Mixed-fishery harvest strategy update

WCPFC-SC19-2023/MI-WP-07 rev 1

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- Table A.2. updated with SKJ MP and purse seine.

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Executive Summary

WCPFC12 agreed to a workplan for the adoption of harvest strategies for WCPO skipjack, bigeye, yellowfin and South Pacific albacore tuna. An important consideration when developing harvest strategies for these stocks is to account for mixed-fishery interactions. SC15 agreed to initially consider a multi-species framework for developing mixed-fishery harvest strategies. Under this framework, fisheries are managed through single stock MPs for skipjack, South Pacific albacore and bigeye.

This report provides an update on the mixed-fishery modelling framework.

Despite the many technical complexities and challenges, recent work suggests that the modelling framework remains tractable and paves the way for all four tuna stocks to be included in the modelling framework. WCPFC-SC17-2021/MI-WP-05 demonstrated how skipjack, bigeye and yellowfin can be included in the mixed-fishery modelling framework. WCPFC-SC18-2021/MI-IP-05 described a proof of concept implementation of also including South Pacific albacore in this framework by focusing on the albacore and bigeye interactions. WCPFC-SC18-2022/MI-WP-07 presented the results of some preliminary mixed-fishery performance indicators for skipjack, bigeye and yellowfin.

Noting the harvest strategy workplan schedules the agreement of Target Reference Points (TRP) for WCPO bigeye and yellowfin at the Commission meeting in 2024, this paper provides some discussion points for SC19 consideration.

Catches of yellowfin in archipelagic waters have increased in recent years. The efficacy of the mixed-fishery framework at achieving management objectives for yellowfin can be examined using similar approaches to that for skipjack when considering catches in archipelagic waters.

The next steps for developing the mixed-fishery harvest strategies include:

- Further considering South Pacific albacore MPs for the southern longline fishery;
- Further developing the operating models for South Pacific albacore;
- Building a full suite of operating models for bigeye and yellowfin;
- Considering candidate bigeye MPs for the tropical longline fishery
- Including all four stocks in the mixed-fishery modelling framework;
- Refining and continuing to develop the mixed-fishery performance indicators.

We invite WCPFC-SC to:

- Note progress in development of mixed-fishery harvest strategies;
- Consider development of bigeye and yellowfin target reference points.

1   Introduction

WCPFC12 agreed to a workplan for the adoption of harvest strategies for WCPO skipjack, bigeye, yellowfin and South Pacific albacore tuna. An important consideration when developing harvest strategies for these stocks is to account for mixed-fishery interactions (Scott et al., 2019b). SC15 agreed to initially consider a multi-species framework for developing mixed-fishery harvest strategies (WCPFC, 2019). Under this framework, fisheries are managed through single stock management procedures (MPs) for skipjack, South Pacific albacore and bigeye. A detailed overview of the mixed-fishery framework is given in Scott et al. (2022a) and the Appendix to the current paper.

The single stock MPs control the fishing opportunities for different WCPO fisheries by setting catch or effort limits based on status estimates of the associated stock (Table A.2).

Each fishery is controlled by one of the three single stock MPs but each fishery may catch a range of tuna stocks. Purse seine, pole and line, and fisheries of Indonesia, Philippines and Vietnam (referred to here as domestic fisheries) are managed through the skipjack MP (an interim skipjack MP was adopted by the WCPFC at the end of 2022) (WCPFC, 2022). The tropical longline (TLL) fisheries are potentially managed through the bigeye MP and the southern longline fisheries (SLL) potentially managed through the South Pacific albacore MP. The impact of these MPs on yellowfin would then be evaluated using a combined evaluation framework to identify whether the mixed-fishery framework can simultaneously achieve management objectives for the stocks. Fisheries in archipelagic waters are not managed through the MPs.

This approach should be regarded as an initial attempt at considering multi-species and mixed fisheries with the harvest strategy approach. If this approach is found to be unsuccessful, in terms of achieving objectives for all four stocks, alternative approaches will need to be developed. It is stressed that the definition and classification of the WCPO fisheries to different MPs under this approach is an initial proposal, and that alternative classifications may also be considered. However, it is also noted that under the interim skipjack management procedure adopted by the WCPFC at the end of 2022, the fisheries managed by the skipjack MP follow those described under the mixed-fishery approach (WCPFC, 2022).

A simple metric of the recent impact of a fishery on a stock is the proportion of total catches by weight taken by that fishery, averaged over the last three years of the most recent assessment for each stock. The total proportions of recent average total catches by stock that would potentially be managed through each single stock MP under the proposed mixed-fishery framework can then be calculated (Table 1). It should be noted that the catch proportions presented in Table 1 do not take into account the selectivity patterns of the fisheries or whether a fishery is catching juvenile or adult individuals, which can impact the stock in different ways. Proportions assigned to the archipelagic waters are taken from the WCPFC Annual Catch Estimates.

Table 1: Percentage of recent catch weight for each stock, based on the average of the last three years of the most recent stock assessment, that would be managed by each management procedure (MP) or come from archipelagic waters and would not be managed through a WCPFC MP. The most recent assessments are: skipjack (SKJ) - 2022 (data up to 2021); South Pacific albacore (SPA) - 2021 (data up to 2019); Bigeye (BET) - 2023 (data up to 2021); Yellowfin (YFT) - 2023 (data up to 2021).

Stock	SKJ MP	SPA MP	BET MP	AW
SKJ	80			20
SPA		87	13	
BET	38	4	43	15
YFT	41	3	13	43

Apart from those catches in archipelagic waters, all of the skipjack catches are from fisheries that are managed through the skipjack MP. The majority of catches of South Pacific albacore are from fisheries that are managed through the South Pacific albacore MP. There are some catches of South Pacific albacore from fisheries that are managed through the bigeye MP (the tropical longline fishery, considered to be operating down to 10 degrees South).

The bigeye catches are mostly split between fisheries that are managed through the bigeye MP and those that are managed through the skipjack MP, with an additional component coming from archipelagic waters. Fisheries managed through the South Pacific albacore MP make up only a small proportion.

Under the proposed mixed-fishery framework, there is no single stock MP for yellowfin. Instead yellowfin is managed through the other single stock MPs. The majority of yellowfin catches are from fisheries that are managed through the skipjack MP or are from archipelagic waters, with the remainder mostly from fisheries that are managed through the bigeye MP, and a small proportion from fisheries that are managed through the South Pacific albacore MP. It is worth noting that the proportion of catches of yellowfin in archipelagic waters has been increasing in recent years.

From a stock specific impact point of view, the information presented in Table 1 supports the current WCPFC workplan of developing single-species management strategy evaluation (MSE) simulation frameworks for skipjack and South Pacific albacore that do not consider mixed fishery interactions. However, any candidate MPs developed using single-species MSE in this way will need to be tested with the mixed fishery MSE to fully evaluate their performance to ensure they are effective in achieving the objectives across the range of stocks affected by those fisheries.

2 Development of the mixed-fishery modelling framwork

Before an MP is adopted, the relative performance of candidate MPs, including their robustness to uncertainty, can be tested using MSE (Punt et al., 2014; Scott et al., 2019a). In MSE modelling frameworks, the biological dynamics of the stocks and the fishery interactions are simulated by operating models (OMs) that provide a virtual "true" representation of how the fish stock reacts to different amounts of fishing and allows the simulation of the impacts of changes to fishery management. Under the proposed mixed-fishery framework, the tuna stocks will be modelled by individual single stock OMs, i.e. there will be individual OMs for skipjack, bigeye, yellowfin and South Pacific albacore (Scott et al., 2019b).

To perform the evaluations it is necessary to set the future effort or catch of each fishery in the OMs using the output of the MP that manages that fishery. Some fisheries for a stock are managed through the MP of a different stock. For example, the pole and line fisheries in the bigeye and yellowfin OMs are managed through the skipjack MP. One of the key challenges for the simulations is therefore including the interactions between the OMs and the MPs.

An MP may use either catch or effort to set the fishing opportunities for the fisheries it controls. In order to transfer the fishery dynamics between OMs the fishing opportunity is converted to the common metric of fishing effort. This means that for a catch controlled fishery, the amount of effort required to take the specified catch must be determined so that the effort for that fishery can be used as an input in another OM. For example, the realised effort made by the tropical longline fisheries to take the bigeye catch limit set by the bigeye MP is also applied in the yellowfin OM and results in the yellowfin catch consistent with the underlying stock biomass.

Several assumptions will need to be made to run the simulations, for example, continued application of the FAD closure for the purse seine fishery and treatment of fisheries in archipelagic waters and territorial seas. It is important that these assumptions are clearly defined and presented to stakeholders in a transparent manner to facilitate input on the modelling, and ultimately management, decisions. Currently, it is assumed that fisheries in archipelagic waters are not managed through any WCPFC MP.

Implementing this mixed-fishery modelling framework presents several technical challenges. Recent work suggests that these challenges can be addressed and the modelling framework remains tractable. This work paves the way for all four tuna stocks to be included in the mixed-fishery modelling framework.

Progress in the development of the mixed-fishery modelling framework is described below.

2.1 Including skipjack, bigeye and yellowfin in the mixed-fishery modelling framework

In line with the harvest strategy workplan, work initially focused on the development and evaluation of the skipjack MP. As noted above, the skipjack MP sets fishing opportunities for fisheries that also catch bigeye and yellowfin (Table 1 and Table A.2). One of the technical challenges to overcome was therefore to include skipjack, bigeye, yellowfin in the same modelling framework. A proof-of-concept implementation was shown in WCPFC-SC17-2021/MI-WP-05 that explores the impact of the choice of skipjack MP on the bigeye and yellowfin populations (Scott et al., 2021).

In this proof-of-concept implementation there was no dynamic bigeye MP and the catch limit of the tropical longline fishery, that would be managed through the bigeye MP in the mixed-fishery framework, remained constant at the average of 2016-2018 levels. South Pacific albacore was not included in this modelling framework. Instead, bigeye catches by the southern longline fishery were also held constant at recent levels. The modelled interactions between the OMs is shown in Figure 1.

The evaluations for each stock were performed in sequence. The skipjack evaluations were run independently as all the fisheries in the skipjack OM are managed through the skipjack MP. The resulting fishing effort of the purse seine, domestic and pole and line fisheries was then transferred and used as inputs in the bigeye evaluations. Finally, the yellowfin evaluations could be run using the fishing effort of the purse seine, domestic, pole and line and longline fisheries from the skipjack and bigeye evaluations as inputs.

This work demonstrates that the technical challenges involved in implementing the mixed-fishery modelling framework can be addressed and the modelling framework remains tractable.

The approach will need to be updated as the work progresses. For example, the modelling framework in WCPFC-SC17-2021/MI-WP-05 assumed that the pole and line fisheries would be managed through the setting of catch limits. However, the interim skipjack MP adopted by the WCPFC sets effort limit for these fisheries (WCPFC, 2022). This should make modelling the interactions between the skipjack and the bigeye and yellowfin OMs simpler.

2.2 Including South Pacific albacore in the mixed-fishery modelling framework

WCPFC-SC18-2022/MI-IP-05 presented a proof-of-concept implementation for including South Pacific albacore in the mixed-fishery modelling framework, focusing on the albacore and bigeye interactions (Scott et al., 2022a).

In the mixed-fishery framework the South Pacific albacore MP sets the fishing opportunities for the southern longline (SLL) fisheries that also catch some bigeye (Table A.2). Similarly, the bigeye MP sets the fishing opportunities for the tropical longline (TLL) fisheries that also catch some South Pacific albacore. Fully incorporating these interactions requires the albacore and bigeye simulations
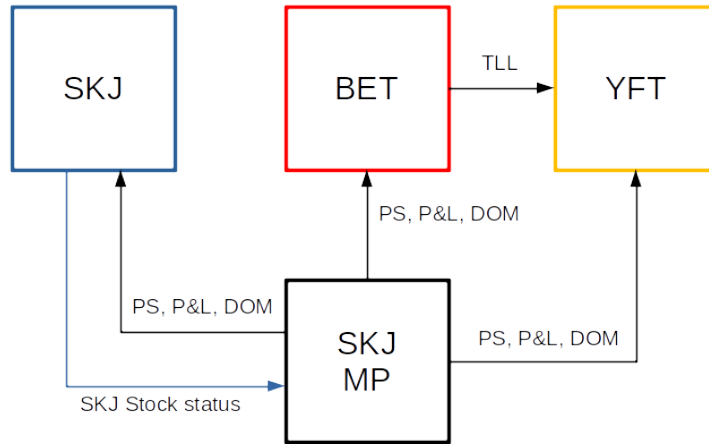
Figure 1: Schematic of the skipjack (SKJ), bigeye (BET) and yellowfin (YFT) evaluations presented in WCPFC-SC17-2021/MI-WP-05. The skipjack management procedure (MP) sets the fishing opportunities for the purse seine (PS), pole and line (P&L), and domestic (DOM) fisheries in the skipjack, bigeye and yellowfin models, given the stock status of skipjack. The fishing operations of the tropical longline fisheries (TLL) are determined by bigeye catch limits and need to be transferred to the yellowfin model. Future evaluations will use a bigeye MP to set TLL catches. The skipjack simulations are run first, then the resulting dynamics of the PS, P&L and DOM fisheries are transferred to the bigeye and yellowfin models. The bigeye simulations are then run and the resulting dynamics of the TLL fisheries are transferred to the yellowfin models. The yellowfin simulations can then be run.

to be run simultaneously where the result of each simulation influences the other. This leads to significant computational complexities that are very difficult to resolve.

Recent catches of bigeye by fisheries that would be managed by the South Pacific albacore MP are only a small portion of the total bigeye catch (Table 1). This means that the potential impact of the albacore MP on the bigeye stock is likely to be small enough that it can be ignored in the bigeye evaluations without materially affecting the results. Instead, in the bigeye evaluations assumptions about the level of bigeye catches from the southern longline fisheries can be made.

A similar approach can be taken with the impact of the South Pacific albacore MP on the yellowfin stock, given the low proportion of catches of yellowfin by the southern longline fisheries (Table 1).

These simplifications makes the mixed-fishery modelling framework technically tractable without materially changing the results. However, the assumptions would need to be carefully monitored in the monitoring strategy.

The proof-of-concept evaluations in WCPFC-SC18-2022/MI-IP-05 implemented within the framework are shown in Figure 2. In the evaluations there was no dynamic bigeye MP, i.e. one that sets fishing opportunities for the tropical longline fisheries based on the stock status of bigeye. Instead, the bigeye catch limit of the tropical longline fisheries was set as a square wave to provide variation in catches. The resulting fishing effort and subsequent impact were realised in the South Pacific
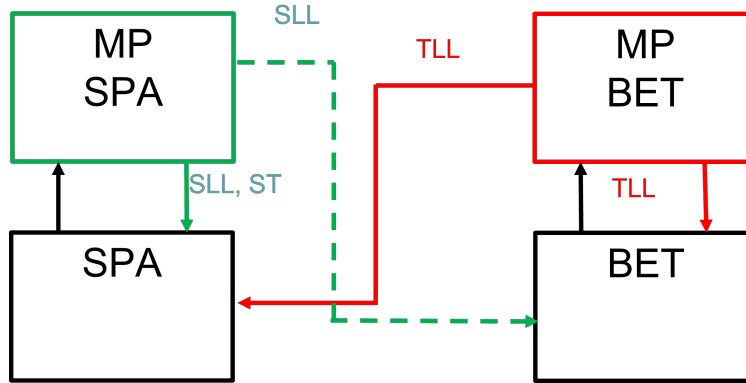
Figure 2: Schematic of the evaluations presented in WCPFC-SC18-2022/MI-IP-05. The South Pacific albacore (SPA) stock is taken by the southern longline (SLL) and southern troll (ST) fisheries, managed through the albacore managment procedure (MP). The bigeye (BET) stock is taken by the tropical longline (TLL) fishieres that are managed through the bigeye MP. By not including the albacore MP in the bigeye evaluations (i.e. removing the the dashed green line), the modelling framework becomes tractable. Otherwise, the albacore and bigeye evaluations need to be run simultaneously, presenting technical difficulties. Assumptions need to be made about the levels of bigeye catch taken by the southern longline fisheries.

albacore model. There was also no skipjack MP. Instead the fishing effort of the purse seine, domestic and pole and line fisheries in the bigeye model were taken from existing skipjack evaluations. The catches of albacore and bigeye by the southern longline fisheries were held constant at recent levels.

The evaluations for each stock were run in sequence. By not including the South Pacific albacore MP in the bigeye evaluations the bigeye simulations can be run independently of the albacore simulations, but will still depend on the output of the skipjack simulations and assumptions about levels of bigeye catch by the southern longline fishery. The fishing effort made by the tropical longline fishery to take the bigeye catch limits set by the bigeye MP is then transferred and used as an input to the albacore evaluations.

These proof-of-concept evaluations pave the way for all four tuna stocks to be included in the mixed-fishery modelling framework (Scott et al., 2022a). Given the dependencies between the stocks described in Scott et al. (2021) and Scott et al. (2022a), the mixed-fishery simulations can be performed by running the skipjack simulations first, then the bigeye simulations, and then the South Pacific albacore and yellowfin simulations, transferring the resulting fishery dynamics from one model to another.

2.3 Performance indicators

Understanding the potential impacts of MP selection on stocks requires the calculation of mixed-fishery performance indicators. For example bigeye is caught by fisheries that would be managed by the skipjack and bigeye MPs. The selection of the preferred bigeye MP will therefore need to

consider the potential impact of the skipjack MP on the bigeye stock. As there is no dedicated yellowfin MP, there will be a need for particular focus on the potential combined impacts of the skipjack, bigeye and albacore MPs on the yellowfin stock.

WCPFC-SC18-2022/MI-WP-07 presented the results of some preliminary indicators for skipjack, bigeye and yellowfin (Scott et al., 2022b). The evaluations were performed using the framework presented in WCPFC-SC17-2021/MI-WP-05 using a range of skipjack MPs (Scott et al., 2021). In the evaluations there was no dynamic bigeye MP. Instead, three bigeye "MP"s based on scenarios for constant future levels of bigeye catch by the tropical longline fisheries were evaluated. Evaluations were performed for each combination of the skipjack and bigeye MPs.

Four performance indicators were calculated for each stock: probability of $SB/SB_{F=0}$ falling below the Limit Reference Point; expected $SB/SB_{F=0}$; expected catches; and the 'impact' of each MP on each stock.

Given the potentially large amount of information that can be calculated with the mixed-fishery performance indicators it will be important to only focus on the key interactions between the different single stock MPs.

Another key consideration is how to present these indicators. In particular, the catch and impact indicators can be calculated over many different dimensions, e.g. different model regions and fisheries, making them potentially challenging to interpret. Noting that the role of indicators is to support the selection of preferred MPs, careful consideration must be given as to how useful these indicators are. If an indicator is unclear, or presents information that is difficult to interpret, then it should not be considered further.

The mixed-fishery performance indicators will need to be developed through consultation with WCPFC members.

3 Challenges and uncertainties

Developing the mixed-fishery modelling framework presents several technical challenges and requires assumptions to be made.

By not including the South Pacific albacore MP in the bigeye evaluations, the mixed-fishery modelling framework is slightly simplified (Figure 3).

The South Pacific albacore evaluations can almost be run independently. However, there will be some level of albacore catches taken by the tropical longline fisheries, which would be managed by the bigeye MP (Table 1). Assumptions will need to be initially made about the level of albacore catch taken by the tropical longline fisheries, noting that the evaluations may need to be rerun when developing the bigeye MP to determine if these assumptions are appropriate.

The bigeye evaluations depend on the skipjack evaluations to provide inputs for the purse seine,
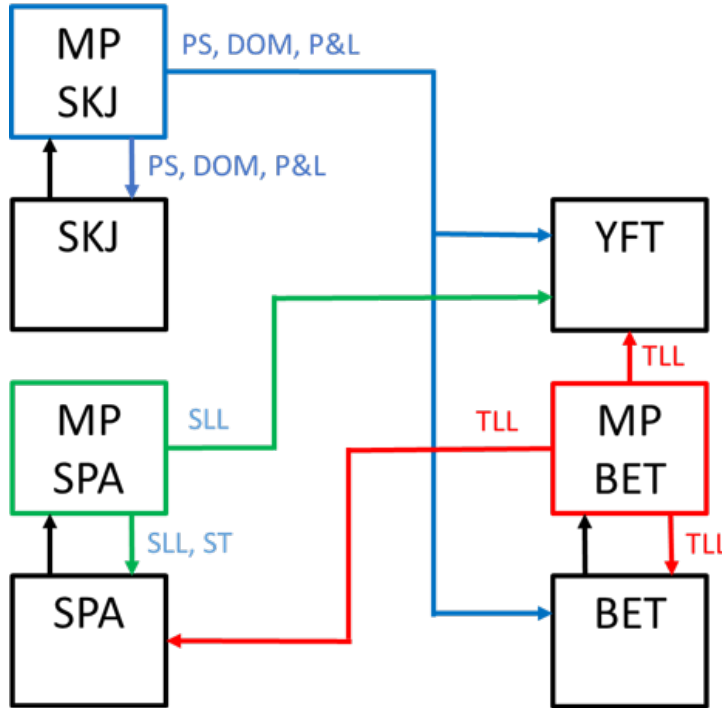
Figure 3: Updated schematic of the proposed mixed-fishery modelling framework, describing which single stock management procedures (MPs) impact which stocks and which fisheries they would manage. By not including the albacore MP in the bigeye evaluations, the modelling framework becomes tractable.

domestic and pole and line fisheries. By not including the albacore MP in the bigeye evaluations, assumptions will need to be made about the catches of bigeye by the southern longline fisheries (e.g. average of recent levels), noting these are small.

Finally, the yellowfin evaluations can be run using the fishing effort of the purse seine, domestic, pole and line and longline fisheries from the skipjack, bigeye and albacore evaluations as inputs.

A decision will need to be made on the timing of the MPs. For example, should all three MPs be used to determine new levels of catch or effort for the next management period in the same year, or should they be staggered, i.e. one MP is evaluated every year under a three year cycle? It should be noted that it is preferred that the MP for a stock is not evaluated in the same year as the main stock assessment. The timing may be influenced by the mechanism through which the outputs of the MPs are implemented. For example, if the Tropical Tuna CMM (TT-CMM) is the mechanism by which the outputs of the bigeye and skipjack MP are implemented there may be a case for running both MPs in the same year, to avoid frequently re-opening the TT-CMM.

The choice of mechanism through which the fishery impacts the stock will be controlled by management, e.g. catch or effort limits, has implications for the implementation of the projections. For example, the MP for bigeye may set the future level of tropical longline bigeye catch, rather than the future effort.

The skipjack evaluations that led to the adoption of the interim skipjack MP assumed that the archipelagic waters of Papua New Guinea, Indonesia, Philippines and Vietnam were not managed through the single stock MPs. Similar assumptions will need to be made when running evaluations for the other stocks. While the proposed mixed-fishery modelling framework captures the potential impact of many of the main fishing gears, when considering yellowfin the activity of the 'other' fisheries that catch yellowfin needs to be carefully considered. Noting that much of this catch is from small scale gears operating within archipelagic waters, a decision on the feasibility of their inclusion within any MP, or assumptions to be made for these fisheries, is needed, noting that they are included under the adopted interim skipjack MP based on skipjack catch (WCPFC, 2022). Catches of yellowfin in archipelagic waters have increased in recent years. The efficacy of the mixed-fishery framework at achieving management objectives for yellowfin can be examined using similar approaches to that for skipjack when considering catches in archipelagic waters. Ultimately, as these are sovereign waters, each relevant CCM will decide on their approach (e.g. adopt the MP's decisions, compatible measures, etc.), which can be modelled within the framework.

Single stock OMs will need to be developed for each of the four tuna stocks. These OMs comprise a grid of models that have been conditioned to capture the main sources of uncertainty. OMs for skipjack already been developed and OMs for South Pacific albacore have been proposed (Scott et al., 2022c, 2023). When conditioning the grid of OMs for the single species models, all combinations of the different conditioning factors are considered. For the mixed-fishery evaluations, care will need to be taken to avoid 'factorial explosion' that can occur by considering all levels of all factors across the OMs of all stocks. One option is to decide on how many simulation replicates are required and then randomly sample that number independently from the available OMs for each species. It will mean that some OM combinations do not get sampled, and that there is a possibility that some will be sampled more than once. Additionally, it may be possible to identify correlations between model grid options to reduce the possible combinations of factors between stocks.

4   Development of target reference points for bigeye and yellowfin tuna

The harvest strategy workplan schedules the agreement of target reference points (TRPs) for WCPO bigeye and yellowfin for the Commission meeting in 2024. Work to inform these TRPs will likely rely on the assessments for these stocks presented to SC19. For the timeline to be maintained, some discussion to frame the subsequent work around TRP values is warranted at SC19.

In the past, SC has identified candidate TRP levels for each of the tropical tuna stocks for consideration by Commission members (e.g. SPC-OFP, 2022a,c). However, the mixed-fishery approach, and the experience gained through the adoption of the skipjack MP, raise some points for SC consideration.

For skipjack, the management procedure and target reference point were adopted simultaneously

within CMM 2022-01, so that the TRP value was in part consistent with the desired 'baseline' settings for the key fisheries exploiting the stock within the MP.

For bigeye:

- Does the Commission wish to identify the bigeye TRP stock level that achieves desirable outcomes, so that an MP can be designed to achieve it on average? This implies pursuing the approach where the implications for stock and fishery of different candidate TRPs are examined, and would require candidate TRP levels to be defined for evaluation.
- In a similar approach to that for skipjack, does the Commission wish to identify 'baseline' levels for the MP (e.g. FAD closure duration, longline catch levels) that will help define the TRP?
- Given that most of the fisheries taking bigeye are under MP control, either directly or through the mixed-fishery approach, it is anticipated that a single TRP value will represent the level around which the stock should fluctuate. However, the points made below for yellowfin may also apply.

Yellowfin does not have its own MP under the current mixed fishery framework. Therefore:

- Will the yellowfin TRP largely be an emergent property of the other MPs, noting that not all fisheries taking yellowfin will be controlled within the mixed-fishery framework?
- Related to this point, how will the catch of relevant components of 'other fisheries' be dealt with within these evaluations?
- Given not all major fisheries catching yellowfin are controlled through the mixed-fishery approach, some consideration of the nature of the yellowfin 'TRP' may be worthwhile to ensure that desirable management objectives can be achieved:
  - Will the yellowfin TRP represent a single value around which the stock should fluctuate, as for skipjack and bigeye?
  - Will it be represented by a range of depletion levels within which the stock should be maintained, rather than a specific TRP value?
  - Will it be represented as a threshold level over which the stock should be maintained (comparable to the approach of defining a minimum stock size compatible with a given permissible level of risk, and the current nomenclature within CMM 2021-01)?

Acknowledgments

A Overview of the mixed-fishery framework

This appendix is adapted from Scott et al. (2019b), Scott et al. (2020), Scott et al. (2021) and Scott et al. (2022a).

Including mixed-fishery interactions in a harvest strategy can be challenging. Recognising this, the agreed WCPFC harvest strategy workplan proposed that the initial focus be on skipjack, followed by South Pacific albacore, and then bigeye and yellowfin. This is because skipjack and South Pacific albacore are mainly caught by a single dominant fishery (purse seine and southern longline respectively) and so single stock evaluations could initially be developed.

Progress has been made towards developing single stock MSE simulation frameworks for these stocks including the adoption of an interim MP for skipjack and proposed operating models for South Pacific albacore (WCPFC, 2022; SPC-OFP, 2022b; Scott et al., 2023).

Table A.2: Proposed integration of stock-based management procedures (MPs) across fisheries under the multi-species modelling framework.

WCPO fishery	Skipjack	Yellowfin	Bigeye	South Pacific albacore
Tropical PS	SKJ MP	SKJ MP	SKJ MP	
Northern PS	SKJ MP	SKJ MP	SKJ MP	
Tropical LL		BET MP	BET MP	BET MP
Northern LL		BET MP	BET MP	
Southern LL		SPA MP	SPA MP	SPA MP
Pole and line	SKJ MP	SKJ MP	SKJ MP	
ID/PH/VN (non-AW)	SKJ MP	SKJ MP	SKJ MP	
Southern Troll				SPA MP
Archipelagic waters and territorial seas	Aligned to SKJ MP, national plan or local MP	Aligned to SKJ / BET MPs, national plan or local MP	Aligned to SKJ / BET / SPA MPs, national plan or local MP	Aligned to SPA MP, national plan or local MP.

The mixed-fishery framework involves developing prospective single stock MPs for skipjack, South Pacific albacore and bigeye. The impact of these MPs on yellowfin would then be evaluated using a combined evaluation framework to identify whether the mixed-fishery framework can simultaneously achieve management objectives for the stocks. If not, alternative approaches will need to be developed. Any candidate MPs developed using single-species MSE will need to be tested with the mixed fishery MSE to fully evaluate their performance. It is worth noting that recent bigeye and yellowfin target reference point evaluations suggest that it is possible for these stocks to be

sustainably managed if purse seine and longline fishing levels are kept at recent status quo levels (Pilling et al., 2019; Hare et al., 2022).
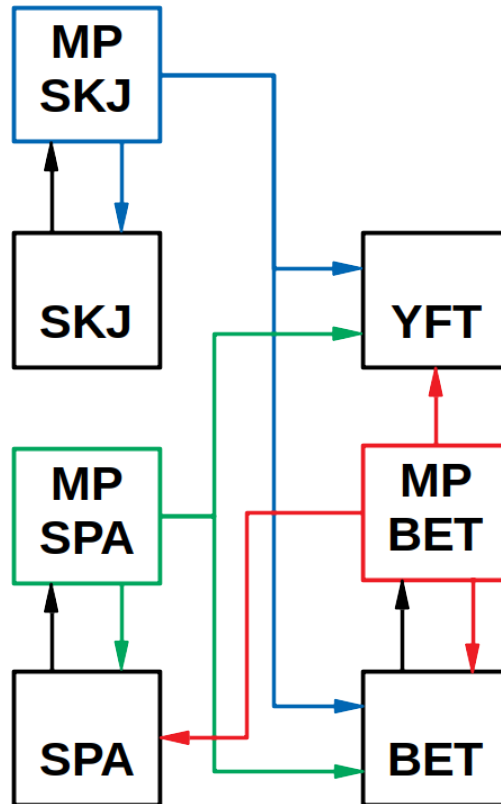

Figure A.4: Schematic of the combined modelling framework used in the hierarchical approach. The management procedures (MP) for the different stocks are signified by the different colours. The stocks that are impacted by the different MPs are shown by the connecting coloured lines. For details of which fisheries are being controlled by which MP and impact which stocks see the accompanying table. The black arrows show the estimated stock status feeding into the MP to set fishing opportunities.

The three single stock MPs control the fishing opportunities for different WCPO fisheries by setting catch or effort limits based on status estimates of the associated stock (Table A.2 and Figure A.4). Each fishery is controlled by one of the three single stock MPs. However, that fishery may catch a range of tuna stocks. It is noted that the definition and classification of the WCPO fisheries to different MPs under this approach is an initial proposal, and that alternative classifications may also be considered.

In Table A.2 the longline fisheries are divided into three categories: northern, tropical and southern. Under the mixed-fishery framework these fisheries are managed through different stock-based MPs. The proposed latitudinal range over which these fisheries operate is given in Table A.3. Although Table A.2 makes a distinction between northern and tropical purse seine, the mixed-fishery modelling framework assumes that they are both managed through the skipjack MP so the latitudinal range of these fisheries does not need to be specified.

Table A.3: Proposed latitude range of the different longline fisheries and the associated single stock management procedure that would manage it.

Fishery	Latitude range	Management procedure
Northern LL	20N - 50N	Bigeye
Tropical LL	10S - 20N	Bigeye
Southern LL	South of 10S	South Pacific albacore

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