuning was also suggested by the Commission in 2014. As noted by the ESC, the adopted MP cannot be run without aerial survey data. No re-tuning is required, to run the MP with a single missing data point in 2015 and a reduced aerial survey in 2016. This issue of whether re-tuning of the MP is warranted, or not, is an issue that would be considered as part of the MP review scheduled for 2017.

5.4.2 A reduced aerial survey

The ESC inter-sessional work and webinar focussed on impacts and feasibility of options for reducing the cost of the aerial survey through flying fewer hours. Three alternatives for conducting the aerial survey in future were provided to the SFMWG;

1. The full aerial survey – 1 plane for 3 months (Jan-March) and a second plane for two months (Jan and Feb). This allows for complete coverage of the transect area with repeat surveying of each of the transect lines each month.
2. 1 plane for 3 months, and 1 plane from mid-Jan to mid-Feb.
3. 1 plane only for the 3 months of the survey.

Funding for option 2 as a "reduced" aerial survey was agreed at the SFMWG meeting. The "reduced aerial survey" reduces costs through reducing the flying hours. Reducing the hours flown will result is a less certain relative abundance estimate, i.e. higher coefficient of variation (CV).

There are additional logistics risks and complications associated with having only 1 plane available for most of the period of the aerial survey. If there is bad weather, then fewer transects will be flown. There will also be limited opportunity for calibrating an additional spotter. Any breakdowns in equipment or loss of availability of personnel will be a risk to the completion of the survey.

The implications of an aerial survey with higher CV's were tested in comparison runs of the MP using scenarios agreed inter-sessionally (CCSBT–SFM/1507/09). The ESC agreed that the MP could be run using the AS with a higher CV (Anon 2015a).

6 Costs and benefits of the aerial survey

The inter-sessional work of the ESC webinars, focussed on examining the impact of scenarios using aerial survey data with a higher CV in the expectation that there would be a standard "risk-catch" trade-off. The results did not, however, demonstrate this trade-off due to the way in which the data are used in the MP and the more optimistic nature of the OM relative to when the MP was tuned in 2011. These issues are discussed further below along with additional analysis completed since the SFMWG meeting.

6.1 Historical estimated benefits of the aerial survey index

The clearest benefit of the aerial survey relates to the actual adoption and implementation of the MP itself. In the 2010-2011 MP evaluation process the aerial survey was a core element of the candidate MPs (Anon 2010a,b; Anon 2013b) and proved to be a major reason for the robustness of the MP to underlying variability, future recruitment failure, and issues with the LL CPUE index (Anon 2011).

The main qualitative benefits of having the MP are:

- Having a scientifically tested rebuilding program for the stock – the first international tuna fishery to do so (Hillary et al 2015b)
- Given the MP recommended the TAC advice to the Commission from the ESC member scientists had additional time to include key new data sources, such as the close-kin data and initial development of gene-tagging.
- Stability and transparency in the TAC as driven by the MP, which is important to industry.
- Increases in TAC driven by positive signals in both the indices that would have been unlikely to be agreed in the previous stock assessment/consensus advice paradigm (Hillary et al 2015b).

There are also quantifiable financial benefits to having the aerial survey in the MP that are central to the discussion on the costs and benefits of the aerial survey to the MP, rebuilding of the stock and wider flow of benefits from the fishery.

The integrated nature of the MP, where the LL CPUE and aerial survey are fitted simultaneously, conditional on the simple population model, means it is not possible to fully separate the contributions of the CPUE and aerial survey with respect to changes in TAC recommended by the MP. However, the structure of the Harvest Control Rule (HCR) in the MP (Anon. 2013, Attachment 10) allows the component of the historical TAC increases that were due to the aerial survey **alone** to be calculated explicitly. This calculation will underestimate the overall historical contribution of the survey index to the TAC increases, as the increase in the sub-adult biomass that contributed to the TAC increases are also influenced by the survey index as part of the simple state-space "miniassessment". Notwithstanding this underestimation, for the TAC increases agreed and implemented for the period 2012-2017, approximately 1,000t of additional quota was added as a direct result of the information on recruitment provided by the part of the HCR that relates to the aerial survey. Even at conservative prices/quota values for SBT the value of this information alone would cover the cost of the survey over this period a number of times over.

6.2 Future estimated benefits with Aerial Survey index

A number of analyses have been performed to look at the potential future impact of a reduced precision aerial survey in future MP TAC setting decisions, using the SBT OM. The majority of the analyses we refer to can be found in CCSBT-SFM/1507/09; an informal report of the MP technical group to the SWFWG meeting. Given the reasonably clear empirical relationship between the annual observation error CV for the aerial survey and the distance flown in that survey, it was possible to define a number of scenarios for future aerial survey CVs for reduced levels of survey effort to explore the likely precision of less intensive surveys in the future.

The first analyses looked only at the effect of a range of reduced future survey effort scenarios on the adopted MP. These results showed that, at least in terms of future rebuilding and average TACs there was little difference observed across the scenarios. That is, provided there was an aerial survey that continued to provide a "reasonable" index, the impact on rebuilding and catch performance of the MP was small to negligible. This result was not expected and, as noted above, reflects the design of the MP itself and the changes in the perception of the stock from the OM since the MP was tuned and implemented.

The second set of analyses looked more closely at the performance of the MP on the key robustness trials explored in the original MP testing program. Given the reduced aerial survey effort scenarios the future recruitment failure trial (*lowR*) was run ***in combination*** with a number of CPUE-related robustness trials (*highCPUECV, upq, omega75*). This new approach, i.e. combining robustness trials, was undertaken as reducing the precision of the aerial survey implicitly places more faith in the CPUE index. It was precisely these trials that the survey proved so important in the original MP testing program (Anon 2011). The conclusion was that, perhaps contrary to prior expectation, the adopted MP was robust to a reduced level of survey effort even when combining several of the key (and previously very influential) pessimistic CPUE and low recruitment robustness trials explored previously. The most important reasons for these results are:

1. The MP was specifically designed to reduce the variability in both the input indices, by fitting the simple population model to both the CPUE and the survey with fixed total effective variance parameters.
2. The part of the HCR in the MP that relates to the aerial survey uses a 5-year moving average of relative recruitment to the adult population. It reacts strongly to reduce TACs when recruitment is below the historically lowest levels in the survey and small TAC increases are permitted when recruitment is above the historic lows. The 5-year moving average means that, even for the scenarios explored here for CVs associated with different levels of survey effort, the actual statistic derived from the survey used in the MP will never exceed a CV of 20% (i.e. fairly accurate and informative) and effectively the same precision as assumed for the CPUE index in the OM and MP.

3. The current estimates of biomass depletion, fishing mortality, natural mortality and uncertainty therein are all quite different (and more positive) than for the OM of 2011 used to test and tune the Bali MP. The most recent reconditioning of the OM (CCSBT-ESC/1409/21) demonstrated that the Bali MP is much more robust to the various robustness trials that had been highly influential in the past. The inclusion of the close-kin data, as well as positive signals in both the CPUE and the aerial survey of several higher recent recruitments, has contributed to this change in overall status for SBT in the reference set of OMs.
4. None of the analyses explored the potential impact of UAM and, given that a number of alternative and plausible UAM scenarios have an impact on the future robustness of the MP (e.g. CCSBT-ESC/1409/15), it is likely that the current assessment of the future performance of the MP under the reference set of OMs is likely to be over-optimistic.

That the MP is robust to a reduced level of survey effort, as explored in the trials, and in conjunction with unforseen recruitment failure and CPUE index problems, is encouraging. However, this outcome needs to be considered in the context of the caveat that not considering the impact of UAM means the current projections are overly optimistic.

The remaining potential impact to explore is the value of continuing the survey into the foreseeable future in terms of the likely realised catches versus the cost of the survey. From the simple historical analysis above, even for conservation price/quota value levels, the added value of the survey outweighs its cost. We have also examined the aerial survey component in potential future TAC scenarios with and without the continuation of the survey.

Given the future likely distribution of both the CPUE and survey indices, estimated in the reference set of projections, the aerial survey component of the TAC calculations in the HCR would add around 500t of extra TAC **per year** (so 1,500t in total for 2018-2020). Again, given previous price/quota value assumptions the value of this additional TAC resulting from the information provided by the survey far exceeds the costs, even at the historically highest levels of effort and coverage.

If, however, we do not run the survey in 2016 (and by implication it terminates permanently) and exceptional circumstances *are* triggered, it is unlikely the advice from the ESC would be to proceed with a TAC increase based on the MP. One scenario is that risk equivalent constant catch projections might be used by the ESC to provide TAC advice in the absence of the MP. Depending on how one defines that risk equivalence the outcome of this approach in terms of the most optimistic outcome would likely be the *status quo* (i.e. no TAC increase) but might also be a decrease in TAC. Assuming *status quo* TAC advice for this scenario, the forgone TAC would amount to approximately 2,500-3,000t **per year** for the 2018-2020 period. The forgone value to the fishery in this scenario, as a result of not having the information on recruitment from the aerial survey, dwarfs the cost of the survey.

If the aerial survey is removed altogether from 2016, which would result in exceptional circumstances, but is done here as another scenario to illustrate the cost and benefits of the aerial survey, we see a similar overall result. The rebuilding performance by 2035 (in terms of the probability of rebuilding to 20% SSB) is 0.73 without the survey and 0.71 with the survey (i.e. basically the same up to the Monte Carlo error of the simulations). However, the estimated foregone TAC averages in the order of 1,800t lower **per year**. So even when integrating across expected future trajectories for both indices, and regardless of the precision of the survey within the bounds explored, the rebuilding performance is the same but the level of forgone of catch is substantial and greatly exceeds the cost of the survey; in the latter case by at least an order of magnitude. The reason for this is quite simple: the aerial survey-related part of the MP acts to decrease TACs strongly for low (relative to historical minima) levels of mean recruitment, and weakly increase them when above. Given the current more optimistic perception of the projections in the reconditioned OM, future declines in mean recruitment seen in the earlier versions of the OM do not occur (see the zero probability of future stock declines relative to 2014 across all scenarios), so the impact of removing the survey is essentially to forego increases in TAC, on average, as mean recruitment (which can only result from an increasing spawning stock given the stock recruit relationship) improves over time. This key feature might also not be fully understood: at the current estimated level of spawning biomass depletion, the stock-recruit relationship is close to linear and time-averaged recruitment and spawning abundance are actually quite closely linked. In other words, the aerial survey acts in two ways: it can give warning of low recruitments entering the fishery, and over longer timescales (at low depletion levels) is also a proxy for the trends in the spawning population.

7 Alternative information on recruitment

7.1 Gene-tagging

Gene-tagging has been proposed as an alternative method for monitoring recruitment of SBT for some time (Davies et al 2008, Anon. 2008). In 2013 it was included in the CCSBT Scientific Research Program as a method for estimating the absolute abundance of juvenile SBT, and work on the detailed design for a pilot program has been initiated (Preece et al, 2013; 2015). A proposed pilot study would take approximately 22 months, from initial tagging to provision of a single estimate of abundance of the cohort tagged, to complete. This is to allow for 12 months mixing, and includes the additional time delay waiting to access to fish at harvest after grow out in the SA farms. The focus of the pilot study is to demonstrate feasibility, refine field logistics and sample and data management protocols that can be used to finalise the experimental design and cost estimates for a longer-term program. If the pilot project is successful, ongoing monitoring using this method could be considered as a replacement for the aerial survey as a recruitment monitoring series.

Table 1 provides an indication of the time line from commencing tagging (in any year – 2016 is used in this example of earliest possibility) through to the use of a single estimate by the ESC. A series of estimates would be needed for recruitment monitoring or for use in a new MP. If gene-tagging started in 2016 and tagging also occurred in 2017, there would be 2 data points available for use in a new MP in the 2019 calculation of TACs. This is not sufficient to provide an estimate of trend; several more estimates would be required.

Table 1. Summary of main events and time-lag between commencing gene-tagging (in any year – 2016 is used in this example as it is the earliest possibility) through to use of a single estimate by the ESC.

Commence tagging (Feb)	Recapture Sampling (July)	Genetics work completed, abundance estimated	ESC use of abundance estimate
Feb 2016	July 2017	October 2017	Sept 2018
Feb 2017	July 2018	October 2018	Sept 2019 (next TAC calculation)

7.2 CPUE

The current Japanese long-line CPUE is age-aggregated (animals aged 4+), not age-structured. In this section we cover some of the issues that would need to be considered to use age-based CPUE in an OM and MP context.

7.2.1 Generating the indices

The raw data will not be CPUE-at-age (in terms of direct age estimates) but CPUE-at-length, which will need to be transformed via the growth relationship to "age" data. This in itself is a complex issue, and will relate as much to historical as to future data. Issues that will need to be resolved include:

- Which length data to use, as one cannot use the length data that is used to generate the catch composition as this will be "double-dipping" of data (i.e. using data twice in the OM).
- Uncertainties in the underlying data from the over-catch are magnified when moving to an age-based setting. Simple assumptions are made to explore scenarios to deal with this issue in the current age-aggregated CPUE index. The length distribution of those unreported catches remains unknown. It becomes very difficult to see how one can generate a suite of indices that reasonably cover this uncertainty given what we think we know about the over-catch (which is essentially limited to two scenarios assuming various contributions of over-catch to CPUE with effort assumed to be well reported).
- Standardisation of these data is far more complicated than the current age-aggregated CPUE indices. It is not possible to independently derive CPUE indices for a given set of age classes as they are correlated on a number of levels (this also has implications for including them in the OM, which is considered below). Given this, it is likely to require the use of general linear models (different to generalised linear models) that can model the data in a multivariate setting. Based on the fact that we have time-varying selectivity in the long-line fleets one can expect the potential for complicated time-length interaction terms would be required. This would make the analyses manifestly more complicated than the current standardisation models and current indices. The CPUE–by-age that are presented in the Indicators papers (e.g. Patterson and Stobutzki, 2015) do not take these issues into account other than to indicate that these are potentially affected by the overcatches.

7.2.2 Including the indices in the OM

At present, all abundance indices in the OM are age-aggregated (CPUE, aerial survey, trolling index) where the age-classes they cover are either estimated directly via selectivity (CPUE) or assumed (aerial survey, trolling index). To include CPUE-by-age data would require development of a different likelihood structure that would need to account for correlated observation and process errors (i.e. multivariate log-normal, most likely). Additional parameters in this form of likelihoods are the catchability-at-age parameters (which could have a constant selectivity ogive structure) so there would be a range of additional parameters required to be estimated and considerable thought as to how best to model them. This would require extensive new code, testing of the inclusion of these data, and development of suitable diagnostics, as are applied to the other data sources in the OM.

7.2.3 Interpretation of indices

In the context of other potential sources of age-structured CPUE (i.e. non-LL1 fleets; Taiwanese, Korean and New Zealand fleets for example), the spatial aspect of the data underlying the age-structured indices will pose serious challenges for the interpretation of the part of the population-at-age they relate to. The OM takes an areas-as-fleets approach to spatial catches of SBT, where the spatial variation in the distribution of age-classes is largely embedded within the selectivity profiles of those fleets. This is a pragmatic approach to account for removals of fish-at-age in a non-spatial manner, given spatially distinct fleet-classes (surface, long-line, spawning ground) which also, *generally,* have quite different age distributions in their catches.

This approach presents some substantial issues when moving to relative abundance indices as (multivariate) time series as would be required for using CPUE at age. The spatial location of the fisheries the indices come from, and the changing spatial distribution in the population they are fishing, becomes important; as we are not simply trying to account for removal; we are trying to infer relative trends in abundance in a non-spatial modelling framework. The global spatial dynamics (GSD) project (Basson et al 2012) demonstrated that, at least for the youngest age-classes that appear in the long-line fleets (the ones of most interest in this setting), the relative recruitment of these fish to the long-line fleets as they begin to leave the GAB (not just in winter/autumn) is not constant over time. That means that changes over time in the indices from quite distinct spatial regions (for example Taiwanese versus New Zealand catches) are potentially as likely to be relative changes in the spatial distribution of a given set of age-classes over time, as they are indicative of the size of particular year-classes, which would be the only real interpretation a non-spatial OM could have.

Changes in catchability are always going to be an issue for CPUE data. In the past a number of empirical (largely visual) analyses of the CPUE-at-age (for the main and New Zealand long-line fleets) have shown clear indications of catchability year-effects in the past. Even in the age-aggregated CPUE index in the OM there was a clear and continued change in catchability of around 35% (increasing) after the major changes in the long-line fleet from 2006-2008 (i.e. from 2008 onwards). These year-effects are very often interpreted as cohort-effects in stock assessment models if one assumes constant catchability over time, which you have to if you are including something as an actual abundance index. Adding in the discarding issue in the long-line data, there are clearly a number of challenges such abundance indices would have in terms of cleanly monitoring the relative abundance of the various cohorts in the population over time.

7.2.4 Including these indices in an MP

Neither the previous nor current MP structures are set up to include age-based indices. We cannot simply “swap” the aerial survey for alternative CPUE-based indices; therefore we would have to develop a completely new MP. That would require significant financial commitment as well as a lot of modeller time in the development phase.

7.3 Trolling survey data

The troll/acoustic survey data series was developed as part of the joint recruitment monitoring program. The series is used as one of the indicators of recruitment in the annual review of the stock and evaluation of exceptional circumstances.

While the series has been included in MP robustness trials, as part of the last MP testing phase, they are not included in the reference set of OMs used to assess stock status. There are a number of reasons for this, which are summarised in the report of the 13th meeting of the ESC (Anon 2008), some of which were being progressively addressed (Itoh and Takahashi, 2014) before the survey was discontinued.

As demonstrated in Section 5.1, the aerial survey directly informs the recruitment trends estimated in the OM and is consistent with the year-class information from other data. Given this, it can be used to examine the consistency of the level of recruitment indicated by the troll index of 1+ SBT. The aerial survey is assumed to observe the biomass of fish aged 2, 3 and 4 with an associated “selectivity” ogive of 0.5, 1 and 1, respectively; the trolling survey is assumed to observe age 1 fish only. To generate an index from the trolling survey that is comparable to the aerial survey a moving average approach was taken.

For any given year, y, for which we have an aerial survey estimate, the years of trolling data that should include the same cohorts in that year’s survey would be y-1, y-2, and y-3, respectively. By creating a weighted sum of these three years of trolling data (weighted by 0.5, 1 and 1 to match the aerial survey weighting by age in the OM) the troll index would then, in some sense, be comparable to the aerial survey estimate. The aerial survey has missing years (2000-2004), and the trolling survey has no data for 2004, so the only directly comparable years for which data exist for both indices are 1999-2000 and 2008-2014 (9 years in total). We then estimated the degree of correlation between the indices using a simple bootstrap approach (given the limited number of samples). The median (and approximate 95%ile) for the correlation between the two indices was 0.11 (-0.15; 0.3). A central assumption of this analysis is that the cohorts first observed in the trolling index experience comparable levels of total mortality before entering the aerial survey age-range (i.e. the cohort-specific Z is quasi-constant over a 4 year moving average range). This assumption will probably be violated in the later data after the TAC reduction in 2009 and the subsequent increase in 2012. However, it is unlikely this impact would be sufficient to account for the lack of apparent correlation between the two indices.

8 Conclusions

We have addressed the 2014 Commission and 2015 SFMWG requests for ESC advice on: 1) the implications for the management procedure process of cancellation of the aerial survey in 2015, 2) the implications of cessation of the aerial survey in 2016 and beyond, 3) costs and benefits of continuing with the current MP and conducting the aerial survey in 2017 to 2019, and 4) alternative recruitment information for use in new MPs. The other requests from the SFMWG (research priorities, alternative MPs and costs, MP review and meta-rules) are dealt with in the meta-rules and management procedure review paper (Davies et al, 2015).

Implications for the Management Procedure of cessation of the aerial survey in 2015

1. The CCSBT's Management Procedure (MP) can be run to recommend a TAC for 2018-2020 if an aerial survey index is obtained for 2016.
2. The lack of the 2015 aerial survey index may trigger exceptional circumstances for the 2018-2020 outcome and possibly also for the 2016-2017 TACs at the 2015 ESC[2].

Implications if the aerial survey does not resume in 2016

3. Complete cessation of the AS would mean that the adopted MP could no longer be used to recommend TACs and the Commission would be without an agreed basis for setting TACs. A new MP would need to be developed.
4. There is not sufficient time to complete the required management strategy evaluation to test performance and robustness of alternative MPs for setting the 2018-2020 TAC in 2016.
5. There would be substantial time and costs associated with developing, testing, agreeing and implementing a new MP.
6. No aerial survey in 2015 and 2016 also means that there is no monitoring of recruitment of the stock, and no warning system for very low recruitment, should this occur. All other recruitment monitoring was cancelled in 2015.
7. Exceptional circumstances would be triggered in 2016. No pre-agreed method for setting the 2018-2020 TACs (in 2016) is in place.
8. The ESC would need to reconsider advice on the TAC for 2016 and 2017 in light of the cessation of the aerial survey and lack of reliable estimate of recruitment.

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[2] There are additional issues that may also trigger exceptional circumstances; unaccounted mortalities and changes in size of fish caught in the Indonesian fishery (possible selectivity change).

Considerations of changes to the MP including data

9. Any substantive change to the management procedure requires the performance of the new management procedure to be evaluated using the Management Strategy Evaluation. The current MP took 4+ years to develop, agree and implement in 2011.
10. An aerial survey every-other-year was suggested by the EC; however the logistics of running the aerial survey every-other-year are extremely difficult. The expertise required is highly specialised. New spotters need to be "calibrated" relative to existing spotter expertise to maintain the consistency of the series. In addition, a change in the frequency of the AS would necessarily involve another MSE process as it is effectively a new MP.
11. Re-tuning the current MP to run without aerial survey data was suggested by the Commission; but the aerial survey data are integral to the operation of the MP. Re-tuning is equivalent to full management strategy evaluation of a new MP based on CPUE only going forward.
12. The inter-sessional work included preliminary investigations of impacts of a "reduced aerial survey" (cheaper through less hours flown, higher uncertainty in the abundance estimates). The MP can be operated using these data. Three options for a reduced aerial survey were provided for consideration at the SFMWG. Option 2 involves 1 plane for 3 months, and use of the 2nd plane for 1 month, however, re-gaining the calibrated spotters for a single year contract is currently looking doubtful, and the aerial survey option 2 may not be possible.
13. Model runs using the "reduced aerial survey" did not show any impact on the predicted TACs, because the MP is designed to respond strongly to low recruitments and conservatively increase TACs, and the current test conditions are very optimistic in terms of future recruitment. The current OM structure (2014 OM) used in these tests does not show the contrast in future projections that were seen as part of the 2011 testing of the MP, and the importance of the aerial survey data are not as evident. This is the result of the more optimistic status and projected rebuilding under the current OM.

Costs and benefits of continuing with the current MP and conducting the aerial survey in 2017 to 2019.

14. Qualitative benefits of the adopted MP include having a scientifically tested rebuilding program for the stock – the first international tuna fishery to do so (Hillary et al 2015b, Garcia and Koehler, 2014).
15. Estimates of the aerial survey related component of the TAC increases that have been adopted by the Commission between 2012 and 2017, if converted to a monetary value, would cover the cost of the aerial survey multiple times over.
16. Estimates for potential future TAC increases under the MP, should it continue to be used to set TACs in 2016, that can be attributed to the aerial survey exceed the costs of the aerial survey by an order of magnitude.
17. Consideration of potential precautionary TAC advice in the absence of an MP suggests that status quo TAC's, or reductions in TAC, would entail loses of 2,500t-3000t TAC per year. The forgone value to the fishery in this scenario, as a result of not having the information on recruitment from the aerial survey, dwarfs the cost of the survey.

Alternative recruitment information for use in new MPs.

18. Gene-tagging is an alternative method for estimating the absolute abundance of juvenile SBT. Detailed design for a pilot program has commenced. The proposed pilot study would demonstrate feasibility and field logistics. If the pilot project is successful, ongoing monitoring using this method could be considered as a replacement for the aerial survey as a recruitment monitoring series.
19. CPUE by age has been suggested as an alternative recruitment monitoring index, however, there are substantial difficulties in dealing with the correlations between ages, the lack of historical information on length frequency and size of the over-catches, and how these data could be integrated into the OM or a new MP.
20. The inclusion of the aerial survey index in the MP development was related to concern over low recruitment, but also due to the concern of relying on an MP using only CPUE and/or catch composition data, given unresolved uncertainties in the historical time-series for the longline fleet, recent changes in the LL1 fleet (due to changes in management and economic drivers) and potential for future changes.
21. Trolling survey data are used qualitatively in the review of indicators of stock status, but are not included in the reference set of OMs used to assess stock status, and therefore are not suitable for use in an MP. There are a number of reasons for this, which are summarised in the report of the 13th meeting of the ESC (Anon 2008), some of which were being progressively addressed (Itoh and Takahashi, 2014) before the survey was discontinued. Examination of the trolling and aerial survey data (which was shown to be consistent with other OM data series) indicates a lack of correlation between the two indices.

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