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SOUTH PACIFIC ALBACORE MANAGEMENT STRATEGY EVALUATION FRAMEWORK

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South Pacific albacore management strategy evaluation framework

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WCPFC-SC15-2019/MI-WP-08

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Executive Summary

In this paper we describe the current status of the management strategy evaluation (MSE) framework for South Pacific albacore. We provide details of the analyses that have been conducted to inform the development of the framework so far following discussions at SC14, and highlight areas for additional work that will need to be undertaken. For the initial development of the framework, work has been focussed in two specific areas; the conditioning and selection of models for the operating model reference set and the design of candidate harvest control rules (HCRs) that use CPUE as the biomass signal.

We present an initial proposal for the range of model settings that will comprise the operating model reference set, which is closely related to the uncertainty grid of the 2018 stock assessment, but are yet to identify scenarios for the robustness set of models.

Axis	**Levels**		**Options**		
	Reference	Robustness	**0**	**1**	**2**
Process Error					
Recruitment Variability	**1**		**1982-2014**		
Observation Error					
Catch and effort	**1**		**30%**		
Model Error					
Steepness ‡	**3**		**0.8**	**0.65**	**0.95**
Natural Mortality ‡	**2**		**0.3**	**0.4**	
Growth ‡	**2**		**estimated**	**fixed, Chen-Wells**	
Size freq wtg ‡	**1**		**50**		
CPUE ‡	**2**		**geo-statistics**	**traditional**	
Implementation Error					
Scenarios to be developed					

South Pacific albacore operating model (OM) uncertainty grid. Scenarios shown in bold are proposed for the reference set. ‡ denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required.

The South Pacific albacore MSE framework represents the first to focus on CPUE as the driver for the management procedure. To this end the paper presents a 'proof of concept' of this framework. We outline a preliminary design for the management procedure and two preliminary HCRs, both of which use CPUE as the primary source of information for controlling future catches. We note that the settings assumed for these preliminary evaluations have been somewhat arbitrarily chosen and we seek advice and recommendations from SC15 on any additional factors that will need to be considered for developing the framework and any alternative settings that may be more appropriate for South Pacific albacore.

The settings for the evaluations have been selected based on the type and style of settings used in other analyses. Further consideration of these settings is recommended to ensure that the most appropriate values for South Pacific albacore are used for future evaluations.

Axis	**Setting**
Management period	3 years
Projection period	30 years
Years for catch scaling	2014:2016
Years for HCR CPUE calculations	last 5 years
Reference CPUE year	2008
Management quantity	catch
Managed fisheries	all fisheries

Table. Settings for the South Pacific albacore proof of concept MSE.

In particular we seek advice from SC15 on:

- whether the sources of uncertainty considered for conditioning the operating models are sufficient and if any further scenarios should be included in the grid.
- whether the ranges of parameter values specified in OM grid reflect our uncertainty in the dynamics of the stock.
- whether the settings assumed for the MSE (Table 2) are considered appropriate or if alternative settings should be considered.
- any additional HCR designs or features that should be included (e.g. HCR formulations, catch constraints, management periods, etc.).

In addition SC may wish to re-seek advice from WCPFC on the following issues:

- whether the fishery should be managed through catch or effort controls, or some combination of the two.
- whether the HCR should apply to all fisheries or a selected subset of fisheries.

1 Introduction

To support the development of a roadmap for the implementation of the harvest strategy approach for South Pacific albacore, SC14 considered technical aspects of the southern longline fishery with specific regard to developing a management procedure (Pilling et al., 2018). The technical aspects considered included management reference points, the methods for estimating the status of the resource and the design of potential harvest control rules. SC14 endorsed an initial focus on empirical-based estimation methods, using catch per unit of effort (CPUE) as the biomass signal, with a secondary focus on model-based approaches. It also endorsed the use of longline CPUE as the primary information source for the estimation method, noting that empirical measures such as CPUE may better align with economic objectives. Subsequently, WCPFC15 adopted an interim target reference point (TRP) for South Pacific albacore of 56% $SB_{F=0}$, with the objective of achieving an 8% increase in CPUE for the southern longline fishery as compared to 2013 levels (WCPFC, 2019; para 207).

In this paper we describe the current status of the MSE framework for South Pacific albacore. We provide details of the analyses that have been conducted to inform development of the framework so far following discussions at SC14, and highlight areas for additional work. For the initial development of the framework, work has been focussed in two specific areas; the conditioning and selection of models for the operating model reference set and, given that this is the first time they has been included within a WCPO management procedure, the design of preliminary HCRs that use CPUE as the biomass signal, as a proof of concept.

The framework described in this paper forms a functioning prototype for South Pacific albacore. To illustrate the design and functioning of the framework we present some results from initial evaluations but stress that these results are preliminary and are shown only as an indication of the type and style of information that will be output. The results of these preliminary evaluations have also been used for the calculation of illustrative performance indicators for the southern longline fishery, which are presented in SC15-MI-WP-03.

1.1 MSE Framework

The harvest strategy approach provides a framework for taking the best available information about a stock or fishery and applying an evidence- and risk-based approach to setting harvest levels. A key element of the harvest strategy approach are harvest control rules (HCRs) that determine how much fishing can take place given the status of the target stock. It is recommended that candidate HCRs are tested, prior to implementation in the fishery, to determine the extent to which they achieve defined management objectives. The most widely adopted process for testing HCRs (and management procedures) prior to implementation is based on simulation analysis and is termed management strategy evaluation (MSE).

A more comprehensive overview of the MSE framework is provided in Scott et al. (2018a). In brief, the MSE evaluation framework (Figure 1) is constructed from two main components, an operating model (OM) and a management procedure (MP). The OM is a mathematical representation of the "true" system, rather like a stock assessment. It simulates the fishery by attempting to capture all existing knowledge and data processes for the exploited populations and associated fisheries.

Our knowledge of the dynamics of populations and fisheries is often incomplete. The OM allows us to evaluate the consequences of this uncertainty by testing management performance against different hypotheses about those dynamics. In this respect a suite of different OMs should be identified, each one representing a plausible alternative hypothesis. Very often the OMs will include a greater level of complexity than that used for the stock assessment so that all important sources of uncertainty might be appropriately included in the evaluation process.

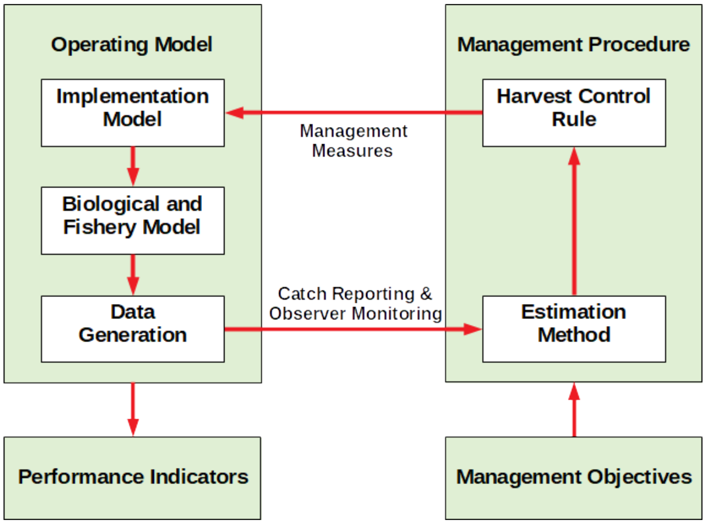


Figure 1: Conceptual diagram of the MSE framework.

2 Albacore in the WCPO

The selection of operating models is informed by our understanding of the biology and the dynamics of the fishery. We provide a brief review of current knowledge of South Pacific albacore and the southern longline fishery. A number of studies provide information on the biology (Murray, 1994; Ramon and Bailey, 1996; Williams et al., 2012; Farley et al., 2014), stock status (Tremblay-Boyer et al., 2018), and fisheries (Williams and Terawasi, 2015; Brouwer et al., 2019) for albacore in the south Pacific Ocean. It is beyond the scope of this report to provide a detailed review of this information. At this stage we simply highlight those aspects of the albacore fishery that may have some bearing on the type and scope of uncertainty that will need to be considered when evaluating candidate harvest control rules.

2.1 Albacore biology

2.1.1 Spatial distribution and stock identity

Albacore are found throughout the South Pacific from the equator to 50°S latitude and from the surface to depths of 300m. Albacore tuna in the South Pacific Ocean are considered to comprise a single discrete stock (Murray, 1994). Very low longline catch rates of albacore in the equatorial region would suggest that there is little mixing between the northern and southern hemisphere populations and tag and recapture data for albacore, although limited, support this assumption. Some studies, using parasite faunal patterns (Jones, 1991) and genetic markers (Takagi et al., 2001; Montes et al., 2012) have suggested further stock structure exists within the South Pacific albacore population however tag recapture information indicates wide scale mixing of adult albacore throughout the South Pacific Ocean.

Albacore in the South Pacific exhibit a marked seasonal migration between feeding grounds in the subtropical convergence zone in the south and spawning grounds in the sub-equatorial regions with movement models indicating relatively high adult advection rates of around 1.0 body lengths per second (Lehodey et al., 2013). Albacore spawning takes place during the austral summer in tropical and sub-tropical waters between latitudes 10°S and 25°S. The juveniles progressively move south towards the coastal waters of New Zealand and generally eastwards along the sub-tropical convergence zone (STCZ) (Murray, 1994) and are believed to move back into sub-tropical waters during the austral autumn. A seasonal migration between tropical and sub-tropical waters has been inferred from monthly trends in longline catch rates (Langley, 2004) although the true nature of albacore migration within the south Pacific remains somewhat obscure. Lehodey et al. (2013) suggest that two separate migration paths may exist with a north-south pattern in the Coral Sea and west Pacific and another following the border of the gyre in the east.

2.1.2 Environmental drivers of productivity

Seasonal movement patterns in albacore appear to correspond with the seasonal shift in the 23-28°C sea surface temperature isotherm location. Sea temperature and dissolved oxygen concentration appear to be important factors that determine optimum feeding habitat (Lehodey et al., 2013) and consequently growth, however the full relationship between environment and the productivity of the stock is not fully known.

2.1.3 Growth, maturity and natural mortality

Daily otolith growth increments indicate that initial growth is rapid, with albacore reaching 45 - 50 cm (FL) in their first year (Leroy and Lehody, 2004). Subsequent growth is slower, at approximately 10 cm per year from ages 2 to 4, declining thereafter. Maximum recorded length is about 120 cm

(FL). Albacore exhibit significant variation in length at age both between the sexes and also spatially (Williams et al., 2012). Growth trajectories are similar for both sexes up to around 4 years of age after which the males grow at a faster rate, reaching a maximum length that is more than 8cm larger than the females. In addition, length at age and growth parameters have been found to be greater at easterly longitudes for both males and females.

Further spatial variation in albacore population structure is apparent in the seasonal and spatial distribution of mature females. Females at more northerly latitudes (where spawning occurs) mature at smaller lengths and ages than females at more southerly latitudes, particularly during the spawning season (Farley et al., 2014). The predicted length at 50% maturity is around 87cm fork length (4.5 years).

The instantaneous rate of natural mortality is believed to be between 0.2 and 0.5 per year. The values assumed in the most recent assessment were 0.3 and 0.4 per year, partly influenced by assessments of albacore in other regions. Both the current MULTIFAN-CL stock assessment (Tremblay-Boyer et al., 2018) and recent SEAPODYM models (Lehodey et al., 2013) exhibit strong sensitivity to the assumed rate of natural mortality.

2.2 The South Pacific Albacore Fishery

Brouwer et al. (2019) and Tremblay-Boyer et al. (2018) provide an overview of the development and current status of the albacore fishery in the South Pacific. Longline fisheries account for the majority of the catch. Catches are distributed over a wide area of the South Pacific but concentrated in the west with less than 20% of the albacore catch being taken east of 150°W. Troll catches are distributed mostly in the coastal waters of New Zealand. The longline fishery catches adult albacore in a relatively narrow size range (90-105cm) whilst the troll fishery takes smaller, juvenile fish (45-80cm). Juvenile albacore are also taken from time to time in the longline fishery.

The most recent assessment of the stock of South Pacific albacore was conducted in 2018 (Tremblay-Boyer et al., 2018) and used data for the period 1960 to 2016. The assessment comprised 21 fisheries across five regions that covered the South Pacific Ocean from the equator to 50°S and from 140°E to 130°W. Uncertainty in the assessment was characterised by a grid of 72 models with varying assumptions for key model settings. The key areas of uncertainty for the assessment were associated with natural mortality, growth rates, the steepness of the stock and recruitment relationship, the relative weighting to be applied to length composition data and the methods for standardising CPUE information.

While the key stock assessment results across all models in the structural uncertainty grid of the stock assessment show a wide range of estimates, all models indicate that South Pacific albacore is above the limit reference point (of 0.2 $SB_{F=0}$), with overall median depletion for 2016 (SBrecent / $SB_{F=0}$) estimated at 0.52 (80 percentile range 0.37-0.69).

3 The Operating Model

3.1 Conditioning the Operating Model

Conditioning an operating model (Rademeyer et al., 2007) involves fitting the model to data in much the same way that a stock assessment model is fit to the available catch, size composition and tag recapture data. The primary objective of conditioning the operating model is to characterise and adequately account for all important sources of uncertainty in the assessment, monitoring and management of the stock. By including all important sources of uncertainty in the evaluation framework we aim to find the management procedure that performs best and is robust to that uncertainty. An approach for conditioning operating models for WCPFC stocks using MULTIFAN-CL has previously been described in Scott et al. (2018b). Comparable to the approach used for skipjack, our primary source of uncertainty is guided by the uncertainty grid of the most recent stock assessment.

3.1.1 Accounting for Uncertainty

Stock assessments conducted by the Pacific Community (SPC) present a range of model configurations, termed the uncertainty grid, that explore the sensitivity of assessment results to alternative assumptions about model settings for which the data are often uninformative. The grid for the 2018 South Pacific albacore assessment is shown in Table 1. Management advice is then based on the resulting range of stock status values across the whole uncertainty grid.

Axis	**Code**	**Levels**	**Options**		
			0	**1**	**2**
Steepness	A	3	0.8	0.65	0.95
Natural mortality	B	2	0.3	0.4	
Growth	C	2	Estimated	Fixed (Chen-Wells)	
Size freq. wtg	D	3	20	50	80
CPUE	E	2	Geo-statistical	Traditional	

Table 1: South Pacific albacore 2018 stock assessment uncertainty grid (Tremblay-Boyer et al., 2018).

The stock assessment uncertainty grid is a useful starting point for considering the range of uncertainty that should be included in the suite of OMs for the MSE analyses. However, the assessment uncertainty grid is concerned primarily with those factors that impact the historical trajectory of the stock, as estimated by the stock assessment. When projecting assessment results forwards in time, as performed by the MSE simulations, it may be necessary to consider a different set of sensitivities in order to adequately capture the most important sources of uncertainty. In the following sections we examine the range of biological and fishery uncertainties for South Pacific albacore in light of the existing uncertainty grid.

3.1.2 Data Sources

An important consideration for the OM is the availability and quality of future data. The South Pacific longline fishery accounts for around 98% of the total albacore catch (Brouwer et al., 2018). The stock assessment of the albacore in the WCPO relies heavily on the CPUE indices derived from the South Pacific longline which, for the stock assessment, have been subdivided into distant-water longline (DWFN) and Pacific Island Countries and Territories (PICT) fleets. The DWFN fleets have targeted albacore since the 1960's and effort of PICT domestic longline fleets have increased significantly since the mid-1990's. Data for troll fisheries operating around New Zealand are also available. 21 fisheries for 5 regions are included in the stock assessment.

3.1.3 Model Error

Model error results from the mis-specification of the model structure. Parameter error refers to the possibility that the parameters used to define the model are incorrect, given that the model form is correct. In this paper we combine the two error types into a single category of model error. The sources of model error outlined here are based largely on the range of uncertainties considered for the 2018 stock assessment. Five primary sources of uncertainty have been identified.

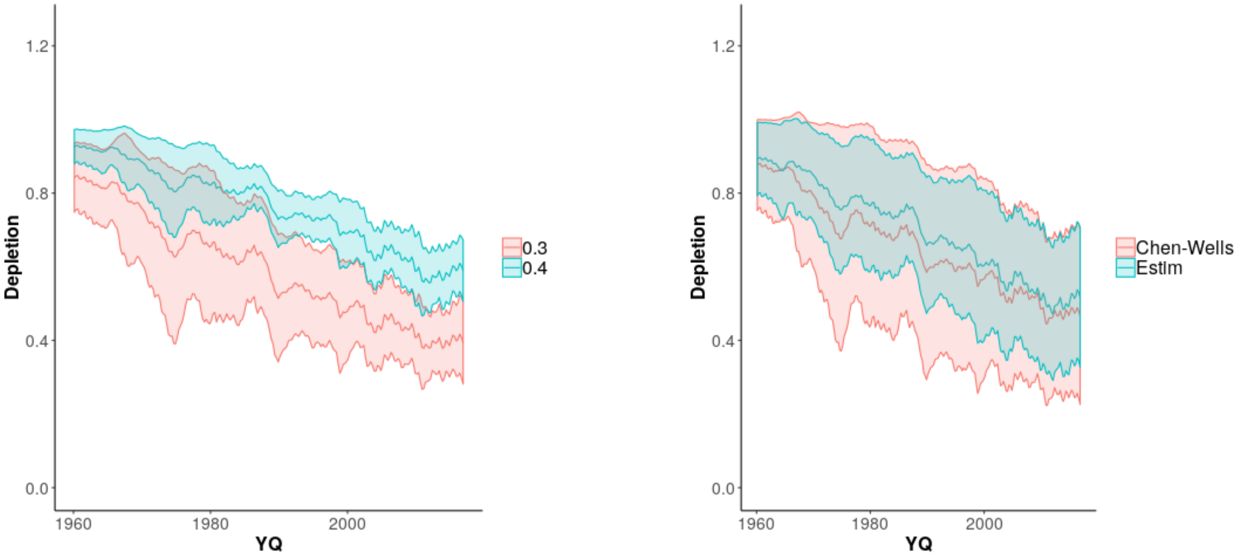
Natural Mortality

The level of natural mortality is considered a key area of uncertainty for the assessment of South Pacific albacore. As for previous assessments, the 2018 stock assessment assumed a fixed, age-invariant natural mortality. Values ranging from 0.2 to 0.5 were examined with values of 0.3 and 0.4 being carried forward to the uncertainty grid. In addition, the stock assessment considered a sex combined version of the natural mortality assumed for the assessment of North Pacific albacore and a Lorenzen based approach that relates mortality to the size of individuals within a species.

In general, higher values of natural mortality led to more optimistic estimates of depletion and lower natural mortality to more pessimistic estimates. Assessment runs using intermediate values of either 0.3 or 0.4 resulted in a broad range of terminal estimates of depletion across the grid of models and these have been included in the proposed MSE uncertainty grid.

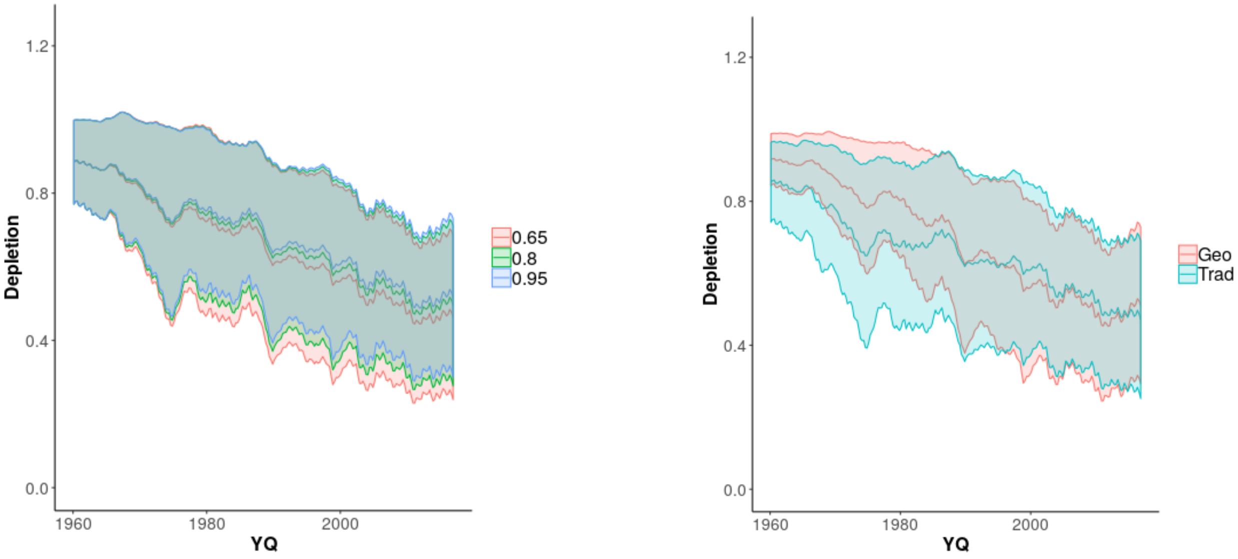
Growth

Growth rate continues to be a major source of uncertainty for the assessment of South Pacific albacore. The 2018 assessment considered two alternative growth models (von Bertalanffy and Chen-Wells) both of which provide a poor fit to age-at-length data for the troll fishery. Potential explanations for this discrepancy include the potential for either spatial variation in growth rates,



(a) Natural mortality

(b) Growth model



(c) Steepness of the SRR

(d) CPUE standardisation method

Figure 2: Estimates of depletion (dynamic, $SB/SB_{F=0}$) for the axes of model uncertainty carried forward to the MSE uncertainty grid.

whereby albacore in the southern regions grow more slowly than those closer to the tropics, or alternatively, temporal variation in juvenile growth rates (Tremblay-Boyer et al., 2018).

At present, the possibility to include alternative growth models, or to allow for spatial and temporal variation in growth, does not exist in MULTIFAN-CL. We retain the settings for uncertainty in growth as specified for the stock assessment grid but note that further work is required in this area to more appropriately model growth rates for South Pacific albacore.

Steepness

For assessments of WCPFC tropical tuna stocks, steepness of the stock and recruitment relationship (SRR) is typically fixed to a moderate level (0.8) for the diagnostic case with two further levels (0.65 and 0.95) also tested in sensitivity runs. This set of values has been determined based on the results of the meta-analysis conducted on tuna stock-recruitment data and has been well established in previous Scientific Committees. The sensitivity results show that different values of steepness for the SRR introduced very little variation into the historical estimates of adult biomass (Figure 2c) However, these settings are retained within the reference set of models as steepness will be an important source of uncertainty when conducting projections.

CPUE standardisation

Two methods were used to standardize CPUE indices for the 2018 South Pacific albacore stock assessment; a “traditional” approach, as used in previous assessments for this stock and an approach based on geostatistics. The difference between the two approaches was most apparent for the early estimates of stock status, prior to 1990. Estimates of stock status for more recent years was broadly similar for the two approaches. In spite of this we have retained the CPUE standardisation within the reference set of models. The projected CPUE from the operating model will form a critical component of the MSE for south Pacific albacore and all potential sources of uncertainty for these data should be retained at this stage.

Length Frequency Weighting

The weighting applied to the length frequency data was also considered for inclusion in the uncertainty grid. The results of the stock assessment show that the variability introduced from this source of uncertainty was generally lower than for the other factors considered. For these preliminary evaluations we consider only a single length frequency weighting but retain this axis in the grid should it require further consideration in future evaluations.

3.1.4 Process Error

Process error arises through natural variability in the biotic and abiotic processes that impact on population dynamics. These processes are difficult, if not impossible, to predict but can have a significant impact on the state of the resource. The simplifying assumption is typically made that future variability will be consistent with the variability observed over some historical period. A common approach when conducting projections is to run multiple iterations with future variability imposed through re-sampling of the historical deviates from a fitted stock and recruitment relationship. The period over which this historical sample is taken and the extent of variability that it covers is therefore an important consideration when running stochastic projections (Pilling et al., 2016) and is a key consideration when testing the robustness of HCRs.

For these initial evaluations we resample annual recruitment from the fitted historical estimates of recruitment for the period 1982 to 2014. Alternative periods may be considered in future work.

3.1.5 Observation Error

Observation error is the difference between a measured value of a quantity and its true value. It includes natural errors that occur in any data collection procedure as well as systematic errors (affecting all measurements) that can arise from, for example, the miscalibration of instruments. Observation error is a key source of uncertainty and a particularly important consideration with respect to the input data to the management procedure. For this evaluation framework the key input data to the MP comprise fishery specific estimates of catch and effort. We assume a 30% CV for both catch and effort noting that improved approaches for incorporating observation error into catch and effort data are under development (see Section 6).

3.1.6 Implementation Error

Implementation error has been included in Table 2 although at this stage no scenarios have been identified for it. In evaluation frameworks for other stocks and fisheries we have considered uncertainties associated with the dynamics of the fisheries. We note that the southern longline fishery may be subject to changes over time in fleet structure and fishing technology that may impact the activity and behaviour of fleets that operate in the fishery. We seek guidance from SC on whether this is considered an important source of uncertainty and, if so, on the types of scenarios that might be considered for the southern longline fishery.

3.2 Reference and Robustness Sets

It is considered best practice to divide the suite of OMs into a reference set and a robustness set (Rademeyer et al., 2007). The reference set is considered to reflect the most plausible hypotheses and forms the primary basis for identifying the 'best' management strategy. The robustness set comprises hypotheses that are considered less likely but still plausible. Performance indicators are calculated from the reference set whilst the robustness set will be used to give a secondary indication of the performance of the management strategy.

We present here an initial proposal for the range of model settings that will comprise the reference set (Table 2) but have not yet identified scenarios for the robustness set.

Axis	**Levels**		**Options**		
	Reference	Robustness	**0**	**1**	**2**
Process Error					
Recruitment Variability	**1**		**1982-2014**		
Observation Error					
Catch and effort	**1**		**30%**		
Model Error					
Steepness ‡	**3**		**0.8**	**0.65**	**0.95**
Natural Mortality ‡	**2**		**0.3**	**0.4**	
Growth ‡	**2**		**estimated**	**fixed, Chen-Wells**	
Size freq wtg ‡	**1**		**50**		
CPUE ‡	**2**		**geo-statistics**	**traditional**	
Implementation Error					
Scenarios to be developed					

Table 2: South Pacific albacore OM uncertainty grid. Scenarios shown in bold are proposed for the reference set. ‡ denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required.

4 The Management Procedure

The management procedure (MP) is a set of rules used to determine management actions in which the data, the methods for analysing the data (including the method of stock assessment, if used) as well as the HCR are pre-specified (Butterworth et al., 1997). Two types of MP can be distinguished:

- **Empirical MPs** where resource monitoring data (e.g. CPUE) are input directly to the HCR with minimal processing.
- **Model-based MPs** where an assessment model is used to generate an estimate of stock status.

In the case of South Pacific albacore, initial work has focussed on developing an empirical MP that uses CPUE as the primary indicator of stock status (Yao et al., 2019a). As this work develops, model-based approaches that employ relatively simple assessment models (e.g. surplus production models) may also be considered. These approaches rely heavily on the use of CPUE data and are consistent with the focus of recent discussions for the southern long-line fishery on catch rates and fleet profitability, as reflected in the economic management objectives that were noted at WCPFC14 (see WCPFC14, attachment K) and in the basis for the TRP that was agreed at WCPFC15 (see WCPFC15, para 207).

4.1 CPUE as an index of stock status

The CPUE achieved by a fishery can provide an indirect measure of stock status. Where CPUE is considered to be a reliable indicator of stock status it can be used as a direct input to a harvest control rule to determine future management action for a fishery. Previous reports to SC have outlined a range of considerations that should be taken into account when selecting and using a CPUE series within a management procedure (Pilling et al., 2018). The key necessary features include:

- The data represent a key fleet or combined fleets whose catch rates reflect regional, rather than local or seasonal, abundance.
- Fleet composition should be relatively stable, with reasonable consistency in targeting over time/within the year (or a consistent pattern of seasonal targeting).
- The existing time series should cover a sufficient (and appropriate) period to allow analysis.
- Data are readily available for the historical period and into the future.
- To reduce time lags, data should be available soon after fishing is completed.
- High coverage operational level data should be available, verifiable through consistent and representative observer coverage (and e.g. electronic monitoring) and catch verifiable through unloading data.

The most recent stock assessment of South Pacific albacore (Tremblay-Boyer et al., 2018) employs a combination of raw and standardised CPUE information. For each region of the assessment model, longline fisheries were divided into DWFN, PICT and where applicable (regions 2 and 3) Australia and New Zealand. Catches for these fishery categories were expressed in numbers of fish and effort as hundreds of hooks.

4.1.1 CPUE series selection

The selection of an appropriate CPUE series to 'drive' the HCR is one of the biggest challenges faced when developing empirical CPUE based management procedures. The use of raw (nominal) CPUE in the management procedure is the simplest and most transparent approach although the management procedure may perform better if the CPUE are subject to some level of pre-analysis before being passed to the HCR. CPUE can be influenced by many factors such as vessel targetting behaviour, vessel performance and environmental factors that can all vary over time or space. For this reason, CPUE time series inputs for stock assessments are often standardised to try to remove these influences and better reflect the underlying stock biomass. The better the selected CPUE series reflects overall biomass, the better the management procedure is likely to perform.

As noted, this is the first WCPO harvest strategy to be driven by CPUE. For the proof of concept evaluations outlined in this paper we have used the CPUE for the PICT longline fishery in assessment region 2, (as input to the stock assessment). The temporal trend in CPUE for this series is very similar to that of the DWFN series (Figure 3), particularly for the most recent years, although neither series appears to track the trend in estimated adult biomass (all regions combined) particularly well. While the selected series is sufficient for this proof of concept example, further work is recommended to identify a more appropriate CPUE series for future evaluations.

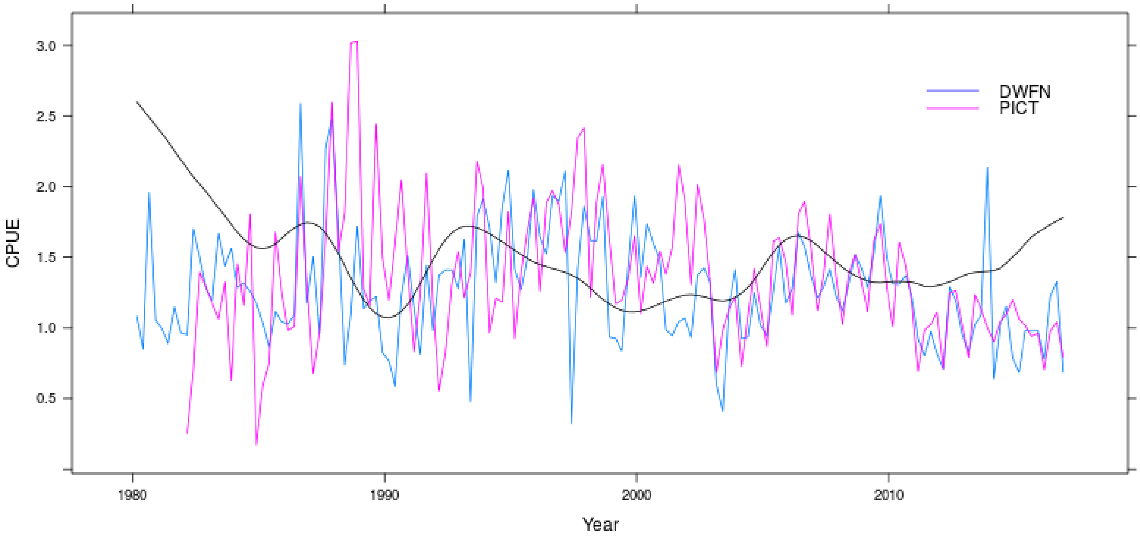


Figure 3: CPUE for DWFN and PICT fisheries in assessment region 2. The smoothed trend of relative biomass for all regions (black line) is overlaid.

4.2 HCR Design

The design of the HCR can take many different forms. We present two potential HCRs here, noting that both of them could be further modified, and that other designs can be developed. The HCRs presented here are i) a very simple single step HCR that relates recent CPUE directly to fishing opportunity, and ii) a two step HCR that additionally takes into account the recent trend in CPUE. Both HCRs return a catch scaler that determines catches for the next management period.

The settings for both HCR 1 and HCR 2 have been chosen arbitrarily and are presented here merely to illustrate a possible approach.

4.2.1 HCR 1

HCR 1 is based on a simple linear relationship between relative CPUE and the resulting catch scaler. Here $\overline{CPUE}$ is the average CPUE over the last 5 years, $CPUE_{ref}$ is the CPUE for some reference period and g is a gain parameter that determines how reactive the HCR is (see Figure 4).

$$Scaler = g * \frac{CPUE}{CPUE_{ref}} + (1 - g) \tag{1}$$

The resulting catch scaler is then applied as a multiplier to some pre-defined catch level. The scaler can optionally be capped to maximum and minimum values (Figure 4) to prevent excessively large changes in fishing opportunities from one management period to the next.

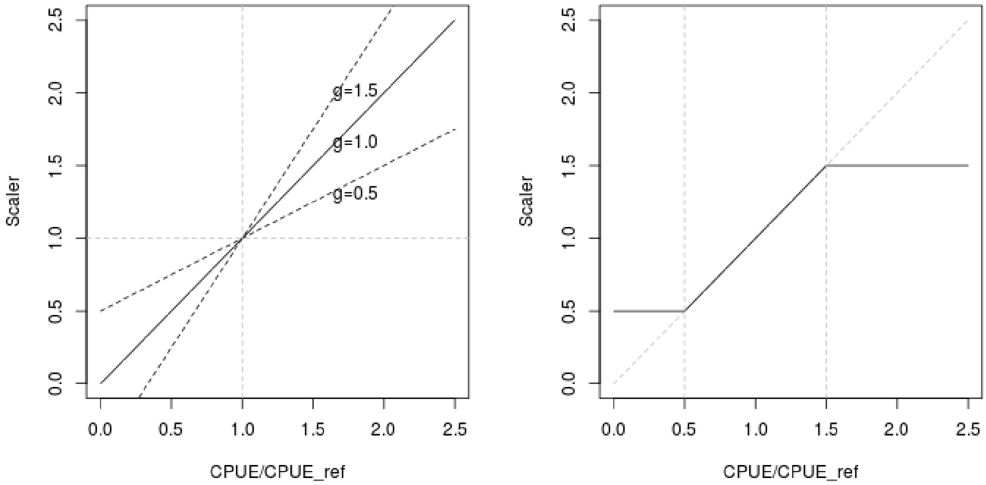


Figure 4: Simple harvest control rule that relates fishing opportunity (catch scaler) to relative CPUE (recent CPUE relative to CPUE in some reference period). The slope of the line can be modified to make the scaler more or less responsive to changes in CPUE (dotted lines, left panel). The HCR could also be modified to have upper and lower bounds on the catch scaler (right panel).

4.2.2 HCR 2

HCR 2 has two components, each returning a catch scaler. Similar to HCR 1, the first scaler is determined from the ratio of CPUE to the CPUE of some reference period, where $CPUE$ and $CPUE_{ref}$ are defined in the same way as for HCR 1. This first part of the rule has just 3 outcomes: if relative CPUE is close to the target CPUE, catches are unchanged, otherwise they are scaled up or down by 30% accordingly.

$$Scaler.1 = \begin{cases} 1.2 > \frac{CPUE}{CPUE_{ref}}, & 1.3 \\ 0.8 < \frac{CPUE}{CPUE_{ref}} < 1.2, & 1.0 \\ 0.8 > \frac{CPUE}{CPUE_{ref}}, & 0.7 \end{cases} \tag{2}$$

The second component calculates the gradient of a straight line fitted to the time series of CPUE for the last 5 years (see Figure 5). If CPUE is increasing the gradient of the line will be positive and the scaler will be greater than 1. Conversely, if CPUE is decreasing the gradient will be negative and the scaler will be less than 1.

$$Scaler.2 = 1 + g * gradient + (1 - g) \tag{3}$$

As before, a gain parameter g can be included to control how reactive the HCR is to the recent trend in CPUE. The resulting overall scaler from the HCR is then calculated as the product of scaler 1 and scaler 2 (ie multiply the two together). Some example outcomes for a range of scenarios are provided in Table 3.

Relative CPUE	**CPUE Gradient**	**Scaler 1**	**Scaler 2**	**Scaler Overall**	**Description**
0.8 < cpue < 1.2	0	1	1	1	CPUE around target, flat gradient
cpue > 1.2	+0.2	1.3	1.2	1.56	CPUE above target and recent trend increasing
cpue > 1.2	-0.2	1.3	0.8	1.04	CPUE above target but recent trend decreasing
0.8 > cpue	+0.2	0.7	1.2	0.84	CPUE below target but recent trend increasing
0.8 > cpue	-0.2	0.7	0.8	0.56	CPUE below target and recent trend decreasing

Table 3: Example outcomes for a two phase HCR. Scaler 1 is determined from the ratio of recent CPUE to the target CPUE. Scaler 2 is determined from the gradient in the trend of recent CPUE. The overall scaler is calculated as scaler 1 multiplied by scaler 2.

5 Proof of Concept MSE

Preliminary evaluations have been conducted across the grid of 24 models outlined in Section 3.1 and for the two HCRs described in Section 4.2. 40 iterations have been run for each OM resulting in 960 evaluations conducted for each HCR. The results of these initial runs form the basis of the performance indicators presented in Yao et al. (2019b). Here we present only summary diagnostics for individual runs to illustrate the general characteristics of the working of the HCR.

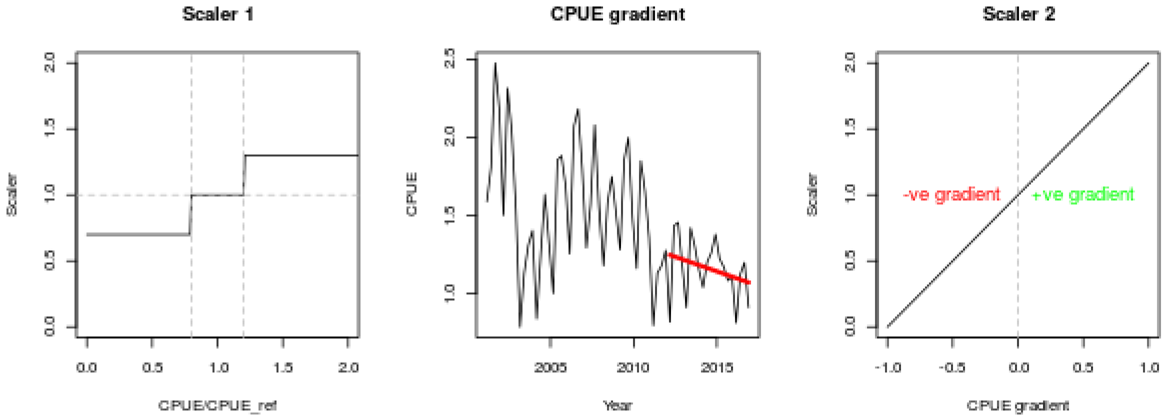


Figure 5: Illustration of a two-phase harvest control rule: Phase 1 produces a simple scaler dependent on the relative CPUE (recent CPUE relative to CPUE in some reference period). Phase 2 produces a scaler dependent on the gradient of the recent trajectory of CPUE (greater than 1 for +ve gradients and less than 1 for -ve gradients). The resulting scaler for management of the fishery is the product of scaler 1 and scaler 2.

Both HCRs rely on a relative catch per unit of effort ($CPUE/CPUE_{ref}$) which has been calculated here as the average CPUE over the last 5 years divided by the CPUE of the reference year (2013, as used as the baseline year in TRP discussions). The years included in the five year average will change at each management cycle. For the management cycle begining in 2020 the average will be calculated for the period 2015 to 2019, for the cycle begining in 2023 the range will be 2018:2022 and so on. The reference year will not change.

The HCR was applied to catch for all fisheries (longline and troll). A 3 year management cycle has been assumed in this instance but shorter (or longer) periods can be considered. The settings for the evaluations (Table 4) have been selected based on the type and style of settings used in other analyses. Further consideration of these settings is recommended to ensure that the most appropriate values for South Pacific albacore are used for future evaluations.

Axis	**Setting**
Management period	3 years
Projection period	30 years
Baseline years for catch scaling	2014:2016
Years for HCR CPUE calculations	last 5 years
Reference CPUE year	2013
Management quantity	catch
Managed fisheries	all fisheries

Table 4: Settings for the South Pacific albacore proof of concept MSE.

5.1 HCR Comparisons

Sample output from the evaluations (Figure 6) shows the two example HCRs have very similar results. They both reduce catches in the medium-term, allowing a moderate increase in biomass and then subsequently increase catches in the long-term although not quite returning to the same catch levels as seen in the short term. Neither HCR is particularly successful at achieving the required increase in CPUE, but do reach the TRP in the long-term. It should, however, be noted that even though a HCR may not perform perfectly, it may perform better than having no HCR at all.

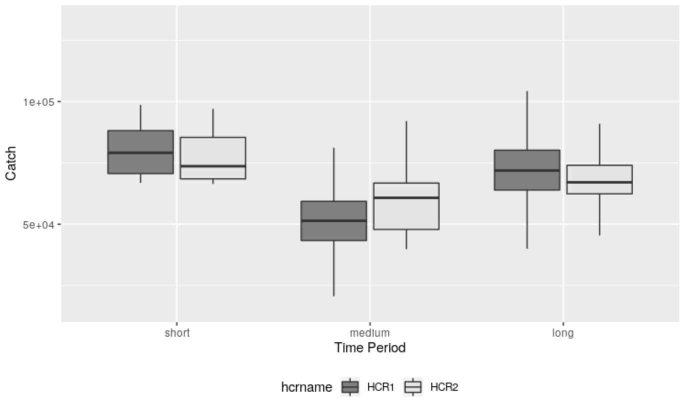
5.2 HCR Performance

To better understand the performance of the HCR and to compare it directly with a situation in which there is no reactive management, a limited set of evaluations were conducted. These comparative evaluations were conducted using just a single OM and using the same set of future recruitment values, random number seeds and model settings such that any differences between the two sets of outcomes results only from the application of the HCR. Table 5 provides a summary of the evaluations and compares the performance at each management step between HCR2 (2-phase HCR) and a constant catch scenario. The relative CPUE (as defined above), the catch scaler as determined by the HCR and the resulting catches and depletion estimates in the first year of each management period are shown. The final column shows the CPUE of HCR2 relative to that of the constant catch scenario.

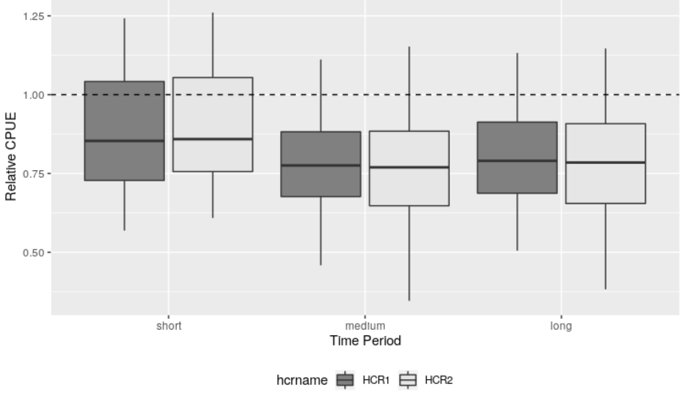
At the start of the simulations, CPUE is above the target (in this scenario) and correspondingly HCR2 increases catches. This leads to a decline in both stock status and CPUE in the medium-term (relative to the constant catch scenario). In response to the the reduced CPUE, HCR2 reduces catches in the medium-term allowing biomass to increase. In the long-term both catch and CPUE are typically higher under HCR2 than under the constant catch scenario. As is so often the case, however, these long-term gains must be offset against the short to medium-term costs of reduced catches.

6 Further Work

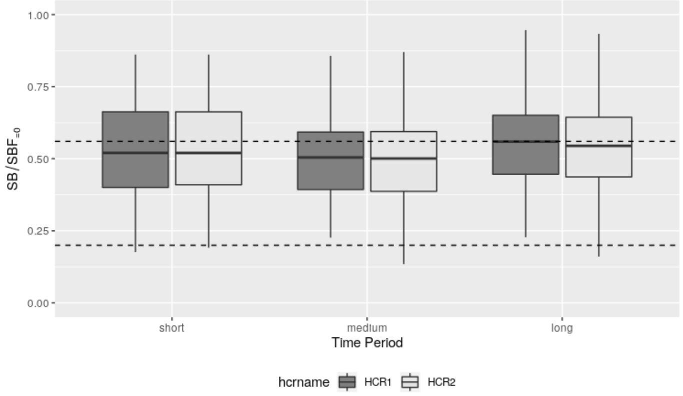
We present here the results of initial investigations into the development of an MSE framework for South Pacific albacore. Whilst we have attempted to address the most significant aspects of developing the operating models and designing the management procedure there remain several key areas in which further work is still required. In this regard we also seek advice and recommendations from SC15 on the further development of the framework.



(a) Total catch



(b) CPUE



(c) $SB/SB_{F=0}$

Figure 6: Catch, CPUE and depletion ($SB/SB_{F=0}$) for the short, medium and long-term for HCR1 and HCR2.

	Status Quo				**HCR2**				
Year	CPUE$_{rel}$	Scaler	Catch	$SB/SB_{F=0}$	CPUE$_{rel}$	Scaler	Catch	$SB/SB_{F=0}$	CPUE$_{diff}$
2020	1.23	1	0.93	0.49	1.13	1.06	0.98	0.49	0.93
2023	1.49	1	0.92	0.62	1.36	1.29	1.16	0.62	0.91
2026	1.10	1	0.88	0.35	0.93	0.91	0.77	0.33	0.84
2029	0.74	1	0.84	0.34	0.54	0.69	0.58	0.27	0.74
2032	0.70	1	0.88	0.38	0.64	0.72	0.64	0.37	0.91
2035	0.73	1	0.88	0.52	0.82	1.01	0.93	0.59	1.12
2038	1.01	1	0.89	0.49	1.17	1.06	0.97	0.59	1.15
2041	1.02	1	0.86	0.39	1.09	0.94	0.81	0.44	1.07
2044	0.91	1	0.89	0.44	0.90	1.02	0.92	0.45	0.99

Table 5: Results summary between a constant catch HCR (status quo) and HCR2. Results are shown for evaluations conducted for one OM and one iteration only. $CPUE_{rel}$ and Catch are shown relative to CPUE and catch in 2013. The final column ($CPUE_{diff}$) shows CPUE for HCR2 divided by CPUE for the constant catch scenario.

6.1 Operating Model Developments

The key sources of uncertainty to be included in the operating model are outlined in Section 3 although further investigation of a number of issues is recommended including the potential variability in future recruitment, methods for implementing alternative growth models in MULTIFAN-CL and the influence of alternative hypotheses of stock structure. We also note that a number of scenarios have been proposed for the reference set of operating models but no scenarios have yet been determined for the robustness set.

Further work is also required to investigate improved approaches for generating pseudo catch and effort data and for introducing observation error into the simulations. Future catch and effort data have been generated assuming a 30% CV for all fisheries specified in the operating model. The variability in future catch and effort introduced through this approach represents a combination of observation error in the reported values of catch or effort and also process error in the underlying relationship between catch and effort. Process error for the historical observations is captured by the MULTIFAN-CL fitting process in the estimation of effort deviations. Stochastic projections that incorporate re-sampling from the effort deviations (in the same way that recruitment deviations are currently re-sampled) would provide a more comprehensive simulation approach and would separate the sources of error more appropriately into their constituent components. This feature for MULTIFAN-CL projections is currently under development and once implemented will be the preferred approach.

6.2 Management Procedure Developments

Further work is also recommended to determine the most appropriate CPUE index (or combination of indices) to be used in the management procedure. We have used the PICT longline fishery in assessment region 2 for these preliminary evaluations. An option that remains to be explored is the possibility to include additional CPUE series i.e. a specific fishery component, in the operating models, in addition to those used in the stock assessment, that can be included specifically for the purpose of informing the management procedure. These investigations should include the potential use of electronic reporting data which would allow for more real-time management of the fishery and substantially reduce the lag between data collection and management action, the benefits of which can be tested.

As recommended by SC14 we have investigated options for a management procedure based on empirical HCRs. We seek advice from SC15 on any additional HCRs or alternative settings for the management procedure that should be evaluated. For example a constraint on the maximum change in catch between management periods could be included so that catches never increase or decrease by more than a certain amount (e.g. 15%). We also note that model based management procedures may be considered for South Pacific albacore and further work will be required to develop these approaches.

7 Conclusions

In this paper we have outlined the important sources of uncertainty that should be considered when conditioning OMs along with the outcomes of analyses to address key uncertainty issues. In Section 3 we make recommendations for the scenarios to include in the reference set of OMs and propose an initial set comprising 24 models, assuming a factorial design. We note, however, that additional factors may also be considered for the reference set and that at this point no recommendations have been made for the robustness set.

We outline a preliminary design for the management procedure and two example HCRs both of which use CPUE as the primary source of information for controlling future catches. We note that the settings assumed for these preliminary evaluations have been arbitrarily chosen and we seek advice and recommendations from SC15 on any additional factors that will need to be considered for developing the framework and any alternative settings that may be more appropriate for South Pacific albacore.

In particular we seek advice from SC15 on:

- whether the sources of uncertainty considered for conditioning the operating models are sufficient and if any further scenarios should be included in the grid.
- whether the ranges of parameter values specified in OM grid reflect our uncertainty in the dynamics of the stock.
- whether the settings assumed for the MSE (Table 4) are considered appropriate or if alternative settings should be considered.

- any additional HCR designs or features (e.g. HCR formulations, catch constraints, management periods, etc.).

In addition SC may wish to re-seek advice from WCPFC on the following issues:

- whether the fishery should be managed through catch or effort controls, or some combination of the two.
- whether the HCR should apply to all fisheries or a selected subset of fisheries.

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