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PROJECT 123: SCOPING THE NEXT GENERATION OF TUNA STOCK ASSESSMENT SOFTWARE

WCPFC-SC22-2026-SA-WP01

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Executive Summary

This report documents progress in the final year of WCPFC *Project 123: Scoping the Next Generation of Tuna Stock Assessment Software*. It provides a summary of the work done since SC21 according to the SC21 Terms of Reference within the funding from WCPFC22 (key focus areas noted below). Two companion papers – [WCPFC-SC22-SA-WP02] related to task I. below (Ducharme-Barth *et al.*, 2026) and [WCPFC-SA-WP03] related to task II. (Mildenberger *et al.*, 2026), describe significant technical work conducted under Project 123 and only brief summaries of those papers are provided in this report. An important role of this report is to draw on the work so far to provide recommendations for SC22 to consider a second phase of the *next generation tuna stock assessment software development* work, to move beyond scoping and proof-of-concept to advancing the development, testing and implementation of new software to support the WCPFC's tuna, shark and billfish assessments over the next 3-5 years.

In summarised form, the WCPFC22 provided funding (50K USD) for the third year of Project 123 to focus on:

I. Work on initial software development design, to deliver functional prototype components (core model objects) containing the population, observed data, and model predictions, depending on resources and the outcomes.
II. Work on the analysis of WCPO skipjack tagging data, with direction from SC21 to collaborate with the Danish Technical University (DTU) on this analysis.
III. A proposal for SC22 describing the next phase of work.

We also note work from late 2025 – specifically, an international online workshop organised collaboratively between SPC and IATTC: *Developing the Next Generation Tuna Stock Assessment Model: CAPAM mini workshop, December 9-11, 2025.* The outcomes report for the workshop is included in appendix 1 [LINK to workshop webpage]. It provides valuable guidance from world leaders in stock assessment science on tuna/tuna like assessment software development needs and priorities and provides useful areas for future work. This delivers on the second technical workshop that was committed under Project 123.

The companion paper on the external tagging analysis work (SC22-SA-WP03) identifies a pathway of work required whereby outputs from external tagging analysis might be available for stock assessment by 2028 /2029. The continued collaboration with the Technical University of Denmark (DTU) on this work is recommended but will require additional funding for a phase 2 project described in the attached TOR. The cost of this work is not trivial, and we strongly recommend discussions among IATTC, DTU and SPC on options for a collaboration framework to maximise cost-effectiveness, given IATTC is also working with DTU on the same approaches. If a WCPFC/IATTC co-funding arrangement with the DTU team could be established, the funding amount in the TOR could potentially be reduced for any funding request to WCPFC23.

The [opal] (open population assessment library) development (SC22-SA-WP02) has provided the poof-of-concept requested by SC21 to develop core software features, repository, and a development approach, methods and code base pathway. The opal work has made significant progress in a short time, with limited resources and demonstrates that development can progress at a pace to meet WCPFC needs. The opal proof-of-concept supports a strong case for moving forward with an open and collaborative Pacific/tuna science led pathway for development of the next generation tuna/tuna like assessment software. Joining, or depending upon, other assessment software development projects that are not tuna focused, that have timelines, priorities, and governance not under direct control or influence of Pacific tuna RFMOs, has high risk and is not recommended by regional assessment science leaders and the authors of this paper. Through a Pacific led software development project, WCPFC and IATTC can enhance their R &D collaborative partnerships and leverage each other's science capacity and unique technical capabilities, as well as leverage project opportunities, funding and expertise.

A software project governance/delivery framework and proposal for a 3-year next phase project (as requested by SC21) is provided, along with a TOR and funding requirement.

We invite the SC22 to:

- Note the achievements of the work under Project 123, in particular the companion papers (SC22-SA-WP02, SC22-SA-WP03), and the workshop summarised in appendix 1.
- Review and provide feedback on the proposal for a Pacific led, collaborative approach to development of the next generation tuna assessment software.
- Review and provide feedback on the proposed software development project governance/delivery framework (Figure 2) and the proposed 3-year next phase project workplan (Figure 3).
- Review and provide feedback on the two draft terms of reference in appendix 2 and consider their priority within the SC project process.
- Convene an Informal Small Working Group at SC22 to discuss the proposed approach within this paper and the bullets above to assist SC22 in its deliberations.

Contents

Background

WCPFC Project 123: *Scoping the Next Generation of Tuna Stock Assessment Software*, was initiated in 2024 in response to a need to transition to new software tools for tuna and tuna like species. This transition was triggered by retirement of the lead developer of MULTIFAN-CL (MFCL), Dave Fournier, with future advances to the MFCL software not expected to be as mathematically innovative as they were in the past. While this does not render MFCL obsolete in the medium term, and enhancement work is continuing with the work of Nick Davies (MFCL consultant to SPC), ongoing support for MFCL development/maintenance is unlikely in the longer term. SPC raised the need to plan and identify whether alternative existing software exists, or new software must be developed in the longer term, to continue to support the specificities and future requirements of WCPFC tuna stock assessments. The WCPFC, through the SC, has supported this need through funding Project 123 across three years.

While MULTIFAN-CL (MFCL) has been the core package for delivering tropical tuna and South Pacific albacore assessments for the WCPFC, all billfish and sharks that have most recently had integrated assessments attempted have transitioned to Stock Synthesis 3 (SS3). Southwest Pacific striped marlin and swordfish were recently transitioned from MFCL to SS3 as part of SC recommendations under Project 123, noting the recent SS3 assessment of Southwest Pacific striped marlin was not used for management advice, in favour of an alternative Bayesian Surplus Production Model. Bigeye, yellowfin, skipjack and South Pacific albacore are still being assessed with MFCL. Development of SS3 is also winding down, and while, like MFCL, it will still be available, innovative development will cease, with NOAA resources being shifted from SS3 to their Fisheries Integrated Modeling System (FIMS) project, viewed as an SS3 replacement. Ultimately, we expect that all the WCPFC tuna, billfish and shark assessments will be transitioning to new assessment software in the near future (i.e. next 5+ years).

The overriding goal of the project is to: ***ensure WCPFC tuna stock assessments remain robust and provide the best available scientific information through the appropriate planning for a state-of-the-art successor to the MULTIFAN-CL assessment software.*** The first two years are summarised in the following SC papers: SC20-SA-WP-01 Magnusson et al. (2024), SC21-SA-WP-01, Magnusson et al. (2025). The project has received strong support from the SC to continue in each of its three years through the SC's annual project ranking system, being the most highly ranked project by SC21 for continued funding in 2026. Core work areas from the original Terms of Reference were outlined (see Table 1, SC21-SA-WP-01) and reported against in the SC21 report referenced above.

Given the scoping nature of the project, the workplans and expectations for each year have been reviewed and modified based on the previous year's work under direction from Informal Small Working Groups (ISGs) convened at each SC meeting. The project has delivered on most of the core areas consistent with the original TORs and evolved in others. The rapid development of programming efficiencies with the growth of AI assisted coding has opened up opportunities for fast tracking software development and the initial expected timelines for developing new software are being reduced.

This summary report focuses on the work since SC21 and planned until the end of this scoping phase, December 2026. It focuses on reporting against the key work areas supported for the final scoping year by the ISG at SC21:

I. Work on initial software development design, to deliver functional prototype components (core model objects) containing the population, observed data, and model predictions, depending on resources and the outcomes.

II. Work on the analysis of WCPO skipjack tagging data, with direction from SC21 to collaborate with the Danish Technical University (DTU) on this analysis.

III. A proposal for SC22 describing the next phase of work.

The report also includes as appendix 1 a report on the December 2025 'Center for the Advancement of Population Assessment Methodology (CAPAM)' workshop jointly organised by SPC (Arni Magnusson) and IATTC (Mark Maunder): Developing the Next Generation Tuna Stock Assessment Model. This workshop was the second expert workshop under Project 123 and delivered on the project TOR commitment to hold two expert workshops. Through collaboration with IATTC there was a major added value to this workshop, which included the world's leading stock assessment scientists providing presentations and discussion on a list of key topics considered as priority areas for developing next generation tuna stock assessment methods and software.

We also direct readers to the SC22 progress report on MULTIFAN-CL, WCPFC- SC22-SA-IP02 (Davies *et al.*, 2026), that provides summaries of several pieces of work that have also contributed to Project 123, most notably:

- 4.1.3 Exploration of Gadget3
- 4.2 mfclrtmb – a package that modernises MULTIFAN-CL in RTMB: https://pacificcommunity.github.io/ofp-sam-mfclrtmb/

Model development work progress

I. Work on initial software development design, to deliver functional prototype components (core model objects) containing the population, observed data, and model predictions, depending on resources and the outcomes.

This work area has been progressed by the contribution of NOAA staff (Nicholas Ducharme-Barth) and external consultants Darcy Webber (Quantifish) and Phil Neubauer (Dragonfly). Darcy Webber was awarded a contract by SPC (funded under Project 123) for this work area, consistent with the budget allocation in the TOR for 2026 work. This group have consulted with the SPC project 123 team (including MFCL consultant Nick Davies) on the development work in regular meetings. The development project is called opal – open population assessment library: https://connect.fisheries.noaa.gov/opal/, (Ducharme-Barth *et al.*, 2026). *The contribution of the work on opal towards Project 123 is significant and should be acknowledged as an in-kind contribution from the US towards the next generation tuna assessment software development.* SPC staff with suitable skillsets have been unable to contribute significantly to the hands-on development work on opal since SC21 due to leading stock assessments for SC22, noting that the mfclrtmb development was done as a side project, with most of the work by the responsible SPC staff (Kyuhan Kim) occurring outside of regular hours. The paper on opal (SC22-SA-WP02) provides the in-depth technical information on the opal development so far.

The opal development follows a modular programming approach based on RTMB, which provides automatic differentiation of the objective function, gradient-based optimization, and the Laplace approximation for models with random effects. opal aims to write the models in R so as to keep the full model definitions within a single language. It is thought that developing the models in human readable R code will assist in collaboration and usability and remove some of the barriers to inspecting and extending the code that would occur if significant C++ coding skills are required. This is consistent with desired criteria for development of the next generation software that is both beginner friendly and can be widely used, to generate a user community. The opal approach is not starting from scratch in terms of the fundamental internals of the stock assessment models. It takes and builds on the *sbt* software package used by CCSBT for the assessment of southern bluefin tuna (Webber *et al.*, 2026), SS3, MULTIFAN-CL and various other assessment frameworks. opal development is initially aiming to provide assessment scientists with a flexible modelling framework that supports the estimation of random effects; facilitates enhanced model diagnostics, including one-step-ahead (OSA) residuals, simulation self-testing, and posterior predictive checks; and integrates directly into a Bayesian estimation framework. Future developments are somewhat open pending WCPFC support for opal and resources available to support development work. A development prioritising process will be important. opal should also not be seen as a purely tuna-centric software development. Although tuna focused application will be front of mind, the development will also consider needs for assessments of shark and billfish stocks, and also application in MSE (Management Strategy Evaluation). It will have general features suitable for a broad range of species assessments.

In brief, the major achievements of opal so far have been to:

- Develop and test proof of concept core model packages in R/RTMB
- Demonstrate its application on two different data sets – Western and Central Pacific 2020 bigeye tuna and Hawai'i 'Opakapaka, with cross platform comparisons.
- Develop an open system for collaborative model development and testing.
- Identify challenges that will need to be rectified, notably in the area of random effects estimation for higher dimensional assessments (i.e. preliminary attempts to apply random effects in the bigeye case study did not appear computationally tractable, although these attempts preceded recent code optimizations and reparameterizations.), a key feature for next generation models.

The recommendations for the opal development work for the next phases as noted by the authors of SC22-SA-WP02 are:

- refinement of existing case studies;
- development of additional case studies (e.g., Indian Ocean yellowfin tuna fleets-as-areas case study based on simulated data);
- code optimization (particularly of the selectivity and size-composition likelihood calculations);
- derivation of biological and fishery reference points;
- additional likelihood components (e.g., age, tag or close-kin mark-recapture data);
- alternative selectivity forms;
- and additional population dimensionality (e.g., spatial structure, sex, or length).

opal has provided a proof-of-concept development phase as requested by the SC21. This now requires consideration at SC22 regarding the option for it to continue as a primary development pathway for the next generation model software for WCPFC tuna and tuna-like species assessments. **We recommend that an Informal Small Group at SC22 for Project 123 discuss this option and provide advice to SC22.**

Skipjack tagging analysis

II. Work on the analysis of WCPO skipjack tagging data, with direction from SC21 to collaborate with the Technical University of Denmark (DTU) on this analysis.

The WCPFC SC21 requested a proof-of-concept study (as part of Project 123) on analysing WCPO skipjack tagging data external to the assessment, using a fine-scale movement model. The work so far on the external tagging analysis is described in SC22-SA-WP03 (Mildenberger *et al.*, 2026). The start of the work was delayed due to some administrative bottlenecks, those issues are now resolved, and the work will continue for a period beyond SC22. The paper to SC22 describes the initial work (phase 1) to explore a movement model for WCPO skipjack tag data with the R package *admove* that is being developed by the DTU collaborators Tobias Mildenberger and Anders Neilsen. The development builds off the promising work on the Eastern Pacific Ocean (EPO) skipjack tag data using *admove.* By modelling the redistribution of tagged fish explicitly on a continuous fine grid, the approach relaxes the region level mixing assumptions that are problematic for the current large block spatial models applied to tuna assessments in MFCL. The paper outlines how the movement model is the first stage of work required to underpin the development of modules to estimate mortality, relative abundance and biomass.

The work on the movement model so far has been on an incomplete proof-of -concept dataset and while promising, in that it indicates feasibility, has also recognised some challenges that will require additional data and time to explore. These include:

- Tag recaptures in the data set used are concentrated in a narrow region and representing a narrow range of environmental covariates which limits the ability to estimate more flexible habitat preference functions. Acquiring tags from other programmes, for example the Japanese programme, which covers areas the PTTP does not, would be useful to broaden the covariate coverage and support more robust and, where warranted, time varying preferences.
- Addition of biological information is needed, especially length at release to separate ontogenetic differences in preference and movement and to enable the length-based mortality module.
- Fine-scale spatial effort data are essential to correct the movement estimates.
- Computational challenges with the large data set.
- Appropriately dealing with the complex island geography and explicit boundary conditions (noting this is not an issue in the Eastern Pacific Ocean example).
- Other developments needed include; handling recapture-location and -time uncertainty as in the EPO, cross-validation against archival tags (none were available for the WCPO), parallelising the code, formal residual diagnostics, improved documentation, and covariate free estimation of habitat preference. The trial code also needs adapting to *admove* and the full transition to RTMB.

The additional data requirements are available and will be provided to DTU. SPC will consult with colleagues from Japan’s Fisheries Research and Education Agency (FRA) regarding the availability of Japan’s tag data set to be added to the analysis.

The movement module with the addition of the spatial effort data to estimate mortality, referred to as phase 1, will be the focus within the remaining time under the current (2026) contract with DTU. It is essential to have this done to move to the relative abundance (phase 2) and biomass (phase 3) modules. The modular approach being applied allows exploration of model structure uncertainty by replacing the different phases of the pipeline with alternative approaches. For example, the predicted spatial density of tagged fish from observed releases could be provided by the movement model estimated by SEAPODYM (or other alternatives), which also uses tags and environmental data, with the subsequent phases for mortality and/or abundance estimation remaining identical the external tag analysis. This would permit a direct examination of different methodologies, and sensitivity of these key outputs to varying movement model assumptions/methods.

Figure 5 in the companion paper SC22-SA-WP03 provides a very useful workflow diagram showing the different phases (modular workflow), how they link together and their data dependencies, with the end goal of informing upcoming skipjack stock assessments. While this workflow is based on skipjack tag analysis it could be equally trialled on WCPO bigeye and yellowfin tagging data pending successful demonstration for skipjack.

After improvement of the movement module with the incorporation of mortality estimation (requiring inclusion of the spatial effort data) – Phase 1, the work will progress to the Phase 2 which will aim to develop relative abundance time series. The estimation of a relative abundance time series is an important requirement for success of the external tag analysis, with respect to its value for stock assessments. The current abundance index for the skipjack assessment equatorial region is based on free school purse seine CPUE and uses daytime travel distance between sets as an effort measure, but this relies on VMS positional data and as such the time series only starts from 2010. Building an abundance index from the external tagging analysis would be a very useful addition to the skipjack assessment, potentially with a longer time series (possible back to the early 2000's), and to compare with the free school purse CPUE abundance index. The phase 1 work will continue post SC under the current Project 123 contract with DTU, and is expected to cover:

- Investigate separate movement estimates for 2-3 length groups (e.g. juveniles - adults) as soon as the length at release data is provided.
- Apply *admove* to the Japanese tag data (if that can be provided) and hopefully estimate clearer temperature preference curves with the much wider data set.
- Create more informed runs with better subsets of cleaned / more reliable tags as soon as some quality scaling for the different tags is available, with provision of the full tag dataset.

Additional Phase 1 work is required beyond that which is supported under this contract. Subject to securing additional funding (see TOR, appendix 2), Phase 1 will be completed and Phase 2 work on developing a relative abundance index would begin in early 2027 and is expected to continue until mid/late 2027. The Phase 3 work on biomass estimation would start mid-2027 overlapping with the phase 2 work and continue until the end of 2027. The proposed schedule in Figure 1, would allow the outcomes to be considered early enough for potential incorporation into the 2028 WCPO skipjack tuna assessment workplan, or if not as test case on that assessment in later 2028 or early 2029. Cost estimates are provided in the appendix 2 TOR.

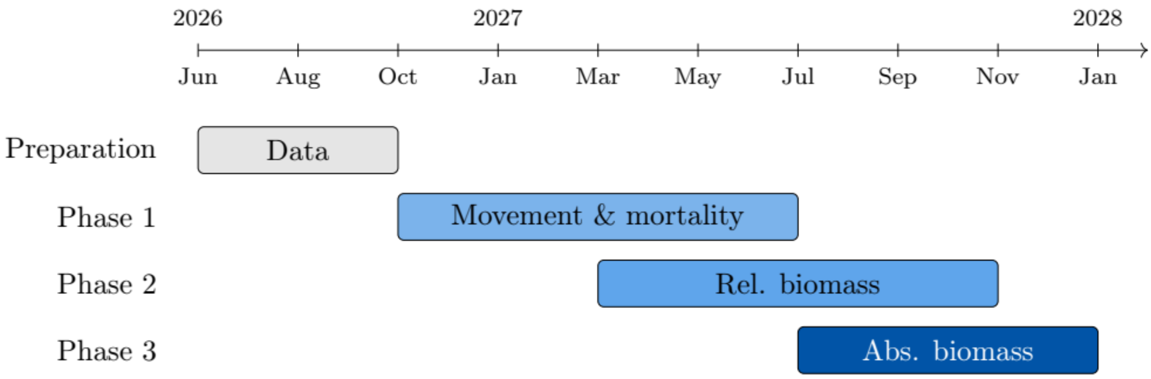

Figure 1 Proposed timeline for the phased workflow of the external skipjack tag data analysis.

Overall, the external tag analysis proof of concept is positive given the initial developments on WCPO skipjack tag data and the previous work on the EPO skipjack assessments. However considerable work is required to demonstrate application for the WCPO skipjack assessment. This will require significant additional funds in a new project bid (see appendix 2 – TOR). The value proposition of the work remains strong, in that it complements the next generation assessment model developments, with less complexity required in these models if they are not required to integrate and fit to tag data inside the model. Further, external analysis of tag data is useful irrespective of its contribution to the typical stock assessments. The information on movement, mortality (natural and fishing), relative abundance and potentially biomass can be used as indicators of regional/local stock dynamics and fishing impacts independent of integrated stock assessment models, albeit at narrower geographic scales. The ongoing development of the fine scale spatial tag data analysis also provides a longer-term (perhaps aspirational) pathway towards developing a fine scale spatial-temporal tag integrated tuna stock assessment model.

Recommendations and planning for advancing next generation tuna assessment software development and implementation

III. A proposal for SC22 describing the next phase of work.

A Pacific-led next generation tuna assessment model development

This section draws from the various meetings, workshops, technical work, and many side discussions on an approach to move forward with the development and implementation of new software to conduct tuna, billfish and shark assessments for WCPFC.

There remains strong impetus for Pacific-led development of assessment software with a flexible, user-friendly code base and to have direct control/influence over the development timelines, priorities and features, and the structure and governance of the work program. The reality is that fishery assessments have a mix of general and more specific requirements for model features/structural approaches/diagnostic methods and different data features etc. The priorities of software developments will not always align among those with different assessment focuses and needs. The development of MULTIFAN-CL over several decades has been driven by tuna assessment specialists to better meet the requirements of the tuna (and tuna like) assessments and tuna fishery data, including extensive tagging data, lack of regular age composition data and dependence on size data, complex fisheries structures, multi-gears, huge geographic areas with spatial structure and lack of fishery independent abundance surveys. MULTIFAN-CL (MFCL) was an incremental software development for the WCPFC, who funded its core development, and it depended on a few key developers employed within, or contracted by, SPC. At that time the need for a wider development collaboration or a broad user community was not a key concern of the MFCL development project, and it has remained mostly only used for WCPFC assessments.

While tuna/tuna like assessment specialists are best positioned to drive development of the next generation assessment software for these stocks, development of a replacement software for MFCL needs to be a wider multi-organisation collaborative effort that can provide resilience against staff turnover in organisations like SPC, and allow development of a wider user community, initially across the Pacific, but ultimately across tuna RFMOs. We also argue that being dependent on software developed outside of the Pacific region and by non-tuna focussed teams, is a step back for Pacific tuna RFMOs. Pacific tuna RFMOs and wider stakeholders will benefit more broadly by developing expertise and skills within their regional scientific communities. There is a very strong cohort of early/mid-career assessments scientists who have been fortunate enough to work with the pioneers of tuna assessment science in the Pacific (who were also the global pioneers). This generation can be supported to continue developing their skills and deliver the tools needed for tuna/tuna like stock assessments and the new era of management procedures in the Pacific. This is the pathway initiated by the opal project (Ducharme-Barth *et al.*, 2026), a flexible, open collaborative approach drawing on the expertise and emerging science leaders already present within the WCPFC membership, SPC, NOAA Pacific Islands Fisheries Science Center (PIFSC) and the IATTC. Leveraging of this expertise and operational knowledge embedded in these organisations would seem wise in terms of both speed of progress, cost effectiveness and delivering fit-for purpose assessment software.

Why not join FIMS?

The NOAA Fisheries Integrated Modeling System (FIMS) development https://noaa-fims.github.io/FIMS/, is their flagship development program for fisheries modelling software tools being designed for application to US stock assessments, but with a more general user group in mind. Discussion among WCPFC and IATTC tuna assessments scientists, who have interacted with the FIMS project, have not shown overwhelming support for becoming formally involved in the FIMS development. Their perception is that having influence on the FIMS development in relation to tuna/tuna like assessment needs and priorities will be difficult, and actually contributing to code development will also be problematic. However, keeping abreast of the FIMS development is obviously important.

The size of the FIMS program including its governance structure and NOAA funding base, would make it difficult to have influence on how resources are deployed. There is also a perception that timelines for FIMS will be too long with respect to imminent needs of the tuna assessment software transition, particularly for WCPFC. For example, integration of CKMR (Close Kin Mark Recapture) will likely be required for the WCPFC/IATTC South Pacific albacore assessment in the very near future, and this can be prioritised to meet a required timeline by a Pacific-led development such as opal, this would not be the case with FIMS. The core FIMS development team is also in the US mainland and not directly involved in the work of the tuna RFMOs. The FIMS project started in 2020, it has many players, greater bureaucratic overhead for involvement/influence and the progress has been slow relative to what the opal project has achieved with its limited resources and in just over one year of part-time work by three developers. Finally, the FIMS software is being developed using a substantial C++ backend, for which there are strong reservations in terms of the collaborative development opportunities (need to be proficient in C++) and flexibility advantages of a purely R/RTMB-based code development used by opal. While noting the computational advantages of C++ are yet to be matched working purely in the human readable R/RTMB, the trade-off involved in RTMB is considered worthwhile to enable the desired collaborative user-base, and RTMB will continue to be developed.

It seems clear that relying on or joining the FIMS development will not guarantee meeting the timelines and objectives for development of the next generation tuna assessment software. Developing the software within the Pacific tuna assessment community, governed by the RFMOs and beneficiaries, and with collaboration/contribution opportunities from across CCMs, has a much stronger chance of meeting the timelines and objectives. The proof of concept is provided by the opal development progress so far.

Moving forward with the opal pathway

Technical recommendations to guide the software development initial priorities are highlighted in the opal paper (Ducharme-Barth *et al.*, 2026), in appendix 1 'Developing the Next Generation Tuna Stock Assessment Model: CAPAM mini workshop' report, and Table 2. Here we focus on the formalisation of an overarching development project and governance framework to drive and guide the work and help ensure objectives and timelines are met. This will require the commitment of the WCPFC and support of IATTC.

The next generation tuna assessment software development is not piecemeal work, and reasonable funding will be required to allow a core development team to focus on development work and fast track the core components. Consultancies will also be necessary to bring in specialised expertise, for support work such as the external tag analysis modules, expert involvement in improving the R-based systems (RTMB) for fitting the computation/data heavy large tuna models, expertise in modular software development to provide review and advice. However, basing the development around R and an open collaborative approach will substantially increase the options for support and engagement, and reduce costs, allowing leveraging of other project work, and speed up development. Furthermore, as noted, this is tailoring and building on a significant body of pre-existing code and proven methods, and leverages on the R software, git and a multitude of packages for support analysis, visualisation and data preparation.

Clear and transparent collaboration, prioritisation and testing processes will be important aspects of the software development project. The collaboration environment has already been developed to a large extent by the work on opal so far, and the approach put forward in this paper aims to ensure that all interested CCMs in both tunaRFMOs can engage (Figure 2). SPC, through its long-term MFCL development has expertise, systems and practices that can provide a basis for developing these procedures. However, an independent software development expert may be worth engaging, at least initially, to advise and assist in ensuring best practice development and collaboration procedures, testing, security and versioning systems.

A project steering committee is proposed, to enable wider engagement, and an ongoing project technical coordinator role is proposed for an individual with sufficient technical skills to oversee the collaborative development, run development team group meetings, and report on progress to a steering group and any funding bodies. Administrative support will be required to manage project budgets, contracting and other project operational support not covered by the technical coordinator role. The technical coordinator and administrative support roles are not likely to be full-time roles and would best be situated in an independent regional organisation such as SPC. We envisage that the steering committee would have a similar function and mandate to those established for the Pacific Tuna Tagging Project or the Pacific Marine Specimen Bank, more focused on oversight, progress reporting and transparency than technical advice and direction, which would be more the role of the development team and collaborators, led by the technical co-ordinator.

It is also important to clarify that collaborative software development remains separate to provision of regular production stock assessments, MSE development etc. for the WCPFC by the scientific services provider. This primary role does mean that SPC-OFP does not have some capacity to support components of key roles proposed in this next-generation software project management process within existing resources over the timescales considered necessary, while also ensuring the existing software frameworks remain fit for purpose and supported (i.e. MFCL) during the development and transition phase.

The software development will necessarily involve existing SPC stock assessment staff who will have a direct role in the development work, data provision and advising on priorities through involvement in the core development team. But they will be prioritised on the core stock assessment work. The proposed technical coordinator role is suggested to also be based at SPC to ensure close liaison with the assessment team and partners.

In Figure 2 we have attempted to distill the project framework described above into a proposed governance/oversight and delivery structure. We hope this figure provides the SC22 with a useful framework to provide comment and further advice.

Workplan

SC21 also requested advice on a proposal for the next phase of work. We propose that this next phase of work is a 3-year 'develop-test-implement' workplan managed according to the framework in Figure 2. By develop-test-implement, we do not suggest this as a staged process, but that development, testing and implementing occur side by side. As the software develops capabilities and passes through benchmark testing, we would be applying it to suitable WCPFC and potentially IATTC assessment data sets, as implementation trials. It may also be possible to develop/apply the software in MSE modelling, such as for southwest Pacific swordfish (Project 131). These implementation trials would not be full assessment workflows or used for management advice but rather leverage off the work of the benchmark assessments (i.e. use the data preparation, model tuning etc. that is done by the benchmark assessments) to cost-effectively demonstrate the software meets certain performance criteria and produces results that are comparable to the benchmark assessments using other software, such as MFCL and SS3, while avoiding 'competing' assessment conflicts. This is another major advantage of the core software development work being nested alongside the main 'production' Pacific tuna assessment process. The implementation trials may also run additional tests of features available in opal that are not available in the current software, for example random effects for time varying selectivity. This way stakeholders will be able to see the software in action on 'real and relevant' assessment data sets, with side-by-side model runs to compare to the benchmark assessments. This will allow stakeholders (and analysts) the time to build awareness and confidence, iron out bugs etc. in the new assessment software before using it in anger on 'real' assessments for stock status advice and harvest strategy monitoring.

We also envisage that alongside this side-by-side develop-test-implement plan, there will be research and development (R & D) space to explore more novel and less proven ideas and methods, that can be brought into the core development work planning should they prove viable and useful. This R & D space will provide opportunity for collaborators to develop new methods/features, without cluttering the core development channel. For example, this is where the external tag analysis collaboration with the Technical University of Denmark or the development of a CKMR model for south Pacific albacore with CSIRO, would be placed. These collaboration and R & D type projects would also have suitable oversight by the technical co-ordinator and reported on to the steering committee, but they would be expected to be separately funded projects (outside the core software development project) or in-kind contributions and take advantage/leverage off opportunities in other relevant funded projects.

Figure 3 provides a technical work/plan framework as the basis for a 3-year next phase of Project 123, and the basis for the Terms of Reference and associated preliminary costings in appendix 2.

We propose that both the project governance/oversight/delivery framework and the 3-year workplan and associated TOR is discussed in an Informal Small Group (ISG) at SC22 and that the ISG provides feedback and recommendations to plenary.

SC22 will be required to provide recommendations on the next phase of work beyond the Project 123 scoping phase. While an indicative budget is provided in the appendix 2 TORs, these would need to be refined post SC22, pending any recommendations/advice/budget availability, to provide a more accurately costed 3-year project budget for the consideration of WCPFC23.

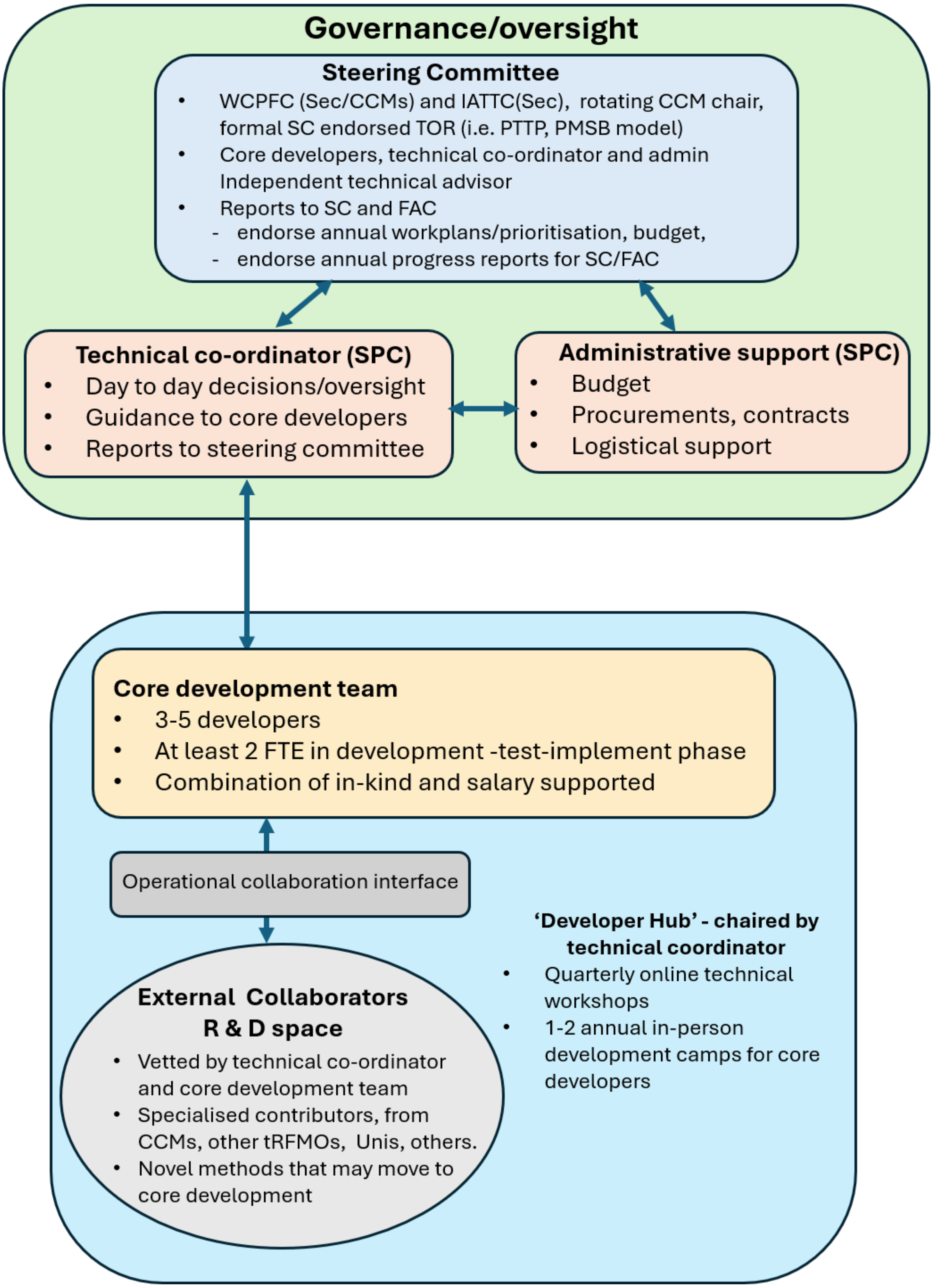

Figure 2 Schematic of the project governance and delivery framework for the next phase of work to develop-test-implement new software for tuna/tuna like assessments.

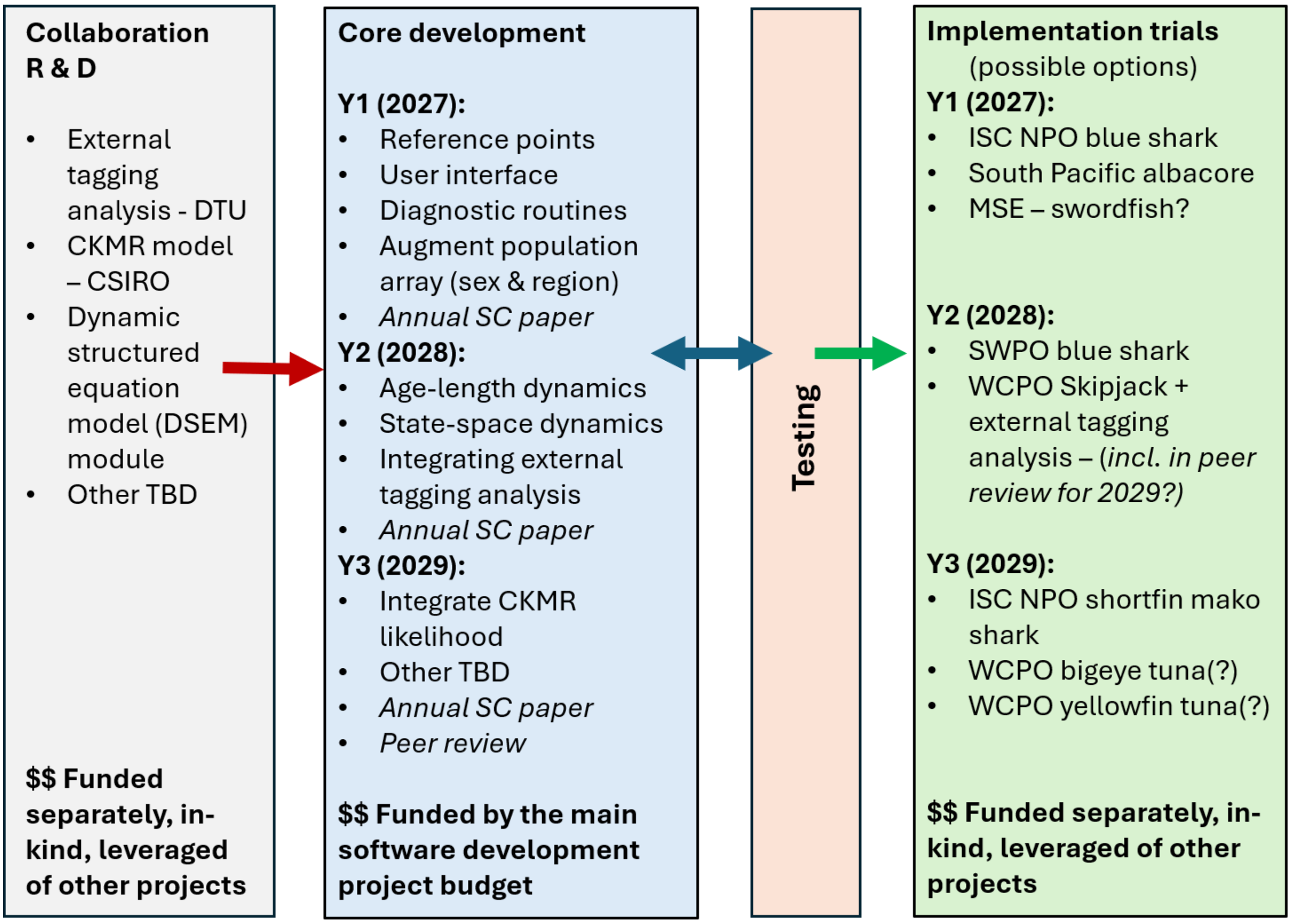

Figure 3 Summary of a proposed work plan for a 3-year next phase project to develop-test-implement new software for tuna/tuna like assessments.

Summary and recommendations

This paper provides a high-level reporting against the key tasks requested under the year 3 workplan endorsed at SC21 and funded at WCPFC22. The work since SC21 has demonstrated the potential of the external skipjack tagging analysis and also pointed out challenges and requirements for additional data and analysis. The companion paper on the external tagging analysis work (SC22-SA-WP03) provides a pathway of work required to reach a point where outputs from external tag analysis might be available for stock assessment. This could align with the 2028 skipjack assessment, or be available for 'trial' on that completed assessment the following year. The continued collaboration with the Technical University of Denmark (DTU) on this work will require additional funding for a phase 2 project described in the attached TOR. The cost of this work is not trivial, and we strongly recommend discussions among IATTC, DTU and SPC on options for a joint collaboration/co-funding framework for cost-effectiveness, given IATTC is also working with DTU on the same approaches.

The opal development has provided the poof-of-concept requested by SC21 to develop core software features, repository, and a development approach, methods and code base pathway. The opal companion paper (SC22-SA-WP02) demonstrates an impressive list of achievements in a short time from a very part time team of three people. The opal work clearly indicates that the region has the skillsets, motivation and knowledge within the Pacific tuna science community to develop a next generation tuna/tuna like species focused assessment software. There is a very strong case for moving forward with a Pacific led but open and collaborative pathway as proposed by opal, rather than joining or depending on other software development projects that are not tuna-focussed, and that have timelines, priorities, and governance not under direct control or influence of Pacific tuna RFMOs. Through a Pacific led software development project, WCPFC and IATTC can enhance their R &D collaborative partnerships and leverage each other's science capacity and unique technical capabilities, project opportunities, funding and expertise.

We hope the project governance/delivery framework and the proposal for a 3-year next phase project (as requested by SC21) provides sufficient information for SC22 to consider supporting the development work to move forward.

Acknowledgments and funds

This work, including the companion papers SC22-SA-WP02 and SC22-SA-WP03, was funded by WCPFC Project 123: Scoping the Next Generation of Tuna Stock Assessment Software.

Declaration of generative AI and AI-assisted technologies

No AI technologies were used in the preparation of this paper.

References

Davies, N., Bouye, F., Kim, K., Magnusson, A., & Hampton, J. (2026). *Developments in the MULTIFAN-CL Software 2025-26*. WCPFC-SC22-2026/SA-IP-02.

Ducharme-Barth, N., Webber, D., Neubauer, P., Kim, K., Magnusson, A., & Hamer, P. (2026). *opal: the open population assessment library*. WCPFC-SC22-2026/SA-WP-02.

Mildenberger, T., Nielsen, A., Magnusson, A., Scutt Phillips, J., & Hamer, P. (2026). *Skipjack tagging data preliminary analysis, review and recommendations for further development and application*. WCPFC-SC22-2026/SA-WP-03.

Webber, D., Parma, A., Ianelli, J., Hillary, R., & Eveson, P. (2026). *Sbt: Southern bluefin tuna stock assessment model.* https://github.com/quantifish/sbt.

Appendices

Appendix 1 Developing the Next Generation Tuna Stock Assessment Model: CAPAM mini workshop, December 9-11, 2025

LINK to workshop webpage

Mark N. Maunder (IATTC) and Arni Magnusson (SPC)

Introduction

On December 9-11 2025, a CAPAM mini workshop was held on developing the next generation tuna stock assessment model. The workshop was an initiative of a collaboration between SPC and IATTC, under the CAPAM framework and the WCPFC funded Project 123 "*Scoping the next generation of tuna stock assessment software*", to address the future needs of these organizations. SPC uses MULTIFAN-CL and IATTC Stock Synthesis to conduct their major tuna stock assessments and both stock assessment packages are coming to the end of their lifespan with no major developments planned. Although very general, these packages lack some features that are desirable in future assessments to take advantage of recent developments and new data sources. Therefore, a new stock assessment package must be developed to ensure that future tuna assessments can provide the best available science, while recognizing the general model is only a part of the whole stock assessment and management ecosystem (Figure 1).

The goal of the workshop was to evaluate several stock assessment model components that might require critical software architecture for their implementation to ensure this architecture is included in the initial stages of the development of the next generation tuna stock assessment model software package. The evaluation would also inform the decision on whether the development of the next generation tuna model should be a collaboration with an existing model, or one in development, or whether a completely new stock assessment model or set of model packages should be developed specifically for tuna.

The components discussed at the workshop were 1) spatial structure, 2) tagging data, 3) random effects, 4) length-based dynamics, and 5) close-kin mark-recapture. For each topic, there was an introductory presentation that reviewed the topic and two presentations focusing on particular research or implementation. A final session was dedicated to aspects of implementing the software.

The workshop followed the CAPAM framework that focusses on discussion. In addition to time for questions and answers after each presentation, there was a 30 minute discussion period at the end of each topic and a final 30 minute discussion period at the end of the workshop. In addition, a website with background information and focus questions was developed before the workshop and made available to participants (https://www.populationassessment.com/tuna/next-gen-model/).

The workshop was completely open to anyone to participate and was announced using the CAPAM mailing list. Over 150 people participated in the workshop depending on the topic. The workshop was coordinated by Arni Magnusson of SPC and Mark Maunder of IATTC and CAPAM. Mark Maunder chaired the meeting. Eighteen people gave presentations and the chair provided a straw man proposal for the development of the next generation tuna assessment. The agenda is provided in Appendix I and the abstracts in Appendix II. The following provides the "Chairs summary" of the topics and discussions. The final section of the report provides the organizers' view on how the next generation tuna assessment model should be developed, drawing from the workshop presentations and discussions.

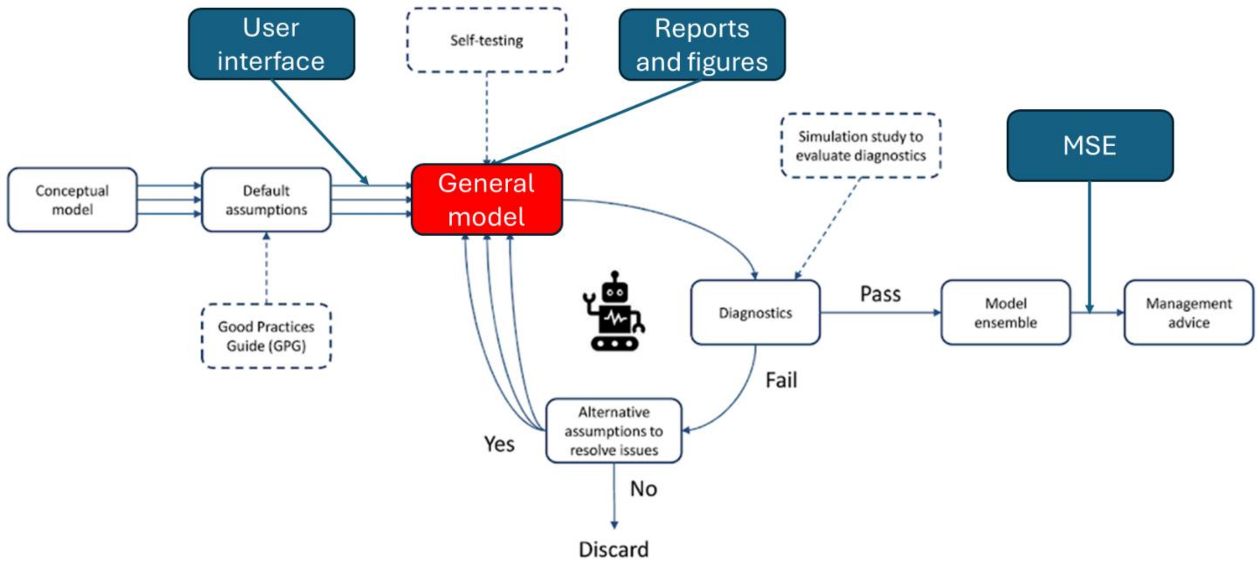

Figure 1. The stock assessment ecosystem, outlining all the components that need to be considered when developing the next generation tuna stock assessment model (adapted from Maunder 2024).

Spatial Structure

Tuna are highly mobile species, and their spatial distribution is potentially affected by multiple factors including environmental conditions, ontogenetic movement, migration, local depletion, currents, etc. Therefore, modelling the spatial distribution of tuna stocks, spatial variability in population processes, spatial distribution of fleets, and fish movement should be considered in tuna stock assessments.

Current tuna assessment models typically address spatial structure using the areas-as-fleets approach (e.g., IATTC assessments in the EPO) or block transfer among multiple large regions (e.g., SPC assessments in the WCPO). The areas-as-fleets approach relies on length composition data to estimate a selectivity curve that describes the proportion of the stock by age or length that occupies that region and is fished by the defined "fleet". The block transfer approach estimates movement among regions and typically requires age or length specific movement, often as a functional form, for which information comes from length composition data, tagging data, or assumptions about common catchability among regions for an index of abundance. Spatial regions are demarcated based on similar consideration of tagging and spatial patterns of size data, but also other biological information/data (e.g., oceanography) through conceptual models, to accommodate assumptions for use of tagging data (i.e. tag mixing), and to match management jurisdictions or needs for spatial management advice. Often the composition data is overly influential on the estimates of movement rates and can be influenced by biological assumptions such as growth and its spatial variability. Assuming catchability is common across regions requires accurate modelling of the spatial distribution of the (CPUE) index of abundance.

Fine scale modelling of the CPUE data and in some cases (i.e. IATTC) tagging data is done external to the assessment. This modeling is important to ensure spatial distribution of the stock and fleet are accounted for in the analyses

There have been some stock-assessment like models (estimating parameters) that use a fine spatial-temporal scale, but these have yet to be used directly to set management action. For example, the SEAPODYM model has been used to model tuna biomass spatial and temporal trends by life stages in the Pacific Ocean and how the dynamics relates to environmental conditions (e.g., Senina et al., 2021).

The decision on what spatial temporal scale should be used in the model will partly depend on whether integrating the tagging data into the assessment is necessary or if external analysis of the tagging data is adequate (see section on tagging data). A model with flexible spatial and temporal scale could be developed, but some concepts need to be considered.

The block transfer approach can easily be scaled, but it would require an approach to define movement among the cells that reduces the number of parameters. For example, spatial movement rates in terms of advection, diffusion, and taxis parameters could be represented as a Gaussian Markov Random Field (GMRF). However, when time is on a finer scale, fishing and natural mortality also need to be considered on the finer temporal scale. Computational efficiency and parameter estimability might become a concern at finer spatial-temporal scales. Particularly when it interacts with the inclusion of random effects or other desirable aspects of the assessment model (e.g., length-based dynamics).

Change in spatial distribution of the stock could be modelled using spatio-temporal correlation rather than explicit movement. However, this might require a different approach to modelling the population dynamics.

Spatial variation in population and fishing processes may complicate the calculations. For example, if growth varies spatially, this causes modelling issues when fish move and change their growth rates such that different fish will have different length-at-age. Explicitly modeling both age and length can facilitate modeling of these processes (see the length-based dynamics section), but consideration needs to be taken about whether growth is genetic, environmental, or both.

Modelling the stock-recruitment relationship (i.e., is the stock-recruitment relationship global or area specific) and how the recruitment is distributed among areas also becomes complicated in spatially structured models.

Chen et al. summarized the common forms of population structure features that should be included in a next-generation tuna assessment model, including approximations for data limited cases or situations requiring less model complexity, but focused on large-area box transfer models. They concluded that next-generation tuna stock assessments should include 1) a wide range of population structures (e.g., panmictic populations, metapopulations, natal homing), 2) flexible recruitment dynamics, 3) apply parsimonious movement formulations, 4) incorporate spatially-varying demography, and 5) accommodate diverse fishery fleet structures.

Thorson presented a general approach to model movement among areas within a spatial stock assessment model based on advection-taxis models, where advection is driven by the gradient of a preference function ("taxis"). The approach is generic, parsimonious, and scale-free, and is therefore ideal to model movement in a general stock assessment model that allows flexible spatial scale.

Senina described the SEAPODYM framework that models fine-scale spatiotemporal dynamics driven by environmental forcings/covariates for recruitment, mortality, and movement. The approach is age structured and fit to geo-referenced catches and size compositions, tagging data, and early-life data, and is therefore similar to traditional stock assessment approaches, but using fine scale spatio-temporal dynamics.

Discussions focused on several topics including the reasons for modeling spatial structure, the scale of the spatio-temporal structure, and how the different types of movement (e.g., ontogenetic or seasonal migration, environmentally drivers) can be represented. The scale of the spatio-temporal dynamics was discussed extensively including whether the approaches presented were appropriate for both fine and course scale, inclusion of data at different scales, and how to convert movement from fine scale to course scale and the need to use biomass weighting.

Tagging

The collection and use of tagging data to estimate abundance, fishing mortality, and movement for tuna stocks has a long history. This is due to the highly distributed nature of tuna stocks such that it is generally not possible to conduct surveys as conducted for groundfish and other species. Traditionally, the tagging data is analyzed outside the stock assessment model. However, integrating tagging data inside tuna stock assessment models using MULTIFAN-CL was one of the first applications (Hampton and Fournier, 2001) and has been used in the assessment of tropical tunas in the WCPO ever since. However, tagging tuna is complicated due to the practicalities of catching tuna in a way that post release survival is high. Therefore, the tagging opportunities are often restricted in space, time and in the sizes of the tuna that can be released. One of the major impediments of using the tagging data is that the tagged fish are not fully mixed with the total population, or that full mixing takes a long time compared to their lifespan, such that much of the information is lost when accounting for the mixing period (e.g., estimating a separate F for the tagged population that differs from the total population).

Fine scale spatial-temporal modelling of tagging data (e.g., Mildenberger et al., 2024) can substantially reduce bias from non-mixing while maximizing the content of the data from recaptures before the tags are fully mixed with the total population. Therefore, integrating the raw tagging data into the stock assessment model would require a fine spatial-temporal scale stock assessment model.

Goethel et al. discussed the benefits of integrating traditional tagging data into stock assessments but also highlighted the auxiliary information and analyses that are needed to minimize biases due to tag mixing, mortality, shedding, and reporting rate. They emphasized the need to include all tag types (e.g., electronic tags, genetic tags, biological tags, and conventional tags) and multiscale frameworks that enable modeling data sources at varying spatiotemporal scales. They also recommended the development of high resolution simulation and management strategy evaluation tools to evaluate different approaches.

Mildenberger presented the RTMB software package admove, a fine-scale spatio-temporal advection–diffusion-taxis model for estimating movement and other stock-assessment-relevant quantities from conventional and archival tagging data using habitat-preference functions and environmental covariates. admove incorporates spatially resolved fishing effort and catch, enabling simultaneous estimation of movement rates, length-based natural and fishing mortality, and abundance indices. The approach was illustrated using skipjack tuna in the eastern Pacific Ocean, including how the outputs can feed into tuna stock assessment models.

de Lestang presented a tag integrated model for lobster illustrating how ontogenetic movement can be modelled in an age-length based model. Senina describes how tagging data is integrated into the fine-scale spatial-temporal age-structured population dynamics model SEAPODYM.

Most of the discussion revolved around using a fine spatial-temporal scale stock assessment model using SEAPODYM as an example. The results from SEAPODYM were also discussed in the context of results from the MULTIFAN-CL assessments. It was highlighted that SEAPODYM uses environmental covariates to force the dynamics in a mechanistic approach and can fill in strata with no observations. A comparison among the models about how they use environmental data to model movement or spatial distribution would be useful. Computational demands for fine scale models were discussed including the use of parallel computing for tagging cohorts. It was suggested that SEAPODYM could be used as an operating model for MSE.

Random Effects

Most, if not all, population dynamics (recruitment, growth, natural mortality, movement) and fisheries process (selectivity, index catchability) vary over time. However, few stock assessment models deal with this temporal variation comprehensively. Most will model temporal variation in recruitment and treat it as a random effect is some way. This means that recruitment is assumed to come from a distribution such that recruitments for time periods where there is incomplete information are informed by time periods where there is information. Traditionally, this has been implemented within a penalized likelihood context and the standard deviation of the distribution is assumed (e.g., 0.6) due to difficulties estimating the standard deviation within the assessment without integration across the random effect. Notoriously, this has caused complications due to the use of the lognormal bias correction factor. Bayesian stock assessments do not have this complication and iterative approximations are available. The introduction of Laplace approximation in ADMB and the consequent development of TMB has facilitated integration across the random effects. Stock Synthesis and MULTIFAN-CL, which are used for many tuna assessments, are not programmed to use Laplace approximation.

The introduction of Laplace approximation has facilitated the development of more comprehensive state-space models (e.g., SAM and WHAM). State-space models and random effects for temporal variation in population and fishing processes are the same thing, although the term state-space model is generally used for more comprehensive use of random effects. A typical state-space model includes temporal variation in recruitment and survival (combined fishing and natural mortality or directly in natural mortality). Temporal variation in selectivity is often modelled and is an integral characteristic of SAM.

Clearly, random effects are a vital part of any contemporary stock assessment model. However, as more processes are allowed to vary and the standard deviations of the distributional assumptions for this variation are estimated, the computational demands will increase, parameter estimability will become more difficult, and data requirements will increase.

Nielsen summarized how random effects can be used in stock assessment models and their benefits. Random effects can be used to formulate flexible time-varying processes with parsimonious parameterization, handle missing observations, account for and predict the effects of environmental variation, objectively weight different data sources; partition observation error from process variation, and estimate variances of latent biological and fishery processes.

Miller described the various ways random effects are implemented in the WHAM software package and outlined conclusions from recent research and simulation studies.

Cadigan illustrated ways random effects are used in state-space stock assessment models. He also reviewed some theoretical and simulation research on properties of marginal maximum likelihood estimates of parameters and empirical Bayes predictions of random effects, the inferential framework used in TMB. He noted that in stock assessment models, random effects are often used as statistical regularization of high dimensional parameters, and this has implications on how variances are estimated for estimates and predictions.

The discussions focused on a few main topics including model selection for which processes to include random effects and/or covariates, estimability of the variance parameters, modelling time varying selectivity, and how to model survival. It was noted that modelling selectivity using age correlated random walks and interpolation across bins for length-based selectivity generally performed well. Survival can be modeled treating numbers as a random effect or natural mortality as a random effect, with the former also representing movement (i.e., apparent survival).

Length Dynamics

Most contemporary stock assessment models include age structure, although some include size instead of age, particularly for hard-to-age species such as crustaceans and shellfish. Few include both size and age because of computational or data requirements. Most contemporary stock assessments for the important tuna stocks are age-structured, although some use biomass dynamics models and a few length-based models have been developed. Including age or length structure is important for many tuna stocks because different fleets catch widely different aged tuna, which may differ from the ages represented by the index of abundance and spawning biomass.

Most tropical tuna stocks have little, if any, reliable age data. Therefore, there is no time series of age data as used in VPA or Statistical Catch-at-Age analysis, unless length composition data is converted into age using cohort slicing or a similar method. Related issues arise with other data, such as tagging, which are available by length, but not age. Aging data is becoming more available for tropical tunas, but there are still some reservations. The lack of age data and the possibility that population (e.g., natural mortality, growth, and movement) and fishery processes are length-based, suggest that length-based models could be considered.

Age-based models that are fit to length-composition data typically assume a constant function for length-at-age (e.g., the normal distribution) and therefore length-based processes do not change the distribution of length-at-age. However, strong length-based processes, particularly selectivity when fishing mortality is high or a minimum legal size is used, can affect the distribution of length-at-age and should be taken into consideration. This requires modelling both age and length dynamics (the model must explicitly keep track of the age and length of fish, which increases the dimensions of the model), considerably increasing the computational and data requirements. Although, approximations such as platoons in Stock Synthesis can reduce the computational demands.

Spatial variation in growth is apparent in tuna length data and may need to be accounted for in stock assessment models. Assuming the same growth curve in current spatial tuna stock assessments can result in different depletion levels among areas simply due to fitting to the length-composition data. However, modelling spatial variation in growth within age-structured spatial stock assessment models becomes complicated since the length-at-age changes as a fish moves within the model from one area to the other. Modelling both age and length dynamics can allow for fish to retain the same age and length as it moves. However, estimating the growth parameters and determining if growth is age-based (genetic) or length-based (environmental) may be difficult. It is not clear if length-based dynamics are important for tuna stock assessment. Further research and simulation studies are important.

Punt described the need for modeling length-based processes in stock assessment models but also highlighted the related computational demands. He contrasted how age-, size- and age-size-structured models are formulated and consequences of an overly simplistic model formulation. Punt highlighted challenges associated with moving to stock assessment methods based on age-size-structured population models including 1) selecting appropriate modelling assumptions, 2) reducing the computational burden, and 3) parameter estimation and data needs.

Elvarsson et al. described how Gadget models both age and length-based processes including how the length-transition matrix is parameterized and showed different use cases and the associated computational costs. They illustrated the approach with a case study in which an age–length model is fitted without the use of age data.

Davies reviewed causes of misspecification of length-based processes with different types of models (age, length, and age-length) and approaches to correctly specify or approximate them. He illustrated the potential for bias from misspecification using Western and Central Pacific Ocean tuna including high levels of both individual growth variability and fishing mortality, inter-annual environmental variation, and large-scale movement.

de Lestang showed how an age-length based model can be simplified by limiting the number of ages classes that are modelled (i.e., a young plus group) to those that are identified to have age-based processes. In his application movement was aged based.

The discussions focused on which situations would require modelling both length and age and whether approximations or a strictly length-based model would be adequate. It is important to make sure that the decisions made don't prevent modelling important length-based processes in the future. It might be useful to map out all the potential length-based effects. However, it was not clear which processes are length-based and which are age-based for tunas. It was pointed out that fitting to length-composition data is one of the reasons appropriately modelling length-based processes is important.

Close-Kin Mark-Recapture (CKMR)

Traditional tagging programs for tunas have several issues due to the practicality of implementing them that can impact their reliability, particularly if they are not well designed. These include tagging related mortality, tag loss, reporting rates, and tag mixing. A well-designed tagging study should minimize these issues and estimate their effect so they can be taken into consideration when the data is analyzed.

Close-Kin Mark-recapture (CKMR) is an alternative that eliminates or reduces the issues with traditional tagging data. This approach uses relationships between individuals (e.g., parent offspring, half sibling, etc.) to "tag" and "recapture" fish. CKMR does not require a fish to be released alive so tagging related mortality does not occur. Recaptures are through genetic samples so reporting rate is 100% and there is no tag loss. It also allows more sampling opportunities since the fish do not have to be released alive. Finally, the mixing rate might be higher because mixing occurs from when an individual is spawned until it is caught and therefore includes egg and larval dispersal and possibly juvenile and adult movement. Although, any effect of family relationship on the probability of capture may affect the results.

CKMR is a new approach in fisheries stock assessment and there is limited experience using the method. Most of the applications are individual case studies or ad hoc modifications of existing general models. There is yet to be a general stock assessment model that has a comprehensive CKMR integrated into the software.

Hillary outlined the implementation of data collection, model building and long-term monitoring potential of CKMR using Southern Bluefin tuna. He then discussed whether CKMR is applicable of larger populations with more complex spatial dynamics using Indian Ocean yellowfin tuna as an example.

Based on his experience with over a dozen CKMR projects in diverse settings, Bravington discussed several aspects related to tunas such as 1) inputs and outputs, 2) suitability, 3) cost, 4) value, and 5) obstacles. He outlines the need for well designed sampling which may overcome spatial structure complexity. Bravington also summarized software requirements and outlined some technical solutions that have worked well.

Fisch presented analyses evaluating the benefit of routinely collecting genetic information for every fish already being collected for age composition analyzed using CKMR integrated within a stock assessment model. The results suggest that CKMR data can provide considerable improvements in accuracy and precision of spawning stock biomass at the end of the time series and parameters defining natural mortality and the population scale. He also outlined experiences with coding CKMR integration into assessments.

Discussions focused on several topics, particularly how CKMR could be integrated into a general model. There is boilerplate code available for the basic components of CKMR, which have been integrated into SAM, that could be used in a simple general model. Some of this code could also be used for specific modules in a general model. However, tuna general stock assessment models are likely to require spatial structure to deal with management questions or to accommodate conventional tagging data. Developing a general spatial CKMR integrated into a stock assessment model would be much more complicated and harder to be generic.

Other discussions included whether consistent unsuccessful breeders would bias the results, how length-based dynamics is important to consider due to age inference, selectivity, and fecundity, and quality of genetic data.

Model Development Concepts

Developing a general stock assessment modelling program is a substantial task and requires expertise in several fields from computer programming through biology and statistics to project management. Many consequential decisions need to be made along the way including the underlying software to use (e.g., RTMB or something else), the development environment (e.g., GitHub or something else), should a professional programmer be used, how decisions are made, etc. There have been several stock assessment programs developed that have implemented general integrated analyses, some early ones have already met the end of their cycle (e.g., Coleraine, ASCALA), while others are still around (MULTIFAN-CL, Stock Synthesis, ASAP). Others have transitioned into a second version through substantial changes (e.g., CASAL, GADGET), new ones are becoming more frequently used (e.g., SAM, WHAM), and others are in development (FIMS). Much can be learnt from these developments.

Methot explained how the looming end of ADMB and SS3 motivated the initiation of NMFS's Fisheries Integrated Modeling System (FIMS) project, a next generation stock assessment model which is a collaboration of all six NOAA Science Centers and the Office of Science and Technology. FIMS has made great progress to develop core capability. FIMS provides the framework and capability to facilitate adding features. Methot suggested that developers from the tuna modeling community can help accelerate the inclusion of features desirable for tuna models.

Webber outlined how RTMB streamlines stock assessment workflows including lightweight packages, enhancing portability, documentation, unit testing, reproducibility, collaboration, and the extensive library of R packages. He illustrated these from three recent RTMB-based assessments including an age-structured model, a length-based model, and an age- and length-structured model.

Magnusson and Maunder outlined the main factors to consider when developing the next generation tuna stock assessment model, ranging from the leadership and governance structure, and methods to collaborate, down to technical decisions such as the programming language used and the individual components of the assessment model.

A large portion of the discussions focused on how to facilitate collaboration within a project and how it works in FIMS. Some components of a large project were highlighted, such as documentation and training materials that involve a considerable amount of human resources but may be overlooked when considering the scope of a project. Also, maintenance and future development is a large commitment and would need the long-term support of an organization. It was noted that even if FIMS is not used for the next generation tuna model, some of the components of FIMS could be used such as displaying results and diagnostics.

The next generation tuna assessment model

The workshop was designed to improve our understanding of what is needed to ensure that the underlying architecture of the next generation tuna stock assessment will meet our future needs. We covered the main topics that might lead to specific underlying architecture in the model code including spatial structure, tagging data, random effects, length-based dynamics, and close-kin mark-recapture, as well as general concepts related to creating the software. Many fruitful discussions were had covering all the topics and related concepts. Maunder and Magnusson presented a strawman proposal for development of the next generation model to promote discussion. Here we, the organizers (Magnusson and Maunder), build on that strawman taking into consideration comments, suggestions, and insights from the discussions, to create a proposal for the way forward.

First, it is important to put the development of a next generation model into perspective given the main needs and possible constraints. It is highly likely that funding will be limited and developing a general model, and providing maintenance and ongoing development, over its lifespan will require substantial long-term resources and organizational commitment. There will be a limited user base for a tuna-specific general model, and contributors will likely be stock assessment scientists. In addition to developing the model, resources will be needed to develop the whole ecosystem surrounding the model including displays for results, diagnostics, documentation, training materials, etc. The perceived need for a next generation tuna stock assessment model is based on the currently used models reaching the end of their development phase and the need for new features such as random effects, better integration of tagging data, age- and length-based dynamics, and close-kin mark-recapture. There are existing general models that include random effects (e.g., WHAM and SAM), but not CKMR or comprehensive integration of tagging data. Based on the assumption that funding will be limited and a simple (narrowly scoped project) will be more successful (at least in the near term), we propose developing a general model for tropical tunas that will be relevant in the short to medium term. The tropical tunas have similar dynamics and data, while the temperate tunas and billfish may have complexities that would require additional features in the model.

Clearly, RTMB should be used for the development of the model due to its ease of use and because it is specifically designed for the type of inference conducted in fisheries stock assessment. It is also familiar to many stock assessment model developers. RTMB automatically incorporates random effects and therefore addresses that need. Random effects address several aspects of tuna assessments models, particularly time varying selectivity, estimation of the standard deviation of recruitment variation, and elimination of the log-normal bias correction issue.

On going CKMR studies at some tRFMOs also need to be considered. However, CKMR should not be included in the initial development of a general tropical tuna stock assessment model. There are no current applications for tropical tuna and those in development probably have a medium to long-term time horizon and will probably go through multiple development cycles. In addition, the spatial models envisioned for dealing with traditional tagging data may cause complexities in developing the CKMR module and some early experience with integrating CKMR in state-space models resulted in convergence issues. Therefore, any CKMR applications, such as for South

Pacific albacore, should be initially developed as bespoke models specifically designed to use the CKMR data. Lessons learned from these bespoke models can be used to develop general models that include CKMR in the future.

The benefits for including length-based dynamics in tropical tuna assessment models have not been evaluated. There is very little aging data currently available for tropical tunas, and ongoing regular collections of age composition data are yet to be implemented. There was not much support from the workshop participants for a full length-based model due to its inability to use age data and include age-based processes (and cohort specific growth), and the need for age dynamics for CKMR. However, for tropical tunas these arguments are not persuasive, so research on spatially structured length-based tag-integrated models is encouraged. We do not propose that the next generation tropical tuna model be length structured. We also support research, such as simulation analysis, to evaluate the impact of length-based dynamics. However, to keep the next generation tropical tuna stock assessment model simple, we recommend not including length-based dynamics in the short term.

Initial design decisions for the next generation tropical tuna model (TTM) involve spatial structure and integration of the tagging data. Tropical tunas are highly mobile and although migrations are not apparent, substantial movement that could impact stock assessment results is indicated by tagging data. Spatial structure is also needed to deal with the tag non-mixing issue.

The timeframe in which a new model is needed also should be taken into consideration when designing the TTM. The timeframes may differ among the tuna Regional Fishery Management organizations (tRFMOs) depending on the software they use and the requirements for the stock assessments. For example, the WCPFC uses Multifan-CL for which the lifespan may be shorter than Stock Synthesis 3 that is used by other tRFMOs (e.g., the IATTC). The WCPFC also explicitly includes spatial structure and integrated tagging data into their assessments.

The TTM should have a flexible and scalable spatial-temporal structure to allow for different assumptions. Ideally, the tagging data should be integrated into the assessment model to ensure that assumptions are consistent, and uncertainty is propagated. However, we believe more work is needed to determine if integrating the fine scale spatial-temporal modelling of tagging data in the assessment model is feasible.

We propose that additional strategic research is needed to determine the best approach for a TTM that can service needs of tuna RFMO stock assessments over the longer term (i.e. 10-20 years). This research would focus on determining the appropriate spatial-temporal scale of the model and whether the tagging data should be analyzed inside or outside the model. In the meantime, a spatially structured stock assessment model, which also encompasses a single region model, should be developed to address stock assessment needs in the short term (i.e. 0-10 years).

The research would decide between the two approaches:

1) Analyses the tagging data outside the stock assessment model using a dedicated tagging fine scale spatial-temporal model and take the results to use in a traditional spatially structured block-transfer stock assessment model (either MFCL, SS or one that uses random effects such as WHAM, SAM, FIMS or the recently initiated opal – Open Population Assessment Library development)
2) Develop a fine scale spatial-temporal tag integrated tropical tuna stock assessment model

The work plan we propose for 2026-2027 includes:

1) Developing a TTM that can incorporate spatial structure for use in the short term
2) Develop a working group to further discuss fine scale spatial-temporal modelling of tagging data and fine scale spatial-temporal stock assessment models
3) Continue developing the DTU fine scale spatial-temporal tagging model
4) Conduct a workshop to discuss the findings and develop a work plan to create the next generation TTM

The initial investigations would include thorough evaluation of existing fine scale spatial-temporal stock assessment type models (e.g., SEAPODYM, SPM). Features of these models would be considered for inclusion in the fine scale spatial-temporal tagging model. In addition, further investigation into dealing with spatial variation in growth or length-frequency distribution should be conducted.

Analyzing the tagging data outside the stock assessment model requires developing methods that can represent biomass, fishing mortality, movement, etc. in course scale block transfer stock assessment models. These methods will also have to be reviewed if this approach is pursued, including the auxiliary data requirements to inform processes such tag reporting rates.

Some questions we need to answer:

- What is spatial structure needed for?
- When do we need to model spatial structure?
- When can we model spatial structure without tagging data?
- What type of spatial structure do we need for tagging data?
- What type of spatial structure is needed in what circumstances?
- Do we need to consider length dynamics in spatial models to deal with spatial variations in length-based processes (e.g., growth)?

References

Maunder, M.N., 2024. Towards a comprehensive framework for providing management advice from statistical inference using population dynamics models. Ecol. Mod. 498, 110836

Mildenberger, T.K., A. Nielsen, and M. Maunder, 2024. A spatiotemporal Petersen-type model for skipjack in the EPO. IATTC Document SAC-15 INF-G.

Senina, I., G. Briand, P. Lehodey, S. Nicol, J. Hampton, and P. Williams, 2021. Reference model of bigeye tuna using SEAPODYM with catch, length and conventional tagging data. WCPFC-SC17-2021/EB-IP-08.

Agenda

Day 1

11:00 Introduction - Arni Magnusson and Mark Maunder (Chair)

Spatial structure

11:10 Assessing the Multiverse: Considerations for Explicitly Integrating Spatial Structure in Next-Generation Stock Assessments - Matt Cheng

11:40 Practical, scale-free, and generic approach to movement modelling: bridging from individual-based to population-scale dynamics - Jim Thorson

12:00 Quantitative modeling of the spatiotemporal dynamics of tuna populations - Inna Senina

12:20 Discussion

12:50 Break

Tagging data

1:10 Mixing It Up: Considerations for Integrating Tagging Data into Next Generation Tuna Stock Assessments - Dan Goethel

1:40 Go with the flow: adding movement to tuna stock assessments with admove - Tobias Mildenberger

2:00 Modelling migration: an invertebrate perspective - Simon de Lestang

2:20 Discussion

2:50 Summary

Day 2

Random effects

11:00 The Essential Roles of Random Effects in Fish Stock Assessment - Anders Nielsen

11:30 Random Effects in WHAM: Use in Northeast US assessments - Tim Miller

11:50 Random effects in stock assessment models - Noel Cadigan

12:10 Discussion

12:40 Break

Close kin mark-recapture

1:00 Incorporating CKMR in tuna stock assessments - Rich Hillary

1:30 CKMR and tuna and software - Mark Bravington

1:50 Routine Collection of CKMR Data and Integration in Assessment: Considerations for Tunas - Nicholas Fisch

2:10 Discussion

2:40 Summary

Day 3

Length based dynamics

11:00 Age-Length-based Stock Assessments: Solution or Just Yet Dead End - Andre Punt

11:30 Length based processes in gadget3 - Bjarki Þór Elvarsson

11:50 Model mis-specification of length-based processes among available model structures - Nick Davies

12:10 Discussion

12:40 Break

General concepts of implementing a model

1:00 Lessons learned from 40 years of Stock Synthesis; handing the baton to FIMS - Richard Methot

1:20 Discussion

1:30 Stock assessment workflow using RTMB - Darcy Webber

1:50 Discussion

2:00 Factors to consider when developing the next generation tuna stock assessment model - Arni Magnusson and Mark Maunder

2:20 Discussion

2:30 Revised Thoughts on the Next Generation Tuna Stock Assessment Model - Mark Maunder and Arni Magnusson

2:40 General discussion

Abstracts

CKMR and tuna and software: Mark Bravington

Drawing on my experience of over a dozen CKMR projects in diverse settings, this talk will touch on:

- Inputs & outputs
- Big questions for CKMR and tuna: suitability, cost, value, and obstacles.
- Summarize six "tuna-like" CKMR projects, in terms of model differences.
- Spatial & Sampling
- Software requirements & tricks
- Where to start?

Random effects in stock assessment models : Noel Cadigan, Memorial University

I illustrate ways I commonly use random effects in state-space stock assessment models (SSAMs) based on a model for thorny skate, which is a data-moderate stock with no aging program and no fishery catch size compositions. The assessment model is estimated using length-based survey indices, estimates of total fishery landings, and weight- and maturity-at-length. I used random effects for F, M, survey catchability (Q), recruitment, and initial population size.

The second part of my talk reviews some theoretical and simulation research on the frequentist sampling properties of marginal maximum likelihood estimates of parameters and empirical bayes predictions of random effects in nonlinear mixed-effects regression models including SSAMs. This is the inferential framework used in ADMB and TMB. This research is particularly relevant for interpreting the results of SSAM simulation studies. I highlight that TMB standard errors are actually mean squared errors (MSEs) or prediction standard errors (PSEs).

In stock assessment the effects we model as random are usually just high dimensional parameters (HPDs) that we model as random for statistical regularization purposes. However, in this case inference should be conditional on specific values of the HDPs rather than the marginal inferences provided by TMB. There is conditional bias to worry about and the conditional variance is smaller than the marginal variance, although the conditional MSE can be approximated by the marginal MSE (i.e., PSEs). Hence, in the end we recommend confidence intervals for stock assessment quantities should be based on the TMB PSEs. It is possible to do better with a bias correction procedure we proposed, which we illustrate with some SAM case studies, but this requires further research.

Assessing the Multiverse: Considerations for Explicitly Integrating Spatial Structure in Next-Generation Stock Assessments: Matt Cheng[1], Daniel Goethel[2], and Aaron Berger[3]

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[2]NOAA, Alaska Fisheries Science Center, Juneau, AK

[3]NOAA, Northwest Fisheries Science Center, Newport, OR

Spatial structure is widespread across marine populations and arises from the interplay among individual movement, recruitment dynamics, spatially-varying environmental conditions that shape demographic patterns, and heterogeneity in fishery dynamics. Although stock assessment models often rely on the assumption of a single, homogenous 'unit stock', there is a growing recognition of the importance of incorporating spatial dynamics to reduce biases in population estimates and ensure robust management advice. Here, we summarize the common forms of population structures encountered across marine systems, which should ideally constitute the minimum set of structural features that a next-generation tuna assessment can accommodate. Approximations for representing spatial structure within panmictic formulations are discussed (e.g., fleets-as-areas models), which remain relevant for tuna assessments when data limitations or model complexity preclude the implementation of fully spatially explicit approaches. General decision points and recommended practices for spatially-stratified stock assessments (i.e., large-area box transfer models) are outlined, with a focus on next-generation spatial considerations in recruitment processes, movement, demography, and fishery dynamics. We conclude that next-generation tuna stock assessments, should at a minimum, be capable of representing a wide range of population structures (e.g., panmictic populations, metapopulations, natal homing), flexibly model recruitment dynamics, apply parsimonious movement formulations, incorporate spatially-varying demography, and accommodate diverse fishery fleet structures. However, it remains unclear whether multi-scalar frameworks that generalize fine-scale spatial processes to spatially-stratified contexts are necessary, and how such an approach could be implemented analytically. Nonetheless, a generalized next-generation tuna assessment platform should support seamless extension from single-region models to multi-stock, multi-region assessments, thereby facilitating application across stocks spanning a spectrum of data quality and availability.

Model mis-specification of length-based processes among available model structures: Nick Davies

An overview of model structures (age-, size-, and age-size-structured) is given to highlight those aspects causing mis-specification of certain length-based processes, and to identify the formulations developed in each that attempt to correctly specify or approximate them. The length-based processes considered are: individual, and inter-annual variability in growth; and, spatial heterogeneity in growth. A ranking of the mis-specification "level" is offered in respect of each model structure in terms of its caveats; with a recommendation given for that model structure having the least mis-specification. The potential for bias from these forms of mis-specification in the context of Western and Central Pacific Ocean tuna is illustrated, and include: high levels of both individual growth variability and fishing mortality; inter-annual environmental variation; and, large-scale movement.

Length based processes in gadget3: Bjarki Þór Elvarsson[1], Jamie Lentin[2], and William Butler[1]

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Many key processes that shape fish population dynamics are size-based, including mortality, fleet selectivity, consumption, and maturation. For stock-assessment purposes, however, these dynamics are often assumed to depend on age rather than size, largely for computational convenience. In practice, sampling is frequently sparse and growth information limited, partly because obtaining reliable age data is difficult.

Integrated assessment models of population dynamics—such as those developed within the Gadget framework—help address these data limitations by combining information from multiple datasets and sources. Typical Gadget models track numbers at age and length at each time step, which allows key processes to be represented directly as length-based. In this presentation, we describe the Gadget approach to parameterising the length-transition matrix, show examples of how it can be adapted to different use cases and discuss computational associated costs. We also explain how data can be incorporated into the model through likelihood components. Finally, we illustrate the approach with a case study in which an age–length model is fitted without of the use of age data.

Routine Collection of CKMR Data and Integration in Assessment: Considerations for Tunas: Nicholas Fisch

Integrated fisheries assessments form the backbone of commercial fisheries management throughout the world, especially for Tunas. Close-Kin Mark-Recapture (CKMR) sampling offers a promising new data source to integrate within fisheries stock assessments. I wonder whether fisheries should consider routinely collecting genetic information for every fish already being collected for age composition. To this end I examine, using self-test simulations, the expected improvements in precision and accuracy of derived quantities and estimated parameters within statistical catch-at-age models when CKMR sampling of the age composition samples is conducted and the data integrated within the assessment. I examine the expected improvements across three life history types (cod-like, flatfish-like, and sardine-like) and different amounts of data available to the assessment, including the uncertainty and inclusion of an abundance index and the sample size and time series length of CKMR and age composition samples. Results suggest CKMR data can provide considerable improvements in accuracy and precision of spawning stock biomass at the end of the time series and parameters defining natural mortality and scale of the population, provided an adequate annual sample size is collected relative to the spawning abundance of the stock during the period of CKMR inference. I will discuss the paper and some of my experiences with coding CKMR integration into assessment, in addition to some tuna specific considerations.

Mixing It Up: Considerations for Integrating Tagging Data into Next Generation Tuna Stock Assessments: Daniel Goethel[1], Matthew Vincent[2], Matt Cheng[3], and Aaron Berger[4]

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Tagging data provides important information on distribution, movement patterns, growth, and mortality for widely distributed and mobile tuna species. Although tag-integrated assessments can directly utilize tagging data to inform parameter estimates, tag 'nuisance' parameters (e.g., tag mixing, mortality, shedding, and reporting rate) must be addressed to ensure appropriate inference and avoid estimation bias. Similarly, for electronic tags, scaling from the dynamics of relatively few individuals to that of the entire population can be inappropriate. We synthesize the methods available to incorporate tagging data within spatial assessment frameworks, then highlight key features to consider for next generation tuna stock assessment models. Capabilities of existing integrated spatial assessments (e.g., conventional tagging sub-models) form the minimal requirements for future tuna assessment platforms. Next, models that integrate all tag types (e.g., electronic tags, genetic tags, biological tags, and conventional tags), including appropriate likelihood assumptions and robust scaling to population level dynamics, will be necessary. Ultimately, multiscalar frameworks that enable modeling data sources at varying spatiotemporal scales (i.e., integrating high resolution tagging modules where movement and mortality estimates scale to the broad stratified units typically assumed for other data sources) may help address tag mixing issues and potentially better inform movement estimates (e.g., through the use of preference functions linked to environmental data). Thus, next generation assessment platforms should ideally meld current high resolution tagging models with spatially explicit stratified assessments to enable joint estimation of parameters, while also allowing these modules to be run independently (given likely run-time constraints) with subsequent integration via priors or penalties on movement parameters.

Developing a modular assessment platform that can easily collapse partitions and allow varying spatiotemporal resolutions among sub-models will ease exploration of adequate model complexity. Yet, consideration should be given to when more complex assessment tools are necessary to provide robust management advice, considering extant data limitations. Concomitant development of high resolution simulation and management strategy evaluation tools could help optimize data collection schemes and potentially inform simpler, more transparent management procedures.

Incorporating CKMR in tuna stock assessments: Rich Hillary

The robust and accurate assessment of global tuna stocks faces many challenges (contracting fishing footprints, patchily sampled commercial data, decreasing funding). CKMR has held a lot of appeal for these stocks and its limited implementation - mostly for the bluefin tuna species - has shown that is has clear potential to be transformative for the other major tuna stocks. This talk will briefly cover off on the fundamentals of the idea and how this layers onto the key stock assessment parameters and variables. Using Southern Bluefin tuna, probably the most "complete" implementation in terms of assessment integration and RFMO long-term buy-in, we outline what implementation might look like in terms of data collection, model building and long-term monitoring potential. Using a spatially-explicit CKMR design program for Indian Ocean yellowfin tuna I also address the issue of whether larger populations with more complex spatial dynamics are a barrier to implementation.

Modelling migration: an invertebrate perspective: Simon de Lestang

In stock assessment modelling, simplicity is preferred, with complexity warranted only when essential for capturing key biological processes or complex reporting requirements. One approach to maintaining spatial simplicity is to use fleets as proxies for areas. However, finer spatial resolution becomes necessary when model outputs are required at smaller spatial scales or when the target species' biology varies markedly across the modelled domain. Once discrete areas are incorporated and the species exhibits movement behaviour, the additional complexity of migration must also be replicated.

Migration can be modelled based on size or age, with the choice informed by the drivers which induce movement, such as an pre-maturation migration to breeding grounds. A critical challenge emerges when animals move between areas with different growth characteristics. Most stock assessment platforms (e.g., Stock Synthesis 3) employ growth equations that describe length as a function of age. When an individual migrates to an area with different growth parameters, its length-at-age no longer conforms to the destination area's growth relationship, preventing direct application of the new growth equation. Size transition matrices, which relate current size to future size distributions, offer a practical solution by enabling differential growth rates without age dependency.

This has led to the adoption of integrated length- and age-based models that track both dimensions simultaneously using length bins and size transition matrices for growth. This framework is currently employed in Western Australia for crustacean stock assessments, including the Western Rock Lobster and Crystal Crab fisheries, successfully balancing spatial realism with operational tractability.

Introduction: Arni Magnusson, Nick Davies, Graham Pilling, Paul Hamer, and Mark Maunder

We introduce the CAPAM mini virtual workshop by outlining the reasons why a next generation tuna stock assessment model is needed. The two main software programs used for assessing tunas in the EPO (MULTIFAN-CL and Stock Synthesis) are coming to the end of their development cycles due to staff retirements and the underlying programming languages becoming outdated. Evaluation of software for tuna assessments presented to the WCPFC Scientific Committee in 2025 concluded that new software specifically for tuna assessments is needed. Development of this software through a collaboration between the Pacific Community (SPC) and the Inter-American Tropical Tuna Commission (IATTC) is clearly advantageous due to their long-standing relationship, comparable datasets, comparable challenges, and overlapping stock distributions. There is also a related ongoing collaboration between SPC, IATTC, and the Danish Technical Institute (DTU) on a fine-scale spatial-temporal model of tuna tagging data. SPC will present a project proposal in August 2026 for funding the development of the next generation tuna model. This workshop will help guide the decisions about what type of software should be developed and how it will be developed.

Factors to consider when developing the next generation tuna stock assessment model: Arni Magnusson and Mark Maunder

We outline the main factors to consider when developing the next generation tuna stock assessment model including initial decisions such as whether the project should 1) collaborate with an existing development (e.g., FIMS), 2) create a new tuna focused general model, or 3) extend an existing fine-scale spatial-temporal model (e.g., SEAPODYM, admove). We discuss several factors including 1) leadership and governance structure, 2) format of the development team, 3) the development environment, 4) code requirements, 5) programing approach and language, 6) and components to include. We also discuss the many other components of a stock assessment ecosystem that need to be included ranging from generating a conceptual model of the system and the good practices to implement it within the software package, through to diagnostics, displaying results, and providing advice using simulations in a MSE framework.

Revised Thoughts on the Next Generation Tuna Stock Assessment Model: Mark Maunder and Arni Magnusson

We outline the main issues involved in developing the next generation tuna stock assessment model identified throughout the workshop. We then provide a strawman proposal to develop the next generation tuna stock assessment model. Although the strawman is based on our current thinking on the best way forward, it is only intended to promote discussion at this stage. This proposal is based on the several factors 1) funding will be limited, 2) potential uses and contributors will be limited, 3) stock assessment scientists will contribute to the development, 4) inclusion of tagging data is essential, 5) the model will be used in the short to medium term, 6) development of a simple software package is more likely to succeed. The straw man includes a) code a new model in RTMB for tropical tunas, b) Include random effects, c) do not include CKMR because there are few current applications and spatial dynamics might complicate the analysis, d) include tagging data, e) include a scalable spatial structure, f) do not include length-based dynamics since there is currently few data on growth for tropical tuna, g) use a focused development approach (i.e., limit the people involved), h) and use a single stock assessment scientist with extensive programing experience to develop the initial version of the model before letting other contribute. We also highlight that it is unclear whether including fine-scale spatial-temporal dynamics and tagging data in the stock assessment model is the best approach.

Lessons learned from 40 years of Stock Synthesis; handing the baton to FIMS: Richard Methot

Six years ago, the assessment community gathered for a CAPAM workshop in New Zealand on the topic of next generation stock assessment models. NMFS used the success of that workshop as a rationale for initiation of a project to build such a model in the U.S. using a team distributed across all six Science Centers and our Office of Science & Technology. Our Fisheries Integrated Modeling System (FIMS) project is designed to provide such a model for the assessment community. It uses a combination of C++, R, and TMB in an open-to-all model development process enabled by github. Today, the end of ADMB and SS3 is much closer than it was 6 years ago. Fortunately, the Fisheries Integrated Modeling System has made great progress to develop core capability. It is scheduled to undergo independent review in April 2026 and several stock assessments in 2026 will see side-by-side FIMS models presented. While FIMS currently is yet to develop all the specific capabilities requested for the next generation of tuna models, it does provide the framework and capability for such features to be added. Developers from the tuna modeling community can help accelerate the inclusion of needed features in FIMS.

Go with the flow: adding movement to tuna stock assessments with admove: Tobias Mildenberger

This talk introduces admove, an advection–diffusion state-space model for estimating movement and other stock-assessment-relevant quantities from tuna tagging data. Taxis, advection and diffusion can be linked to smooth habitat-preference functions of environmental covariates such as sea surface temperature and mixed-layer depth. admove can be fitted to both conventional and archival tags and allows incorporation of spatially resolved fishing effort and catch, enabling simultaneous estimation of movement rates, length-based natural and fishing mortality, and abundance indices. The model is implemented using two numerical approaches, a matrix-exponential method on a spatial grid and a continuous-space Kalman filter. We illustrate the framework using skipjack tuna in the eastern Pacific Ocean, highlighting inferred habitat preferences, seasonal movement patterns, and spatially explicit mortality and biomass estimates. Finally, we show how admove outputs can feed into tuna stock assessment models and outline ongoing work to extend the approach to other species, tag types and ocean basins.

Random Effects in WHAM: Use in Northeast US assessments: Tim Miller

In this talk, I briefly review the various ways random effects can be implemented in the WHAM software package, a state-space age-structured assessment modeling platform, we use in the Northeast US, and what random effects options are used in assessments for managed stocks. I then summarize conclusions from recent research on application of random effects in state-space age-structured assessment models including simulation studies carried out as part of a working group investigating the reliability of state-space assessment models.

The Essential Roles of Random Effects in Fish Stock Assessment: Anders Nielsen

A primary goal of fish stock assessment models is to provide outputs that are valuable for fishery management. Consequently, a key requirement is the ability to predict year-to-year changes in stock status and to quantify the accuracy of those predictions. At its most fundamental level, this is precisely what state-space models are designed to do. Furthermore, random effects --- the defining feature of state-space models --- offer elegant solutions to many persistent challenges in stock assessment. These include formulating flexible time-varying processes with a parsimonious number of parameters; handling missing observations; accounting for and predicting the effects of environmental variation; objectively weighting different data sources; partitioning observation error from process variation; and estimating variances of latent biological and fishery processes. While most applications to date have focused on biomass or age-structured models, the core benefits of the state-space approach --- particularly its ability to structure flexible processes and account for correlations --- are perhaps even more critical for length-based assessment models required for tuna stocks.

Age-Length-based Stock Assessments: Solution or Just Yet Dead End: André E. Punt

School of Aquatic and Fishery Sciences, University of Washington

Most fishery stock assessments are based on age- or size-structured population dynamics models and are fit to a variety of data sources. Stock assessments based on age-structured models are computationally less burdensome than those based on size-structured models but often require very strong assessments to fit to size-composition data, an important data source for many hard-to-age species. Stock assessment methods based on age-structured models also fail (generally) to account for changes in length-at-age due to size-selective fishing. In contrast, stock assessments based on size-structured models account for size-selective fisheries but generally cannot represent any age-specific processes and cannot fit to age-composition and conditional age-at-length data. Age-size-structured models can however overcome these concerns at the cost of increased computational demands. This talk contrasts how age-, size- and age-size-structured models are formulated and some of the consequences of an overlying simplistic model formulation. It then summarizes past studies on the performances of each type of assessment framework and highlights challenges associated with moving to stock assessment methods based on age-size-structured population models. These challenges can be divided broadly into: (a) selecting appropriate modelling assumptions, (b) reducing the computational burden, and (c) parameter estimation and data needs.

Quantitative modeling of the spatiotemporal dynamics of tuna populations: Inna Senina

SEAPODYM is a Eulerian modelling framework for describing basin-scale, spatiotemporal dynamics of migratory top predators under the influence of environmental variability and fishing. Today it is designed for quantitative modeling of the spatiotemporal and age-structured dynamics of tuna stocks. The underlying advection–diffusion–reaction equation with an ageing term (ADR-a), completed with appropriate initial and boundary conditions, is discretized on a regular grid and solved with an alternating-direction implicit method. The ADR-a describes three key dynamic processes being movement, reproduction, and mortality, which are environment-driven; the environment is represented by ocean forcings consisting of physical, biogeochemical variables and prey distributions.

To enable quantitative skills, the modelling framework includes parameter estimation, global sensitivity analysis, twin experiments, and likelihood profiling, and integrates multiple sub-models. Applications include: (i) simulations of population dynamics with or without exploitation; (ii) a tagged-fish movement model; (iii) spawning and feeding habitat models; and (iv) evaluation of stock connectivity across regions or EEZs. Parameter estimation (for applications i–iii) is done by minimizing the negative log-likelihood with a quasi-Newton optimizer and an exact analytical gradient provided by the model's adjoint code. Parameters are informed by geo-referenced fisheries data (catches and length compositions), tagging data, and early-life data. Adding non-fisheries data is essential, as relying on fisheries data alone can bias estimates toward high non-directional mixing (diffusion), weak directed movement (advection), and artificially elevated variability driven by local reactions. Incorporating tagging data improves estimates of environmental preferences and movement (both advection and diffusion) and reduces the amount of predicted unobserved biomass. Early-life data, although sparse, provide a valuable information on the spatial–seasonal distribution of spawning habitat and spawning biomass. Overall, maximum-likelihood estimates produce stock sizes consistent with those from the MULTIFAN-CL stock-assessment models in the Western and Central Pacific Ocean.

Because estimated population-dynamic parameters are invariant in space and time within this mechanistic framework, SEAPODYM can be validated against independent fisheries and tagging datasets. Once validated, it becomes a powerful tool for management: testing marine spatial planning scenarios, assessing environmental effects on recruitment and stock size, and projecting climate-change impacts on abundance and distribution at basin and regional scales. It can also support stock assessments by supplying movement rates, regional abundance indices, and indicators of fishery change (e.g., effort creep). These benefits come with challenges—in particular, high dimensionality, optimization non-linearity, parameter identifiability, and biases in oceanic forcings—which must be addressed to quantify uncertainty and to enable potential use for stock assessment.

Practical, scale-free, and generic approach to movement modelling: bridging from individual-based to population-scale dynamics: Jim Thorson

Population dynamics are driven by movement, but stock assessment has a limited toolbox for directly measuring or modelling movement relative to other ecological subfields. Here, I provide a quick introduction to advection-taxis models, which define a partial differential equation (PDE) where advection is driven by the gradient of a preference function ("taxis"). In particular, I discuss three numerical approaches for solving advection-taxis movement: using individual location as a variable (state-space Lagrangian models); discretized spatially at high resolution to solve as a Hidden Markov Model (archival tag track reconstruction); or discretized at low resolution within a "few-box" population-dynamics model. I claim that advection-taxis is a generic, parsimonious, and scale-free approach to model either fine-scale (individual-based) or coarse (population-dynamic) movement.

Stock assessment workflow using RTMB: Darcy Webber

Transitioning to RTMB has significantly streamlined stock assessment workflows for my team and me, offering seamless integration with R's ecosystem. By implementing models directly in R, we can encapsulate them into lightweight packages without relying on compiled code, thereby reducing package size, eliminating compilation delays, and enhancing portability. This approach harnesses R's robust tools, such as roxygen2 for function documentation, vignettes for comprehensive package overviews, test that for unit testing (easily automated via GitHub Actions), and access to an extensive library of R packages. In this presentation, I will showcase excerpts from three recent RTMB-based assessments: an age-structured model for southern bluefin tuna, a length-based model for New Zealand red rock lobster, and a combined age- and length-structured model for New Zealand bluenose. These examples illustrate how RTMB promotes reproducibility, collaboration, and rapid iteration in fisheries science.

Appendix 2 – Terms of Reference

TOR: Next generation tuna assessment software - core development-test-implement project

Part A: Administrative Summary	
1. Project Title	Next generation tuna assessment software - core development project
2. Organization	• Pacific Community
3. Administrative Contact	Paul Hamer/Graham Pilling (SPC)
4. Principal Investigators (PIs) and CVs	TBD – Technical Co-ordinator role see Collaborations section for likely collaborators
5. Commencement and Completion Date	Planned duration: 3 years *Commencement: [01/02/2027]* · *Completion: [31/12/2029]*
6. Project Budget Summary	Approx 2 x FTE Senior Science roles for 3 years, plus operating. USD: Year 1: $360,000, Year 2: $360,000, Year 3 $310,000 Total over 3 years: $1,030,000

Part B: Project Proposal Description	
1. Project Title	Next generation tuna assessment software - core development project
2. Background and Need	MULTIFAN-CL (MFCL) is reaching the end of its development life following the retirement of its lead developer, and Stock Synthesis 3 (SS3) development is winding down as NOAA shifts resources to its Fisheries Integrated Modeling System (FIMS). WCPFC tropical tunas and South Pacific albacore are currently assessed with MFCL; billfish and sharks with integrated assessments have transitioned to SS3. All WCPFC tuna, billfish and shark assessments are expected to require new software within roughly the next five years. The scoping phase of Project 123 (2024-2026) delivered opal (open population assessment library) as a proof of concept, demonstrating that R/RTMB-based, modular assessment software can be developed at a pace suited to WCPFC needs. This ToR covers the transition from scoping and proof of concept to development, testing and implementation.
3. Objectives and Benefits	To ensure WCPFC tuna, billfish and shark stock assessments remain robust and continue to provide the best available scientific information by advancing a state-of-the-art successor to MFCL. This phase aims to take opal from a proof of concept toward a platform capable of supporting operational assessments, while building regional scientific capacity and an open user community.
4. Note	This is the proposed second phase of the transition to new assessment software, following the 2024-2026 scoping phase. A project governance and delivery framework is proposed (WCPFC-SC22/2026-SA-WP01 Figure 2) and a 3-year workplan (WCPFC-SC22/2026-SA-

	WP01 Figure 3). The indicative budget in this TOR will likely require refinements following SC22 advice before submission to WCPFC23.
5. Rationale	The proposal is for a Pacific-led, tuna/tuna like species focused, open and collaborative development built on R and RTMB, giving the WCPFC direct influence over development timelines, priorities and features, and providing resilience against SPC staff turnover. It builds upon regional expertise rather than depending on software developed outside the region by non-tuna-focused teams. The development is not starting from scratch: it builds on the sbt package (CCSBT southern bluefin tuna) and draws design influences from other assessment packages including SS3 and MFCL. The decision not to depend on or formally join externally-governed developments such as FIMS reflects assessed constraints on influencing priorities and timelines within a larger program, and the collaboration and flexibility advantages of an R/RTMB code base relative to a C++ backend, noting RTMB's current computational trade-offs, which are expected to improve overtime.
6. Assumptions	WCPFC and or other donors commit funding for this phase; IATTC contributes staff time and collaboration; NOAA PIFSC continues its in-kind contribution; suitable consultants remain available; SPC hosts the technical coordinator and administrative support; RTMB continues to be developed and does not present a significant hurdle for the implementation of high-dimensional tuna models (this may require contributions from the DTU developers of RTMB); SPC assessment staff can contribute alongside their production assessment commitments; and converged MFCL/SS3 diagnostic-case inputs are available to seed case studies using the new software.
7. Scope of Work	Work is organized in three parallel workstreams. **<u>Core functionality for current production assessments</u>** ● added population dimensionality (space and sex); ● additional likelihood components (age composition, conditional age-at-length, tagging); ● biological and fishery reference points; ● diagnostic routines; ● a user interface; ● prior definitions; ● and code optimization. **<u>Research and model improvement (parallel, lower immediate operational priority)</u>** ● state-space dynamics, ● age-length dynamics, ● close-kin mark-recapture (CKMR), ● and a dynamic structural equation model (DSEM) module. **<u>Implementation</u>** A develop-test-implement approach running opal side by side with existing MFCL and SS3 assessments, converting converged diagnostic-case inputs into an opal-compatible format and benchmarking outputs. Single-region models are indicative candidates from 2027, with spatial

	structure added to the framework in 2028-2029 pending development of added population dimensionality. Implementation trials leverage benchmark assessments and are NOT intended to inform management advice. The model comparisons exist to demonstrate the software meets certain performance criteria and produces results that are comparable to the benchmark assessments using other software. The implementation trials may also run additional tests of features available in opal that are not available in the current software. Indicative case studies (subject to revision) for testing and feature development: ● ISC North Pacific blue shark, ● SWPO blue shark, ● South Pacific albacore, ● WCPO skipjack with an external tagging analysis, ● SWPO swordfish, ● WCPO bigeye tuna and yellowfin tuna, ● and South Pacific albacore. Supporting activities include establishing the governance and collaboration structure (steering committee, technical coordinator, developer hub), producing a prioritized requirements list to guide the development pathway, and putting in place collaboration, testing and versioning procedures.
8. Activity Schedule	

Activity / milestone (Indicative; to be aligned with WCPFC-SC22/2026-SA-WP01 Figure 3, and funding availability/timing)	2027	2028	2029
Establish and implement steering group/governance structure, coordinator, developer hub	X		
Develop prioritized requirements list	X		
Review progress & requirements		X	X
Core developments	Reference points, user interface, diagnostic routines, augment population dimensions	Age-length, state-space, integrate external tagging analysis	Integrate CKMR likelihood, TBD

<table>
<tr><td></td><td>
<table>
<tr><td>Research track</td><td>TBD</td><td>DSEM</td><td>TBD</td></tr>
<tr><td>Implementation track</td><td>NPO BSH, SPA, SWPO SWO (?)</td><td>SWPO BSH, WCPO SKJ + external tags</td><td>NPO SMA, WCPO BET (?), WCPO YFT (?)</td></tr>
<tr><td>Working paper to SC</td><td>X</td><td>X</td><td>X</td></tr>
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</td></tr>
<tr><td>9. Project Outcomes</td><td>By the end of 2029, opal supports single-region and spatially-structured configurations with the core likelihood components and reference points; has been benchmarked against MFCL and SS3 across multiple case studies; has been exercised in side-by-side implementation trials; operates under an established governance framework with documentation and a user interface; and is guided by a maintained, prioritized requirements list, with an ongoing resource and administrative an technical support base. Some research-track capabilities may carry into a subsequent phase.</td></tr>
<tr><td>10. Forms of Results</td><td>Working papers to SC23, SC24 and SC25; final project report to the WCPFC Secretariat; an open GitHub repository containing source code, examples and documentation; and a package documentation website.</td></tr>
<tr><td>11. Methods</td><td>Modular R/RTMB development on GitHub; a case-study-driven approach; cross-platform benchmarking against MFCL and SS3; unit testing; and application of Openscience practices for transparency and reproducibility.</td></tr>
<tr><td>12. Data Management Plan / Data Sets Required</td><td>Case study development will require examples of the data used in WCPFC tuna assessments. The SPC - TAF repository for YFT 2023, for example, demonstrates all the data types required for the early software development: catches, CPUE, length comps, weight comps, otoliths, and tagging data. TAF repositories from previous assessments are already online and available. Additionally, simulated datasets from the Indian Ocean YFT study (Goethel et al. 2024) can be used as a basis for evaluating the estimation performance of the statistical methods.

Data will be stored in GitHub repositories (small to medium size data), GitHub release assets (large data), or other data repositories (very large data).</td></tr>
<tr><td>13. Other Related Projects</td><td>DTU external tagging analysis (separate ToR; R&D track); CKMR development for South Pacific albacore (e.g., with CSIRO; R&D track); MSE work such as SWPO swordfish; and mfclrtmb. These are separately funded, in-kind, or leveraged from related project work. Case studies leverage of the WCPFC core assessments and project-funded assessment (i.e. sharks), by using the prepared data and biological information, plus they benefit from the learnings/model testing from those assessments using MFCL or SS3.</td></tr>
<tr><td>14. Collaborations</td><td>SPC (project coordination and assessment expertise); NOAA Fisheries PIFSC (Ducharme-Barth, in-kind); Quantifish (Webber); Dragonfly Data Science (Neubauer); IATTC (Maunder et al.). External collaborators from CCMs, academia and other tuna RFMOs subject to consideration by the</td></tr>
</table>

	technical coordinator and core development team. R&D collaborations include DTU (RTMB & tagging) and CSIRO (CKMR).
15. Project Staff and CVs	Core development: Nicholas Ducharme-Barth (NOAA PIFSC), Darcy Webber (Quantifish), Philipp Neubauer (Dragonfly), Nick Davies (Takina). SPC: Arni Magnusson, Kyuhan Kim, and other staff as available and depending on skillsets. IATTC: Mark Maunder, others TBC. Oversight and support: SPC-OFP - Paul Hamer, Graham Pilling, IATTC – Mark Maunder. Technical coordinator and administrative support (SPC-OFP, to be identified).
16. Risks of Project Not Achieving Objectives	Principal risks are funding uncertainty for the full program; RTMB computational limits at high dimensionality; staff turnover; and competition with production assessment workloads. Scope is managed through the prioritized requirements list and the separation of core, research and implementation workstreams. If elements prove infeasible, alternative approaches would be identified to meet the overriding objective.
17. Timeframe	Three years (2027-2029), within a broader transition to the new software by 2032.
18. Budget	As Part A, item 6. Indicative figures below to be refined post-SC22, with a costed 3-year budget prepared for WCPFC23. Indicative budget: **Year 1** Salaries/consultants 2 x FTE Senior Science level = 300K USD Operating (travel and administrative overheads) = 60K USD **Year 2** Salaries/consultants 2 x FTE Senior Science level = 300K USD Operating (travel and administrative overheads) = 60K USD **Year 3** Salaries/consultants 1.75 x FTE Senior Science level = 260K USD Operating (travel and administrative overheads) = 50K USD Summary Salaries/consultants: 860 K USD Operating (travel and administrative overheads) = 170K USD Total = $1,030,000 USD
19. References	• Ducharme-Barth et al. 2026 (SC22-SA-WP-02, opal) • Mildenberger et al. 2026 (SC22-SA-WP-03, tagging) • Davies et al. 2026 (SC22-SA-IP-02, MFCL) • Magnusson et al. 2025 (SC21-SA-WP-01) • Magnusson et al. 2024 (SC20-SA-WP-01) • CAPAM mini workshop report (SC22-SA-WP-01 Appendix 1) • Webber et al. 2026 (sbt) • Goethel et al. 2024 (Indian Ocean YFT simulation study)

	● Punt et al. 2020 (essential feature list for next generation software) ● FIMS (https://noaa-fims.github.io/FIMS/).

TOR: External skipjack tagging analysis - phase 2 project

Part A: Administrative Summary	
1. Project Title	WCPO skipjack external tagging analysis: phases 2 and 3 analyses for abundance indices and biomass estimation
2. Organization	• SPC (with subcontract to Technical University of Denmark - DTU)
3. Administrative Contact	Paul Hamer/Graham Pilling (SPC)
4. Principal Investigators (PIs) and CVs	Tobias Mildenberger and Anders Neilsen (DTU) Joe Scutt Phillips (SPC)
5. Commencement and Completion Date	Planned duration: 2 years *Commencement: [01/02/2027] · Completion: [31/12/2028]*
6. Project Budget Summary	Approx. 0.5 FTE Senior Research for 2 years, plus operating USD: Year 1: $110,000, Year 2: $110,000 Total over 2 years: $220,000

Part B: Project Proposal Description	
1. Project Title	WCPO skipjack external tagging analysis: phases 2 and 3 analyses for abundance indices, biomass estimation and preliminary test on skipjack assessment
2. Background and Need	WCPO assessments currently fit tagging data within an integrated model, which requires assuming that tagged fish are well mixed across broad regions, which is an assumption that is hard to meet and to which the assessments are sensitive. Following promising work in the Eastern Pacific Ocean (EPO), the WCPFC requested a proof-of-concept study (as part of WCPFC Project 123) on estimating movement by analysing WCPO SKJ tagging data externally to the assessment, using the fine-scale movement model admove. By modelling the redistribution of tagged fish in continuous space or on a fine grid, the approach relaxes the critical region-level mixing assumption. With limited resourcing available under project 123 the work so far has made good progress on the tag movement model, but this only the first phase, of three phases required to develop the external tagging analysis to the point where it could be utilised in an assessment. The full framework to provide movement, mortality, and biomass estimates for an assessment, requires two more phases; - Relative abundance estimation - Biomass estimation

	Trialling on a test case assessment such as the 2028 skipjack MFCL assessment would then be required to compare the fully tag data integrated assessment with an alternative using the external tag analysis approach. This proposal is to request funding support to complete these next two phase of external tag analysis and testing with the 2028 skipjack assessment, as a full test of the external tagging analysis approach compared to the MFCL tag integrated modelling. Also noting the general difficulties in modeling tag data within integrated assessment are not unique to skipjack. External tag analysis is important to cross-check external tag-based biomass scales against the influence on tag data on population scaling within the integrated assessments (skipjack, yellowfin and bigeye). Further, the current skipjack CPUE abundance indices derived from the equatorial free school purse seine would benefit from cross-checking against a tag-based index. The free school purse seine index also can only start from 2010 as it depends on VMS travel distance as an effort metric, whereas external tag base index could extend back to the early 2000's. External tag analysis can provide estimates of mortality, relative abundance and biomass, albeit at more restricted spatial areas, that could be used as indicators independent of the full stock assessment, i.e. in MP monitoring strategies. Finally, the capability to use the external tag analysis to provide external derived parameters or priors greatly simplifies the complexity required with the next generation assessment software, and will further fast track the implementation of that new software on WCPFC assessments.
3. Objectives and Benefits	1. Complete external skipjack tag analysis phase 2 – develop abundance indices 2. Complete external skipjack tag analysis phase 3 – develop biomass estimation 3. Test the use of external tag analysis outputs on the 2028 skipjack assessment Benefits discussed in Background and Needs - increased confidence in the use of tag data to inform status, increased flexibility with modelling options (including software development needs), provides stock indicators independent of a full stock assessment.
4. Note	
5. Rationale	Improved use of tagging data in stock assessment is important to make best and appropriate use of these valuable data and increase confidence in the influence of tag data on stock status indicators for monitoring and management advice.
6. Assumptions	DTU PIs Mildenberger and Neilsen remain available, sufficient funding is provided, the required data can be provided by SPC.
7. Scope of Work	1. Complete external skipjack tag analysis phase 2 – develop abundance indices 2. Complete external skipjack tag analysis phase 3 – develop biomass estimation

<table>
<tr><td></td><td>3. Test the use of external tag analysis outputs on the 2028 skipjack assessment

Provide writing progress reports on each of the above, and a final report, all provided to WCPFC SC, regular meetings with SPC co-PI and administrative contact.</td></tr>
<tr><td>8. Activity Schedule</td><td><table>
<tr><th>Activity / milestone</th><th>Months</th></tr>
<tr><td>Year 1 - 2027:
- Develop abundance indices
- Progress report to SC23</td><td>6</td></tr>
<tr><td>Year 2 – 2028:
- Jan-August - develop biomass estimation
- Progress report to the SC24
- August – Dec - Test the use of external tag analysis outputs on the 2028 skipjack assessment
- December: Final report (also delivered to SC25)</td><td>3

3</td></tr>
</table></td></tr>
<tr><td>9. Project Outcomes</td><td>Completion of the full framework for external tag data analysis to provide movement, mortality, and biomass estimates for the WCPO skipjack assessment. Test the application of the external tag analysis on the next (2028) skipjack assessment for comparisons against the benchmark MFCL tag integrated model.</td></tr>
<tr><td>10. Forms of Results</td><td>Reports, papers, presentations, GitHub repository.</td></tr>
<tr><td>11. Methods</td><td>See SC22 paper – WCPFC-SC22-2026-SA-WP-03 pages 3-6, for background and higher-level summary of the methods/approaches.</td></tr>
<tr><td>12. Data Management Plan / Data Sets Required</td><td>SPC holds all the required data and will be collaborating on this with DTU analysts. All the work can be tracked and will be available on a GitHub repository.</td></tr>
<tr><td>13. Other Related Projects</td><td>Pending funding, the development of the next generation tuna assessment stock assessment software – i.e. opal project – will have close linkage with this project. The WCPFC funded PTTP – Pacific Tuna Tagging Programme is directly liked to this proposal as the key data source for the analysis and the future data source for application of the methods/models developed. There are linkages with projects by the IATTC also collaborating with DTU – a joint research initiative/collaboration on this work area needs to be explored to see if cost-efficiencies can be increased.</td></tr>
<tr><td>14. Collaborations</td><td>The main collaboration is between DTU and SPC, but we would explore a wider collaboration with IATTC – SPC – DTU.</td></tr>
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<table>
<tr><td>15. Project Staff and CVs</td><td>Tobias Mildenberger https://www.researchgate.net/profile/Tobias-Mildenberger-2
Anders Nielsen https://www.researchgate.net/profile/Anders-Nielsen-25
Joe Scutt Phillips https://www.researchgate.net/profile/Joe-Scutt-Phillips</td></tr>
<tr><td>16. Risks of Project Not Achieving Objectives</td><td><table><tr><th>Risk</th><th>Mitigation</th></tr><tr><td>Modeling approach fails</td><td>Proof-of-concept already provided and examples of application in the EPO skipjack assessment.</td></tr></table></td></tr>
<tr><td>17. Timeframe</td><td>Total duration 2 years</td></tr>
<tr><td>18. Budget</td><td>Indicative budget:
Year 1
Salaries/consultants
0.5 x FTE Senior Science level = 70K USD
Operating (travel and administrative overheads) = 40K USD

Year 2
Salaries/consultants
0.5 x FTE Senior Science level = 70K USD
Operating (travel and administrative overheads) = 40K USD

Total
$220,000 USD</td></tr>
<tr><td>19. References</td><td>Tobias K. Mildenberger, Anders Nielsen, Arni Magnusson, Joe Scutt Phillips, Paul Hamer (2026) Skipjack tagging data preliminary analysis, review and recommendations for further development and application. WCPFC-SC22-2026-SA-WP-03</td></tr>
</table>