



**SCIENTIFIC COMMITTEE
FIFTH REGULAR SESSION**

10-21 August 2009
Port Vila, Vanuatu

**Management strategy evaluation for Australia's east coast tuna and billfish fishery:
progress update.**

WCPFC-SC5-2009/SA- WP-8

Ann Preece¹, Dale Kolody¹, Campbell Davies¹ and Jason Hartog¹

¹ CSIRO Marine and Atmospheric Research, Hobart, Australia

Management strategy evaluation for Australia's east coast tuna and billfish fishery: progress update.

Ann Preece, Dale Kolody, Campbell Davies and Jason Hartog.

CSIRO Marine and Atmospheric Research, Hobart, Tasmania 7000, Australia.

Contact: Ann.preece@csiro.au

Abstract

Australia's Harvest Strategy Policy requires fisheries under the control of the Australian Commonwealth Government be managed by Harvest Strategies (HS) that lead to sustainable stocks and maximise economic productivity. Harvest strategies are also known as management strategies, management procedures and harvest control rules. They generally include the decision rule and the data and methods used to calculate recommended future management actions (e.g. changes to catch or effort). The Australian HS policy states that Management Strategy Evaluation (MSE) should be used to test the performance of alternative HS with respect to risk, biomass targets and limit reference points.

The Eastern Tuna and Billfish Fishery (ETBF) operates on the East Coast of Australia. The catch consists of five main species (yellowfin, bigeye, albacore, swordfish and striped marlin). Using the agreed framework for the harvest strategy for the ETBF, we have evaluated a range of alternative HS specifications using simulation operating models. These operating models were initialised using population parameter estimates from Western Central Pacific Fishery Commission (WCPFC) stock assessments. There are inconsistencies between the intention of these assessments and our need for local ETBF parameter estimates, and these issues are discussed. We have attempted to represent a range of plausible states and dynamics of the target stocks without having to produce ETBF specific stock assessments.

To evaluate whether a HS is likely to perform as envisaged, it is tested in operating models that encompass a wide range of uncertainties. We included uncertainty in assumptions about regional connectivity, migration rates, non-ETBF effort, ETBF effort creep, CPUE and recruitment variability and sampling error (among others). In the case of swordfish, we also included a wide range of assessment model uncertainty. This was also possible, to a lesser extent, for bigeye tuna and will be possible for other species as results from future work on assessment model uncertainty become available. HSs are evaluated against a more likely reference set of uncertainties, as well as a more extreme, but plausible, "robustness" set of uncertainties. These reference and robustness sets are different for each species.

For each species, the performances of the various individual HS are shown as trade offs between biological risk and average catches and catch rates. On the basis of these comparisons, industry and management representatives have selected a harvest strategy specification for each species and these will be implemented in the ETBF in Nov 2009. This paper reports on operating model development and HS evaluations to date. The results so far indicate that the performance of the HS will be determined by a number of

species-specific fishery characteristics (e.g. stock structure, life history parameters, and the actions of international fleets), such that Australian domestic actions may have considerable capacity to effectively manage some species (swordfish and striped marlin), while unilateral domestic management actions might be largely ineffective for other species (e.g. bigeye and yellowfin).

The paper illustrates the type of process that might be undertaken if the WCPFC decides to manage the Western Central Pacific Ocean fisheries using Management Strategy Evaluation.

Table of Contents

1.	Introduction.....	3
2.	Methods.....	4
2.1	Process for developing and evaluating management strategies.....	4
2.2	The ETBF HS Framework.....	4
2.3	Conditioned operating models.....	5
2.4	Uncertainty and robustness.....	5
2.5	The MSE simulation loop.....	5
2.6	Performance measures.....	6
3.	Results.....	6
3.1	Yellowfin: operating model and harvest strategy evaluation.....	7
3.2	Bigeye: operating model and harvest strategy evaluation.....	14
3.3	Albacore: operating model and harvest strategy evaluation.....	18
3.4	Swordfish: operating model and harvest strategy evaluation.....	23
3.5	Striped Marlin: operating model and harvest strategy evaluation.....	27
4.	Discussion and summary.....	31
5.	Acknowledgements.....	33
6.	References.....	33

1. Introduction

Australia’s Harvest Strategy Policy requires fisheries under the control of the Australian Commonwealth Government be managed by Harvest Strategies (HS) that lead to sustainable stocks and maximise economic productivity (Anon., 2007). Harvest strategies are also known as management strategies, management procedures and harvest control rules. They generally include specification of a decision rule and data and methods used to calculate recommended future management actions (e.g. changes to catch or effort). We have used these terms interchangeably throughout this document. For each Australian commonwealth fishery, a HS framework has been developed (Campbell et al, 2007). The framework specifies the structure of the decision rule, but does not give detailed specification of alternative HS, which must be evaluated in simulation models. The Australian HS policy states that Management Strategy Evaluation (MSE) should be used to test the performance of alternative HS with respect to risk, biomass targets and limit reference points.

The Eastern Tuna and Billfish Fishery (ETBF) operates on the East Coast of Australia, on stocks that are connected with southern, western and greater Pacific Ocean stocks. The catch consists of five main species (yellowfin, bigeye, albacore, swordfish and striped marlin). HS evaluation of these stocks has been conducted using conditioned operating models which are initialised using population parameter estimates from Western Central Pacific Fishery Commission (WCPFC) stock assessments. There are inconsistencies between the intention of these assessments and our need for local ETBF parameter estimates, and these issues are discussed.

In this paper we discuss the HS evaluation process undertaken and the preliminary results. There has been significant progress since reporting results for swordfish in 2007 (Kolody et al, 2007). The technical side of this project is intended to quantify the fishery dynamics for the target species, and to illustrate the trade-off among management objectives that result when different specifications of the HS framework are simulation tested. However, it is ultimately the job of the fisheries managers, ETBF Resource Assessment Group and Management Advisory Committee to make the hard decision of selecting the final HS (Kolody et al 2009a,b). A technical review is planned for later this year, and HS implementation is expected from Nov 2009. The current research project will finish in early 2010.

2. Methods

2.1 Process for developing and evaluating management strategies

The aim of a management strategy or harvest strategy is to agree on a method for adjusting future catch or effort in a fishery, based on agreed data and an agreed method for analysis of that data. The process for developing and evaluating management strategies involves several steps: 1) setting objectives and performance measures, 2) developing candidate HS, 3) developing operating models (OM), 4) simulation testing, 5) HS selection and 6) implementation. Objectives and performance measures for the ETBF are specified in the HS policy and guidelines. They specify biological and economic goals, and target and limit reference points. The HS working group developed a framework for HS to be used in the ETBF (Campbell et al, 2007), details within the HS framework were not defined, and alternative values for these give alternative HS for evaluation. The current project has taken the HS framework and candidate HS and evaluated these using a conditioned operating model. Relative performance of these HS are presented to industry and management to enable selection of a single rule that will be used for adjusting future catches in the ETBF.

2.2 The ETBF HS Framework

The ETBF HS decision rule is a 4 level decision tree. Level 1 of the rule makes the major adjustment to the recommended biological catch from one year to the next, based on the slope from recent standardised CPUE trends for prime sized fish to the target CPUE level. The recommended catch is potentially adjusted down in the next 3 levels of the decision tree. The intention in the lower three levels is to detect trends in the status of recruits and older aged fish that can indicate changes in population structure that may not be evident in the standardised CPUE for prime sized fish. These lower three levels use catch rates for small fish and large fish and the proportion of the catch that is large sized fish, and measures current levels relative to thresholds for these. This is an empirical decision rule that does not require a formal model-based stock assessment, but does require catch, effort and size data and calculation of a standardised CPUE by size group. In principle, the final recommendation from the decision tree could be an adjustment to

catch or effort, but in the case of the ETBF we are making recommendations on future catches.

2.3 Conditioned operating models

Using the agreed framework for the harvest strategy for the ETBF, we have evaluated a range of alternative HS specifications using conditioned operating models. Conditioning an operating model is the process of developing models that are consistent with the historical fisheries data and biological research for a stock. The ETBF operating models were initialised using population parameter estimates from Western Central Pacific Fishery Commission (WCPFC) stock assessments. There are inconsistencies between the intention of these assessments and our need for local ETBF parameter estimates, and these are discussed. We have attempted to represent a range of plausible states and dynamics of the target stocks to characterise some of the uncertainty associated with the stock assessments as discussed below, however, it was beyond the scope of the project to produce 5 ETBF-specific stock assessments.

The generic operating model contains two areas which correspond to population and fleet dynamics in the ETBF and the non-ETBF. Information from WCPFC stock assessments for these species is used to partition the regional Western Central Pacific Ocean (WCPO) assessments into the 2 area operating model. The partitioning is different for each species, depending on the spatial arrangement in the stock assessment and information about linkages between areas in the stock assessment. The details of the partitioning are discussed for each species.

2.4 Uncertainty and robustness

To evaluate whether a HS is likely to perform as envisaged, it is tested in operating models that encompass a wide range of uncertainties. We included uncertainty in assumptions about regional connectivity, migration rates, non-ETBF effort, ETBF effort creep, CPUE and recruitment variability and sampling error (among others). In the case of swordfish, we also included a wide range of assessment model uncertainty. This was also possible, although to a lesser extent, for bigeye tuna and will be possible for other species as results from work on assessment model uncertainty become available. HSs are evaluated against a more likely reference set of uncertainties, as well as a more extreme, but plausible, “robustness” set of uncertainties. These reference and robustness sets are different for each species. Only results from reference sets are described here. The aim is to find harvest strategies that perform well even when the underlying dynamics and population parameters are not well known.

2.5 The MSE simulation loop

The many uncertainties that we wish to evaluate HS against, lead to many operating models. Each of these models is run many times to replicate stochastic variation (e.g. in recruitment levels, CPUE observation errors and implementation errors). The models project the population forward from the current year to 2030 and simulate the dynamics of the fishery and the fleet, and simulate the data collected and implementation of the HS. The end year was selected to give the model enough time to demonstrate long term performance (e.g. to distinguish whether the HS is capable of using feedback to stabilize

the system in a satisfactory state, or if instability is likely). However, it is not expected that the fishery would be managed until 2030 without review, and the appropriate time frames for evaluating risk have not yet been defined.

2.6 Performance measures

The Australian harvest strategy policy defines performance measures. The limit reference point is defined as 20% of initial (unfished) spawning stock biomass levels. Biological risk is a measure of the frequency of the spawning biomass being below 20% of initial (unfished) spawning stock biomass levels. For the ETBF, CPUE has been identified as a primary indicator of economic performance, because a minimum CPUE has to be maintained for the fishery to be viable. However, total catches are also related to overall economic returns for the fishery, and the relationship between catch and CPUE is one of the most important management trade-offs under consideration. Biomass targets are expressed in the HS decision rules using the CPUE level as a directly observable proxy. The ETBF fishery developed rapidly in the late 1990s, and the average standardised CPUE over the years 1997-2001 was broadly recognized as a desirable target.

3. Results

For each species there is a description of the operating model conditioning and the main components that differ by species. From the WCPFC stock assessments models we use estimates of numbers at age, an estimate for average unfished initial spawning stock biomass (SSB₀), selectivity in the ETBF and non-ETBF region, stock recruit relationship and parameters, natural mortality at age, maturity at age, length-age relationship etc. The details are not all specified here, but will be subject to a technical review and specified in papers prepared for that review.

The regional assessments cover different areas in the Pacific Ocean, and are subdivided in different ways for each species. The method used to make an approximation to an ETBF and non-ETBF area is explained.

A range of HSs is evaluated for each species and the details of the specifications for the thresholds and values used in the harvest strategies are not discussed here. Constant catch strategies have also been used in the simulations, to contrast with the feedback decision rule results, and zero catch simulations have been run to examine the population dynamics for each species in the absence of fishing.

In this paper, the main harvest strategy performance trade-offs are qualitatively summarised in a graphical format that relates the expected catch distribution to the distribution of CPUE and an index of biomass risk. These trade-off plots summarize the relative performance of harvest strategies over the period 2009-2030. The relationship between the trade-off plots and the more familiar time series plots are illustrated for the yellowfin tuna example.

3.1 Yellowfin: operating model and harvest strategy evaluation

The Yellowfin operating model was conditioned on the 2007 WCPFC regional stock assessment results (Langley et al, 2007). The spatial structure of the assessment covers the whole Western and Central Pacific Ocean (Figure 1). The entire southern region is assumed to be a distinct population in the conditioned operating model, with the south-west (region 5) corresponding to the ETBF component of the stock, and the south-east (region 6) the non-ETBF component. The current assessment estimates that there is relatively low mixing between the southern and equatorial regions (though movement estimates are highly uncertain). Other key reference set assumptions for yellowfin are:

- Non-ETBF Effort is assumed to remain constant at 2005 levels because the distant water fishing fleets are responsible for most of the catch.
- The unfished ETBF region is assumed to have 72% of the operating model population and new recruitment.
- The migration linkage between the ETBF and non-ETBF regions is assumed to be an equal mix of scenarios with 1%, 20% and 60% per quarter diffusive mixing.

Main concerns related to the conditioning of the operating model for yellowfin:

- The migration and local-scale recruitment dynamics are poorly quantified in the assessment. The spatial domain is large, and important dynamics for the ETBF may not be described appropriately (e.g. CPUE variation might be driven by migration dynamics within the East Australia current more than regional recruitment dynamics).
- The bulk of the catch is removed from the tropical area, which is part of the ETBF region in the assessment, but this purse seine fishery is moved to the non-ETBF region in the operating model. The impact of this depends on the extent and nature of the connectivity among the regions, but there is quite limited empirical data available to address this question outside the assessment. Potential future impacts of the equatorial purse seiners are not considered.
- Quantification of the uncertainty in the assessment for yellowfin was not comprehensive (a single assessment model was used to represent the current population structure).

The operating model trends for predicted CPUE were consistent with the observed standardised CPUE for yellowfin. If fishing was stopped in both the ETBF and non-ETBF areas, the operating models predict an average biomass increase of about 50%, which is higher than recent years and the late 1970s, but lower than the 1950s and late 1980s.

Figure 2, 3 and Figure 4 illustrate the estimated catch, CPUE and spawning biomass trajectories for four ETBF Harvest Strategies that were selected to demonstrate a range of options. There are 1200 trajectories summarised in these plots for yellowfin, for each HS.

“Tradeoff plots” summarize the average catch and average CPUE (or biomass risk) from each time series trajectory, and plot the distribution of these averages against one another (in this paper, the distribution is summarized by the medians and upper and lower 10th

percentiles on each axis). Figure 5 is a “trade-off” plot that illustrates the estimated relationship between Catch and CPUE for a range of Harvest Strategies. The operating model is clearly suggesting that the ETBF fishery has very little effect on the regional population dynamics of yellowfin (within the range of catches prescribed by the selected HSs).

Figure 6 is a “trade-off” plot that illustrates the estimated relationship between Catch and Biomass risk associated with the different harvest strategies, and strongly suggests that the ETBF does not represent a substantial risk to regional yellowfin populations (within the range of catches prescribed by the selected HSs). The specific biomass risk definition is described in the figure caption. We do not consider this specific definition to be a very good indicator of absolute risk, but it seems to be a consistent measure of relative risk that is reasonable for ranking HSs.

Primary conclusions about the yellowfin HS evaluations:

- Any choice of ETBF HS within the range of options tested is not likely to have a substantial impact on the SW Pacific population as estimated by the most recent WCPFC assessment.
- As such, the yellowfin population is considered to be the lowest risk target species from a stock conservation perspective.
- The current assessment and operating model are not sufficient to resolve localized fishery impacts (e.g. is there a Coral Sea sub-population or localised depletion within the ETBF).

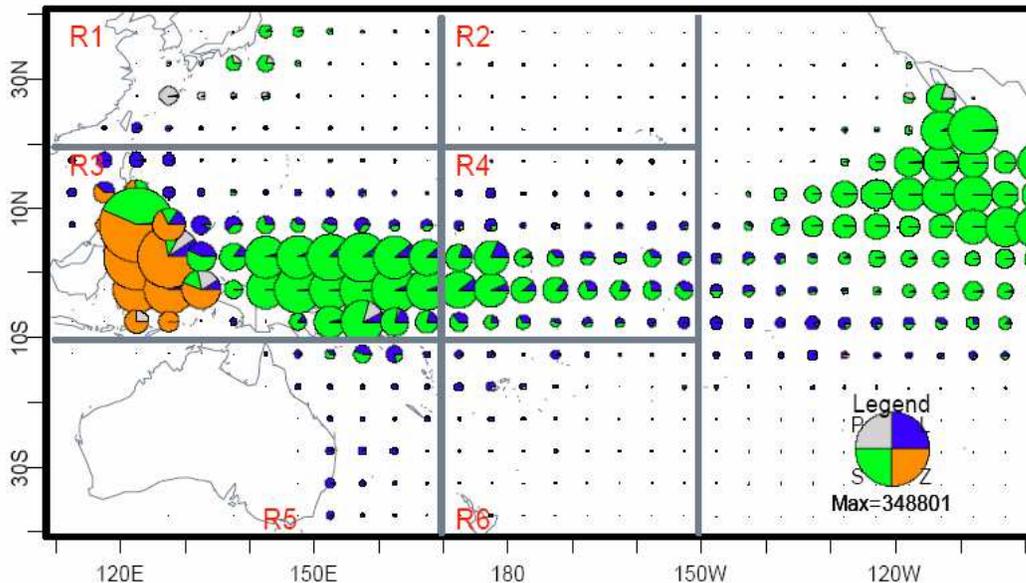


Figure 1. Yellowfin tuna assessment model spatial domain from Langley et al (2007 Figure 5). Distribution of cumulative yellowfin tuna catch from 1990–2005 by 5 degree squares of latitude and longitude and fishing gear; longline (L, blue), purse-seine (S, green), pole-and-line (P, grey) and other (Z, dark orange). The grey lines indicate the spatial stratification. In the ETBF HS operating model, area 5 is defined as the ETBF, area 6 as the non-ETBF.

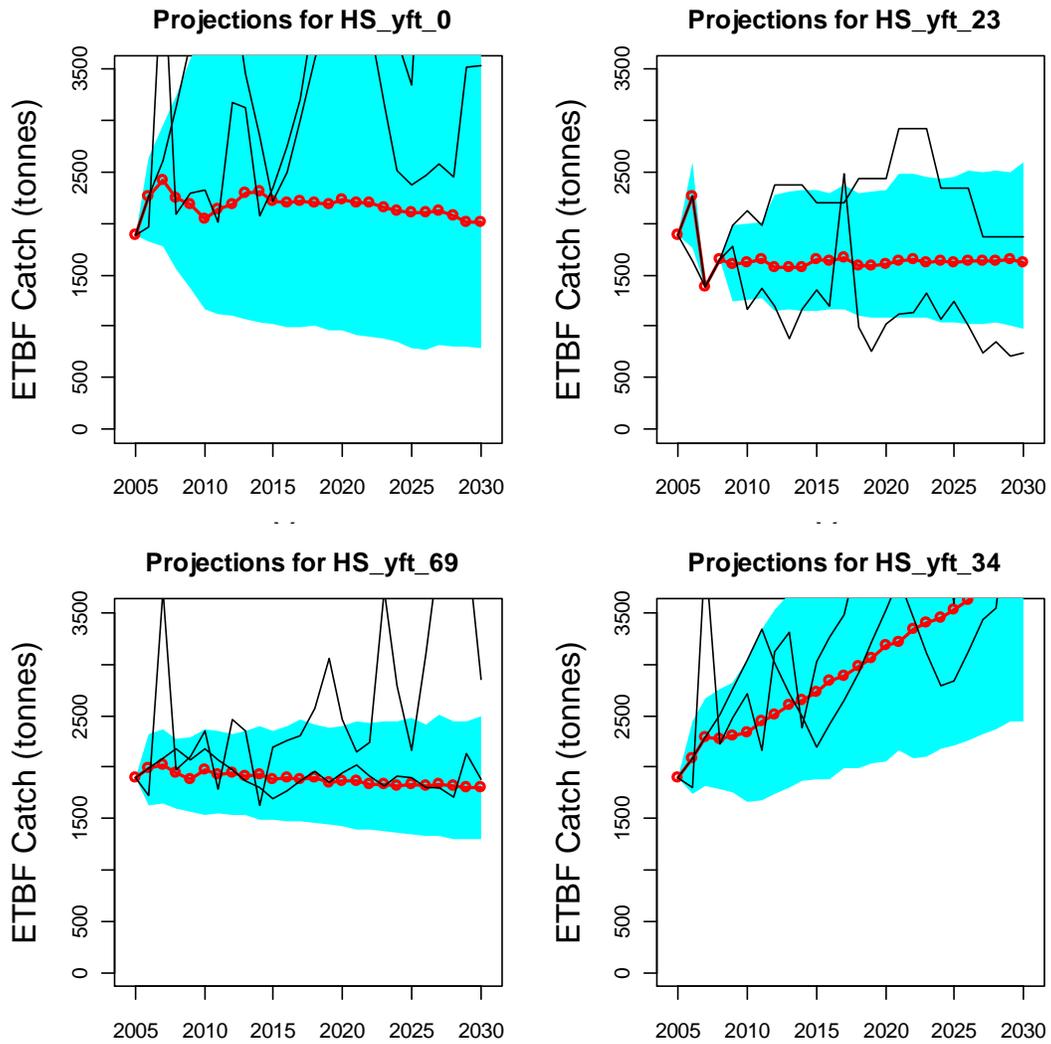


Figure 2. Yellowfin tuna estimated catch trajectories for four ETBF Harvest Strategies. Red circles indicate median projections, shaded blue region represents the 10th and 90th percentiles of the distribution, and thin black lines represent two random trajectories.

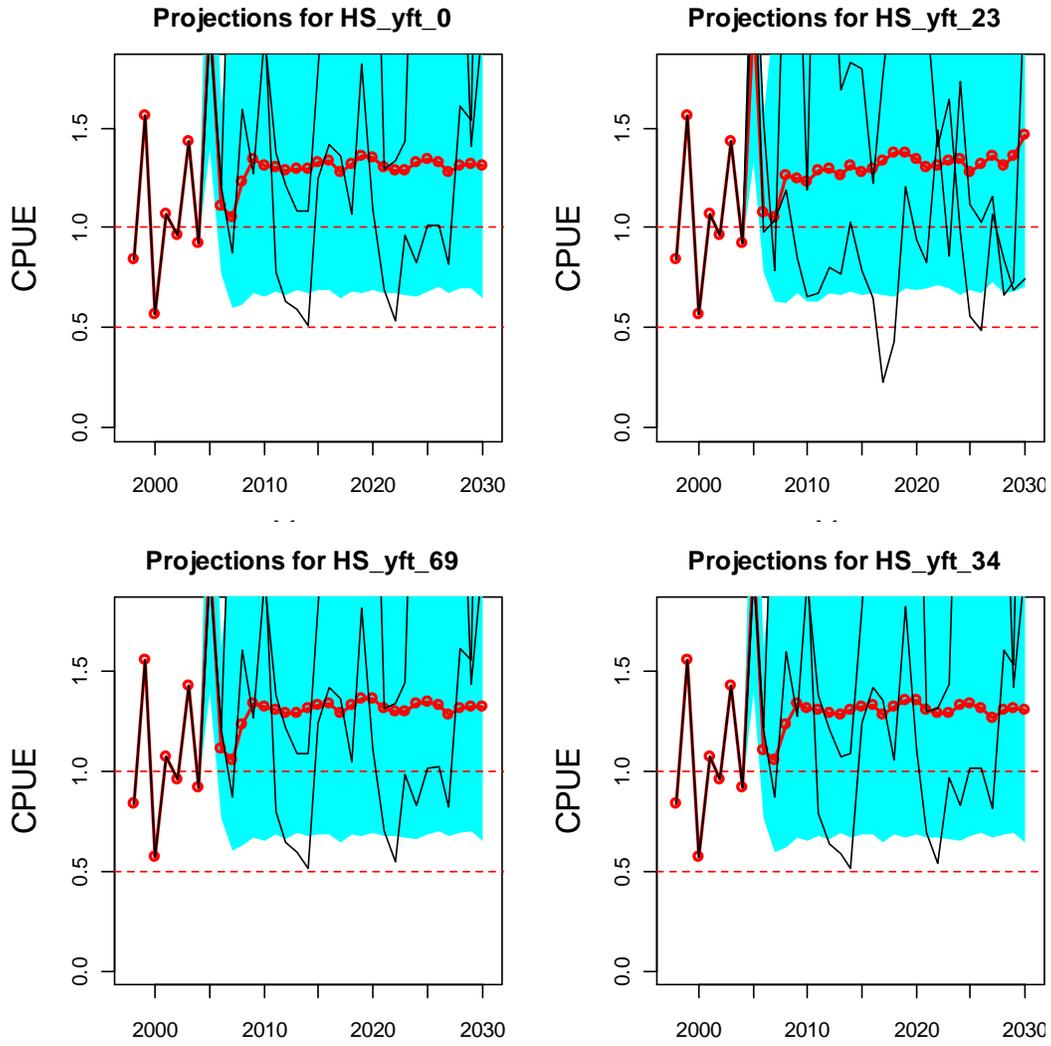


Figure 3. Yellowfin tuna estimated ETBF CPUE trajectories for four ETBF Harvest Strategies. Red circles indicate median projections, shaded blue region represents the 10th and 90th percentiles of the distribution, and thin black lines represent two random trajectories.

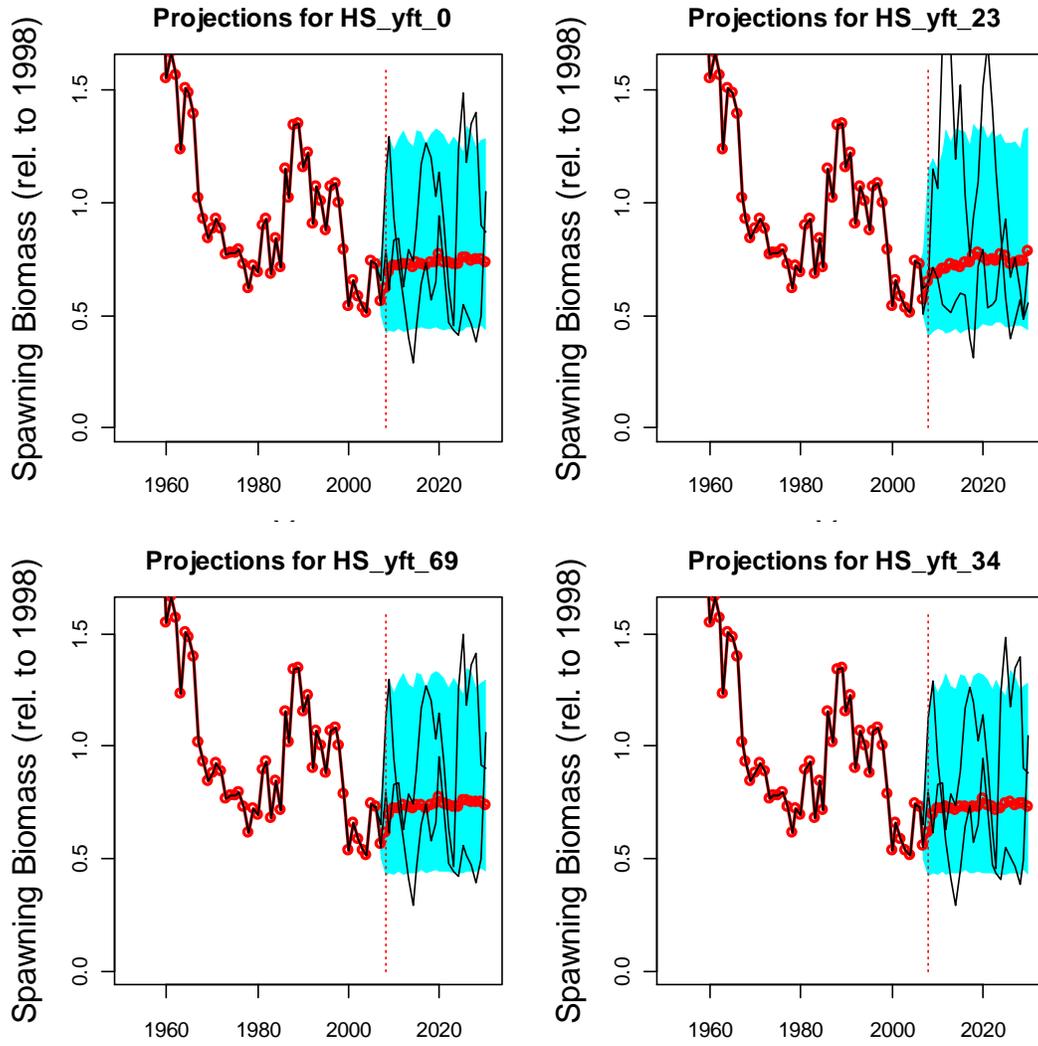


Figure 4. Yellowfin tuna estimated spawning biomass trajectories for four ETBF Harvest Strategies. Red circles indicate median projections, shaded blue region represents the 10th and 90th percentiles of the distribution, and thin black lines represent two random trajectories.

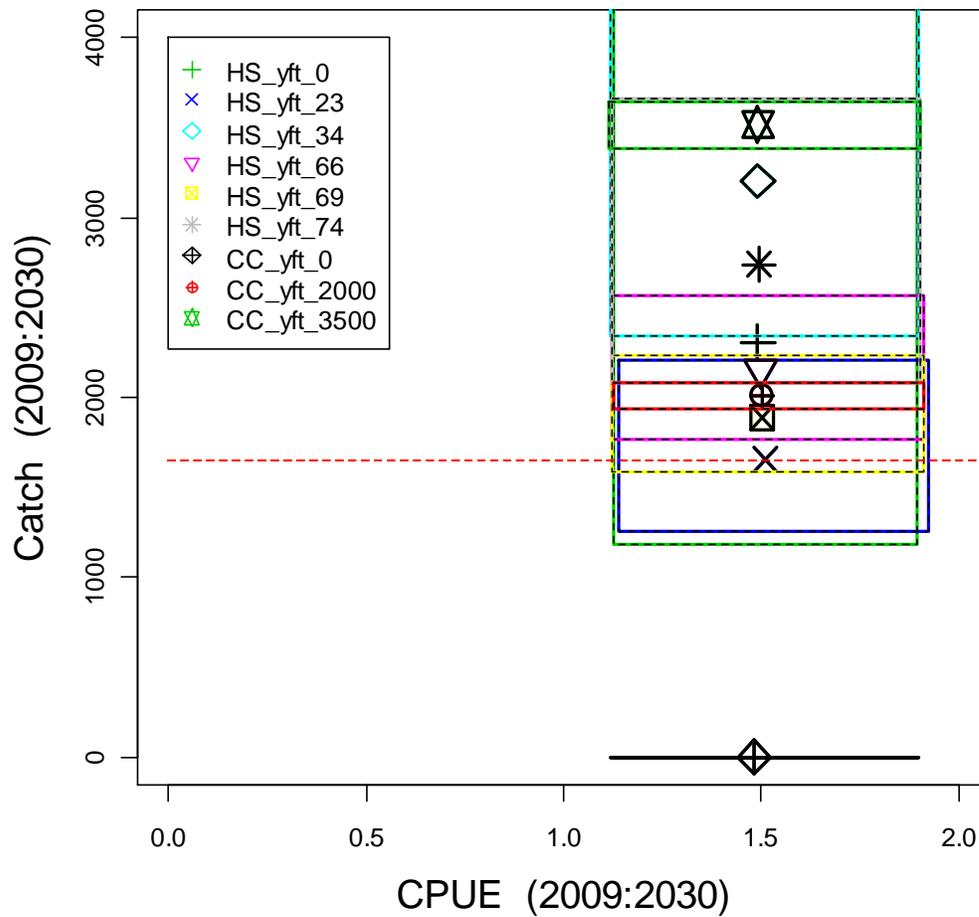


Figure 5. Yellowfin tuna trade-off plot illustrating the estimated relationship between ETBF Catch and CPUE for a range of Harvest Strategies. Symbols represent the median performance (averaged over time) for all realizations; boxes bound the 10th-90th percentile region in both dimensions. The broken red horizontal line indicates the 2007 catch level.

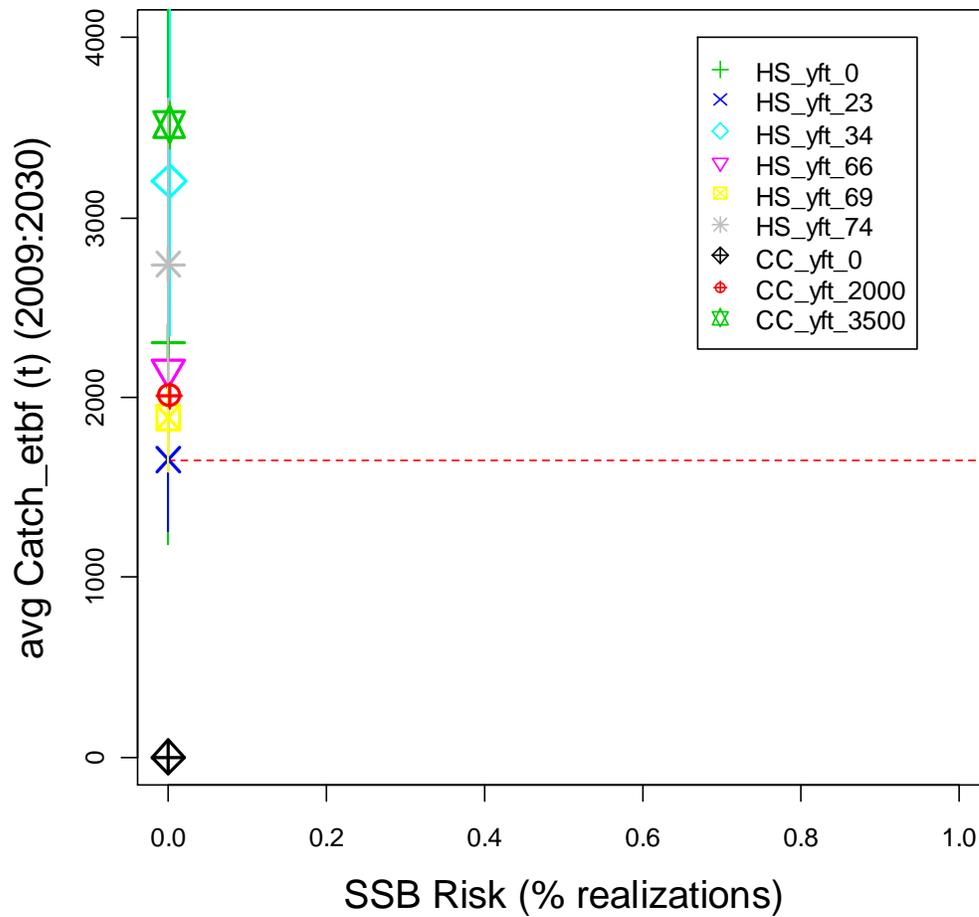


Figure 6. Yellowfin tuna trade-off plot illustrating the estimated relationship between ETBF Catch and biomass risk. Risk is defined as the proportion of stochastic projections in which spawning biomass (SSB) drops below 20% of unfished levels (0.2B0) more than 10% of the time (3 or more years). Dotted vertical lines show how specific levels of risk might be used to remove some candidate HSs from further consideration. The broken red horizontal line indicates the 2007 catch level.

3.2 Bigeye: operating model and harvest strategy evaluation

The Bigeye operating model is conditioned using results from the 2008 regional stock assessment (Langley et al., 2008). The assessment estimates relatively low mixing between southern and equatorial regions. Therefore in the operating model the southern region is assumed to be a distinct population, with the south-west region (5) of the WCPO corresponding to the ETBF component of the stock, and the south east region (6) to the non-ETBF component (Figure 7). Other key reference set assumptions for bigeye include:

- Non-ETBF Effort is assumed to decrease by 30% from 2007 levels by 2011 (corresponding to the implementation of the most recent WCPFC management measure).
- The ETBF region is assumed to have 51% of the operating model population and new recruitment.
- The migration linkage between the ETBF and non-ETBF regions is assumed to be an equal mix of scenarios with 1%, 20% and 60% per quarter diffusive mixing.
- Five different sensitivity trials for the BET assessment are represented in the operating model (to encompass some of the stock status uncertainty). This is more extensive than for yellowfin, albacore and striped marlin, but not comprehensive.

Main concerns relating to the conditioning of the operating model for bigeye:

- Migration dynamics are poorly quantified in the assessment. The spatial domain is large, and important dynamics for the ETBF may not be described appropriately. Large fisheries in the tropical region are part of the ETBF region as defined in the assessment model, but this fishery is moved to the non-ETBF region in the operating model.
- The models estimate that in the absence of fishing there will be a rapid recovery in the spawning biomass, which seems too fast and might be based on poorly quantified recent recruitment. The implications for short-term projections (and HS implementation) should be treated with appropriate caution.

The predicted CPUE from the bigeye operating model showed consistent trends with the observed CPUE data from the ETBF. Constant catch strategies of 0 catch were run to simulate the population dynamics in the absence of fishing. For bigeye, an average biomass increase of about 50% is predicted, which is higher than recent years and the late 1970s, but lower than the 1950s and early 1980s.

A range of HS were evaluated and the results for some of these HSs suggest that the stock could be driven to a level of spawning biomass that would substantially increase the risk of future declines in recruitment, which would be inconsistent with the objectives of the Commonwealth Harvest Strategy Policy.

Figure 8 illustrates the estimated relationship between Catch and CPUE for a range of Harvest Strategies. The operating model suggests that the ETBF fishery has a small effect on the regional population dynamics of bigeye (within the range of catches prescribed by the selected HSs), relative to the non-ETBF fleet. Median CPUE levels in the ETBF appear to be below the target.

Figure 9 illustrates the estimated relationship between Catch and biomass risk associated with the different harvest strategies. The plot indicates that the regional spawning biomass of the bigeye stock is estimated to often fall to a level lower than the limit reference point specified in the CHSP (even in the absence of the ETBF fishery (CC_bet_0)). Even though the impact of the ETBF fleet itself may be small, relative to the other fleets, it can plausibly increase the biomass risk to the regional bigeye population with catches near current levels (i.e. if the population is already near a threshold, it may only take a small amount of additional effort to exceed the threshold).

Primary conclusions about the bigeye HS evaluations:

- Any choice of ETBF HS within the range of options currently tested is likely to increase the risk to the already depleted regional population, as estimated by the most recent WCPFC assessment.
- The current assessment and operating model are not sufficient to resolve localized fishery impacts (e.g. is there a Coral Sea sub-population), or localised depletions within the ETBF.

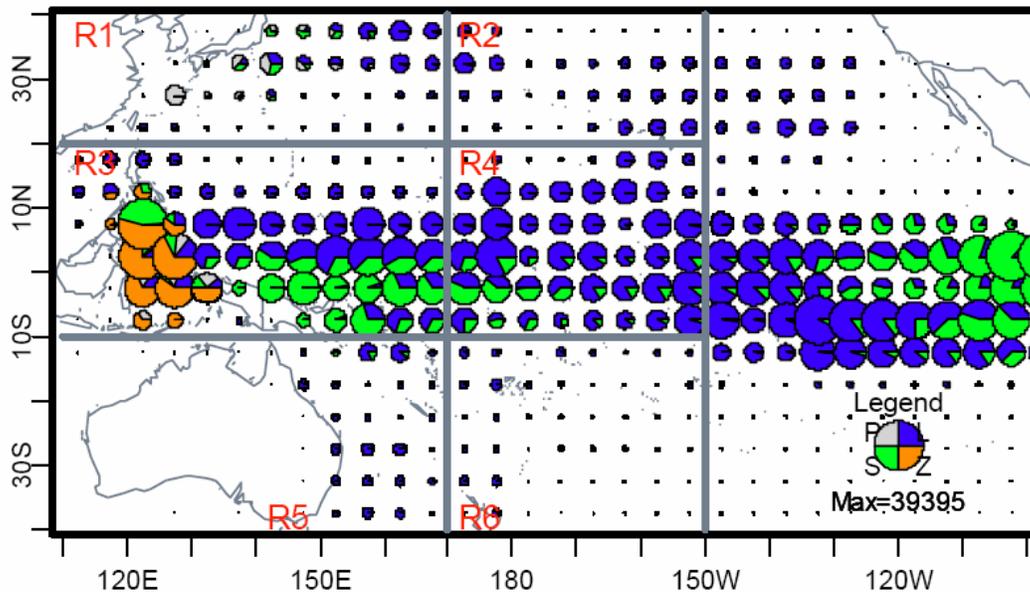


Figure 7. Bigeye tuna assessment model spatial domain from Langely et al (2008). Circles indicate the distribution of cumulative bigeye tuna catch from 1990–2006 by 5 degree squares of latitude and longitude and fishing gear; longline (blue), purse-seine (green), pole-and-line (grey) and other (dark orange). The maximum circle size represents a catch of 40,000 mt. The grey lines indicate the spatial stratification of the six-region assessment model. Area 5 is defined as the ETBF, Area 6 as the non-ETBF.

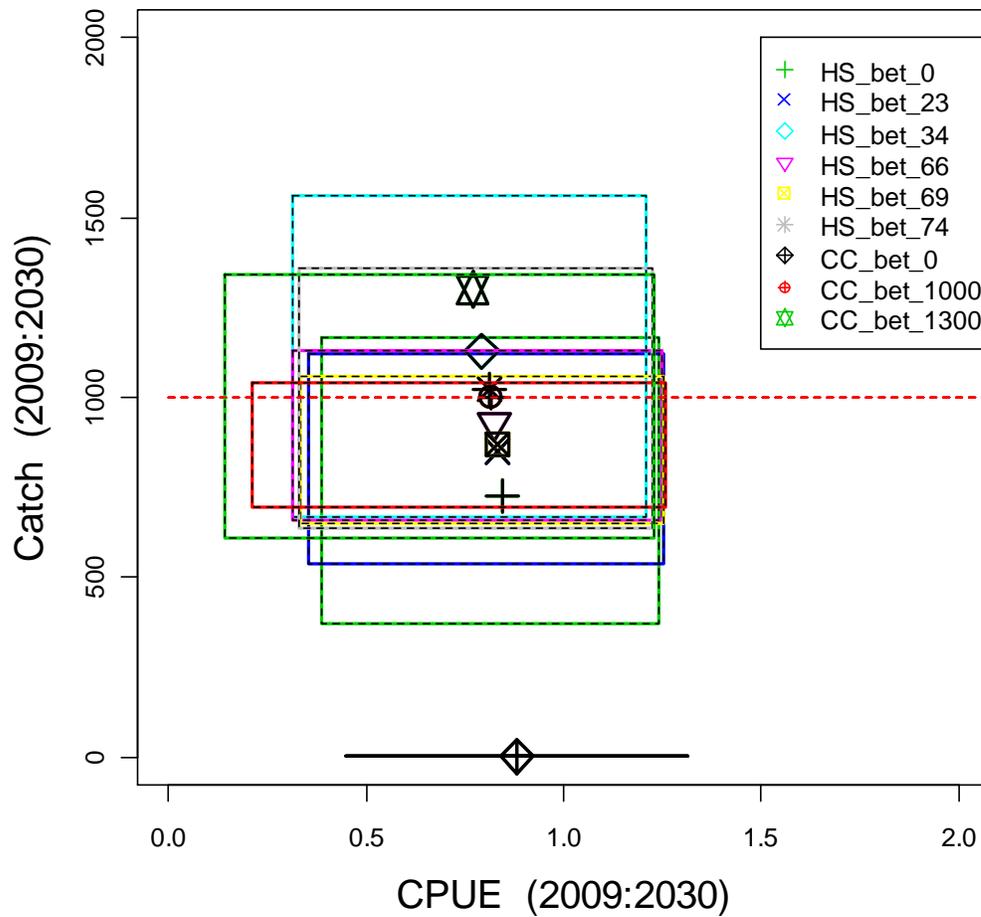


Figure 8. Bigeye tuna trade-off plot illustrating the estimated relationship between Catch and CPUE for a range of Harvest Strategies. Symbols represent the median performance (averaged over time) for all realizations; boxes bound the 10th-90th percentile region in both dimensions. The broken red horizontal line indicates the 2007 catch level.

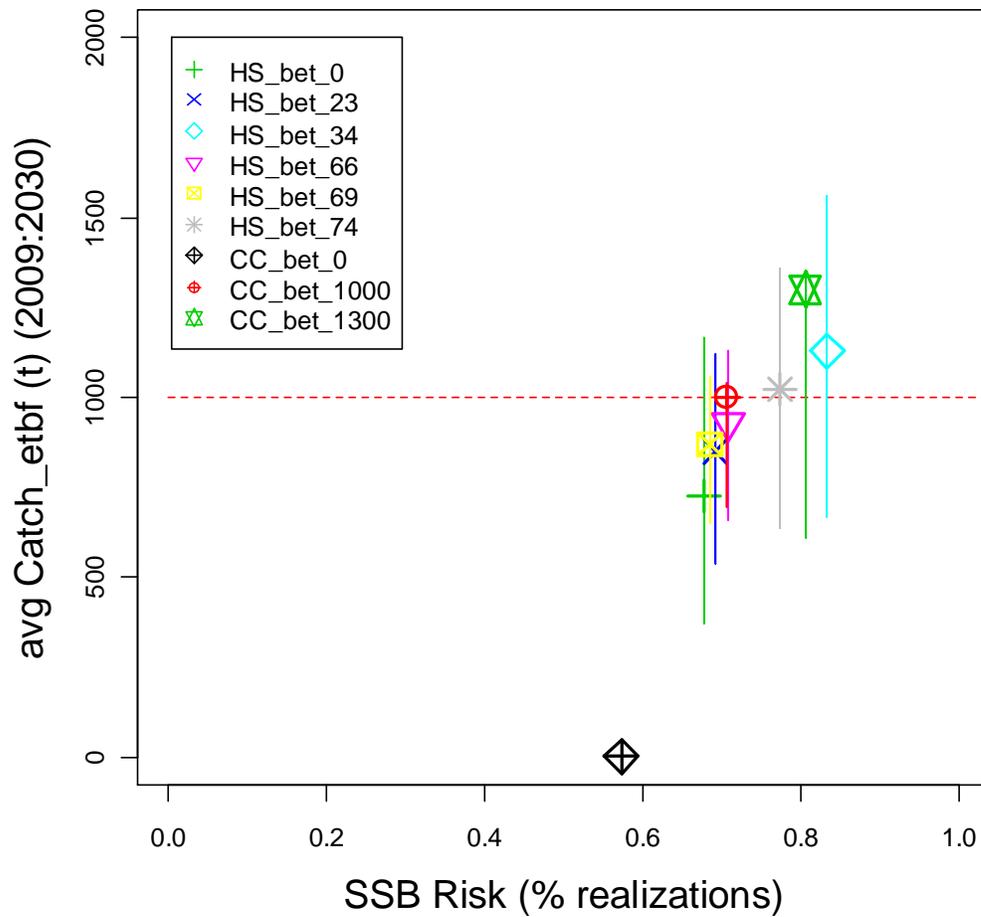


Figure 9. Bigeye tuna trade-off plot illustrating the estimated relationship between Catch and biomass risk. Risk is defined as the proportion of stochastic projections in which spawning biomass (SSB) drops below 20% of unfished levels (0.2B0) more than 10% of the time (3 or more years). Dotted vertical lines show how specific levels of risk might be used to remove some candidate HSs from further consideration. The broken red horizontal line indicates the 2007 catch level.

3.3 Albacore: operating model and harvest strategy evaluation

The OM is conditioned using the 2008 preliminary regional stock assessment by Hoyle et al. (2008). The spatial structure of the assessment covers the whole southern hemisphere Pacific Ocean (Figure 10). In the operating model, this population was partitioned into an ETBF region and a non- ETBF region, with a dividing point corresponding approximately to 165E. Other key reference set assumptions for albacore:

- Non-ETBF effort is assumed to remain constant at 2007 levels.
- The ETBF region is assumed to have 20% of the operating model equilibrium population and new recruitment.
- The migration linkage between the ETBF and non-ETBF regions is assumed to be an equal mix of scenarios with 1% and 20% per quarter diffusive mixing.
- The monitoring data currently available for albacore does not include size composition, so the HS uses an aggregate CPUE, while all other species use CPUE from 3 separate size classes (Campbell 2009).

Main concerns about the albacore operating model:

- The connection between the extreme SW and extreme SE Pacific populations is probably very weak, and this stock connectivity problem is poorly quantified.
- Fishery selectivity seems to vary substantially by season for albacore, and possibly also in relation to shifting targeting. Selectivity is assumed to be constant in the operating model.
- Only a single 'preferred' assessment model was adopted for the operating model, so the uncertainty is understated.
- The 2008 albacore assessment was considered preliminary with substantive revisions planned for 2009.
- Figure 11 illustrates the nature of the discrepancies between the predicted and observed albacore CPUE for the ETBF. This suggests that either the assessment model did not fit the CPUE series very well, or the Australian CPUE series are not consistent with the distant water fishing series that were used. This could indicate changing catchability, in one or more of the fleets, in a way that is not captured in the catch rate standardization. Or it might indicate that the relative abundance trends differ by region in a way that simply cannot be described by the spatially aggregated model.

In the absence of any fishing, the spawning biomass and CPUE is estimated to almost triple if fishing stops, which would result in biomass on average comparable to the period from the 1970s to mid-1990s, but less than that in the 1960s.

All of the HSs evaluated prescribe immediate catch reductions, and there is a large drop in the CPUE in the first year of the projections. This decline is related to the discrepancy between predicted and observed CPUE, such that the model estimates the biomass to be much lower in 2008 than the ETBF CPUE suggests.

Figure 12 illustrates the estimated relationship between Catch and CPUE for a range of Harvest Strategies. The operating model suggests that the ETBF fishery has a relatively

small effect on the regional population dynamics of albacore (within the range of catches prescribed by the selected HSs), relative to the non-ETBF fleet.

Figure 13 illustrates the estimated relationship between Catch and Biomass risk associated with the different harvest strategies. The plot indicates that the regional albacore stock is estimated to already be in the region of the limit reference point (even in the absence of the ETBF fishery (CC_alb_0)). The impact of the ETBF fleet is estimated to elevate the biomass risk to the regional albacore population, but not to the same extent as with bigeye.

Primary conclusions about the albacore HS evaluations:

- The assessment and operating model suggest that there is some risk to the regional albacore population, irrespective of the ETBF fishery, but that the range of HS options explored does not substantially elevate the risk.
- We consider the albacore results to be the least reliable of the five target species for several reasons:
 - The 2008 WCPFC assessment was preliminary with limited uncertainty quantification and has been updated in 2009.
 - The spatial domain of the assessment cannot resolve ETBF dynamics adequately.
 - There is a substantial inconsistency between the predicted and observed ETBF CPUE time series which are the primary abundance indices in the operating model and HS.

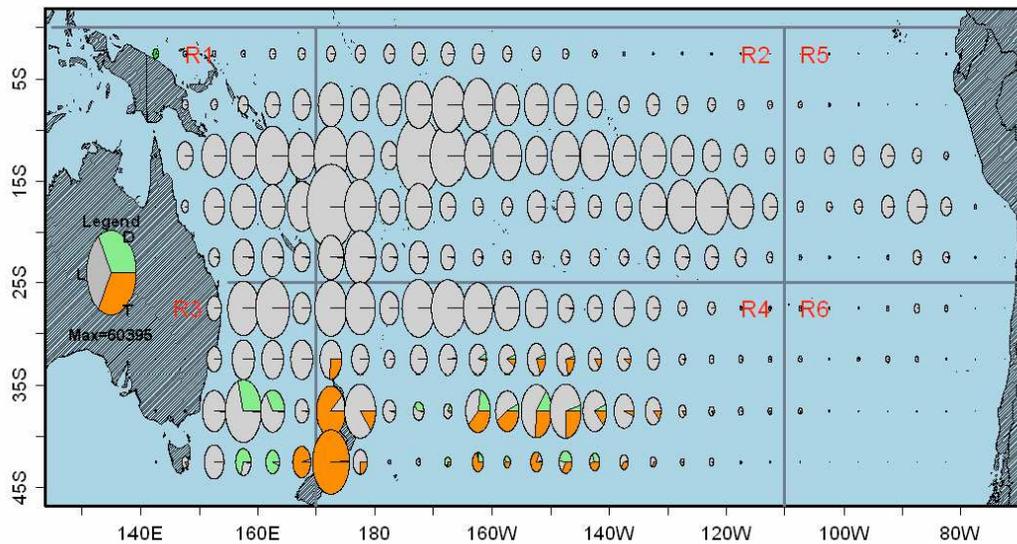


Figure 10. Albatross assessment model domain from Hoyle et al. (2008). Note that regions R1-R6 are used to define fisheries, but the fish population is aggregated.

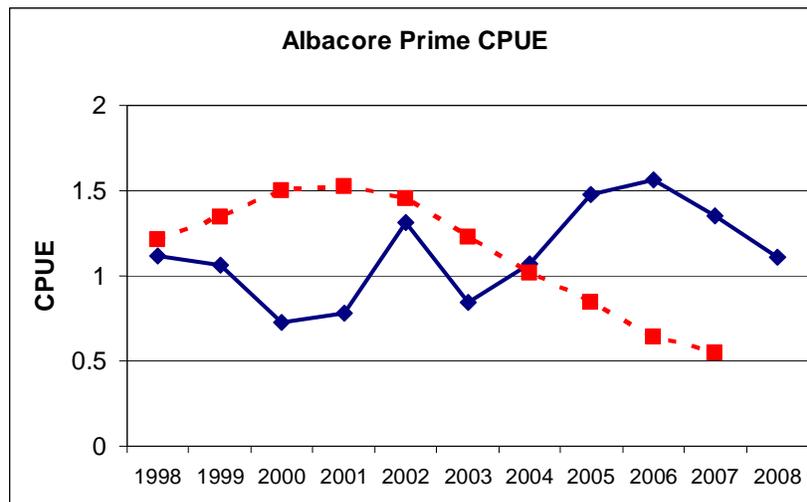


Figure 11. Albatross tuna comparison between predicted and observed CPUE for the Australian ETBF. Solid black lines (diamonds) are the observed standardized CPUE (aggregated across size classes); broken coloured lines are the equivalent assessment model estimates (later years are not shown because they consist of stochastic projections).

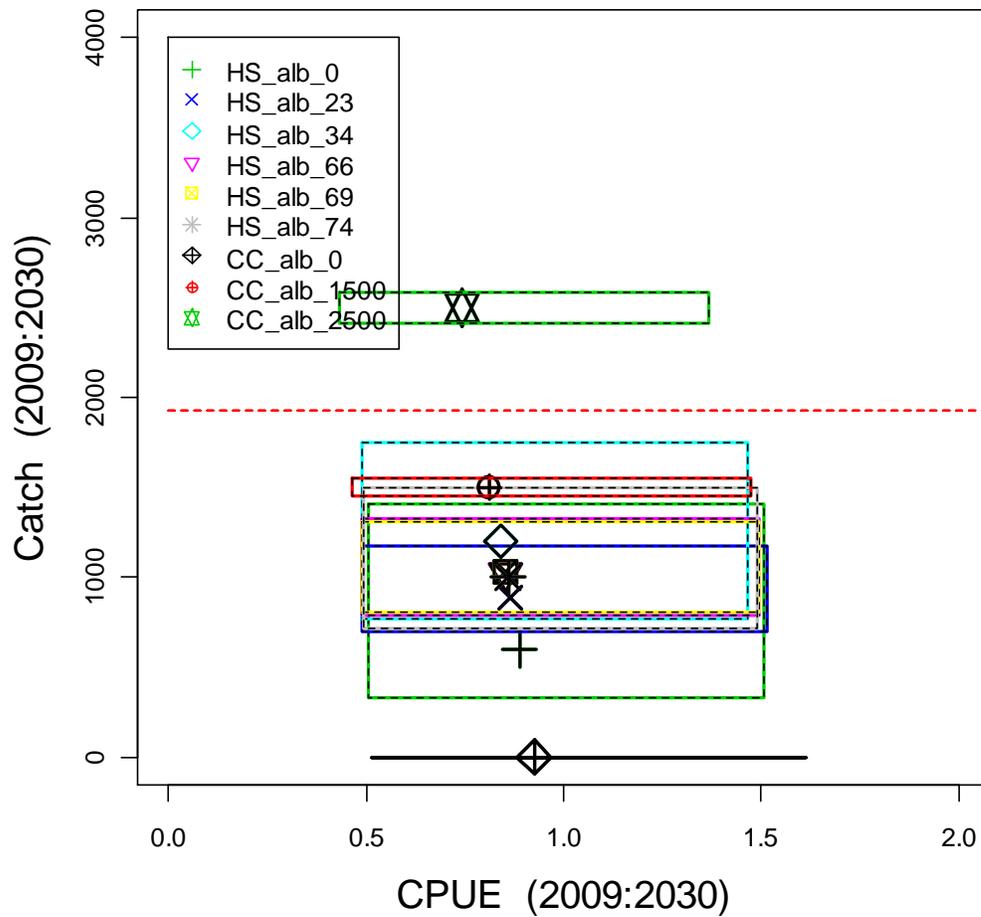


Figure 12. Albacore tuna trade-off plot illustrating the estimated relationship between Catch and CPUE for a range of Harvest Strategies. Symbols represent the median performance (averaged over time) for all realizations; boxes bound the 10th-90th percentile region in both dimensions. The broken red horizontal line indicates the 2007 catch level.

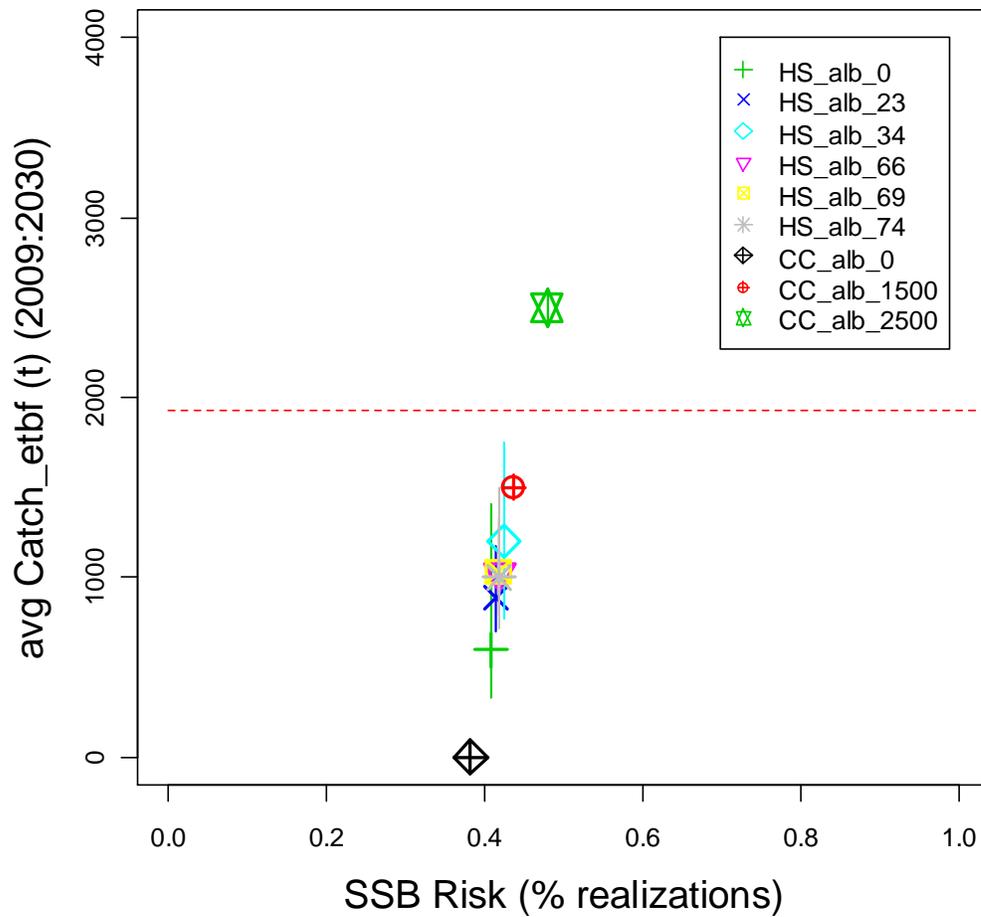


Figure 13. Albacore tuna trade-off plot illustrating the estimated relationship between Catch and biomass risk. Risk is defined as the proportion of stochastic projections in which spawning biomass (SSB) drops below 20% of unfished levels (0.2B₀) more than 10% of the time (3 or more years). Dotted vertical lines show how specific levels of risk might be used to remove some candidate HSs from further consideration. The broken red horizontal line indicates the 2007 catch level.

3.4 Swordfish: operating model and harvest strategy evaluation

Conditioning of the swordfish operating model was simpler because the swordfish assessment was conducted with the requirements of the harvest strategy evaluation in mind (Kolody et al, 2008), and as such we are generally more confident in these results. The spatial structure in the assessment consists of the two western areas shown in Figure 14 and the two regions are adopted for the ETBF and non-ETBF regions in the operating models. Other key reference set assumptions that differ by species:

- Unlike the other species, non-ETBF Effort is assumed to change in relation to the harvest strategy. This reflects the fact that New Zealand has been the other major fishery in the region in recent years, and it shows a similar catch and effort history to the ETBF, and seems to be operating under similar economic conditions.
- The ETBF region is assumed to have 50% of the operating model equilibrium population and new recruitment.
- The migration linkage between the ETBF and non-ETBF regions is assumed to be an equal mix of scenarios with 1% and 20% per quarter diffusive mixing.
- The assessment had a strong emphasis on the quantification of uncertainty. Fourteen different assessment models were used to represent alternative plausible population dynamics in the operating models (and these 14 span the range of uncertainty reflected in a full set of 192 models).

Main concerns about the swordfish operating model:

- Migration within the ETBF and non-ETBF regions remains poorly quantified. However, a number of conventional and electronic tags, and consistency of catch rates among fleets, provide some justification for treating the SW Pacific population as reasonably distinct from the SE (and North) Pacific populations.

There is reasonable agreement between the predicted and observed swordfish CPUE for the ETBF, and the biomass is estimated to return to pre-1990 levels if fishing stops.

Figure 15 illustrates the estimated relationship between Catch and CPUE for a range of Harvest Strategies. In these figures the times series is split into 2 temporal groups, and CPUE is in terms of the catch rates for the “far off” areas in the ETBF. The target CPUE in these units would be approximately 1000.

Figure 16 illustrates the estimated relationship between Catch and biomass risk associated with the different harvest strategies. Since it is assumed that the non-ETBF effort is managed the same as the ETBF effort in these scenarios (unlike the other species), these figures do not partition the specific effect of the ETBF. However, given that the ETBF has the largest catches in the region, the largest fishing impact is also attributable to the ETBF.

Main conclusions from the swordfish HS evaluations to date:

- For the level of effort from these HS evaluated there is a level of conservation risk.

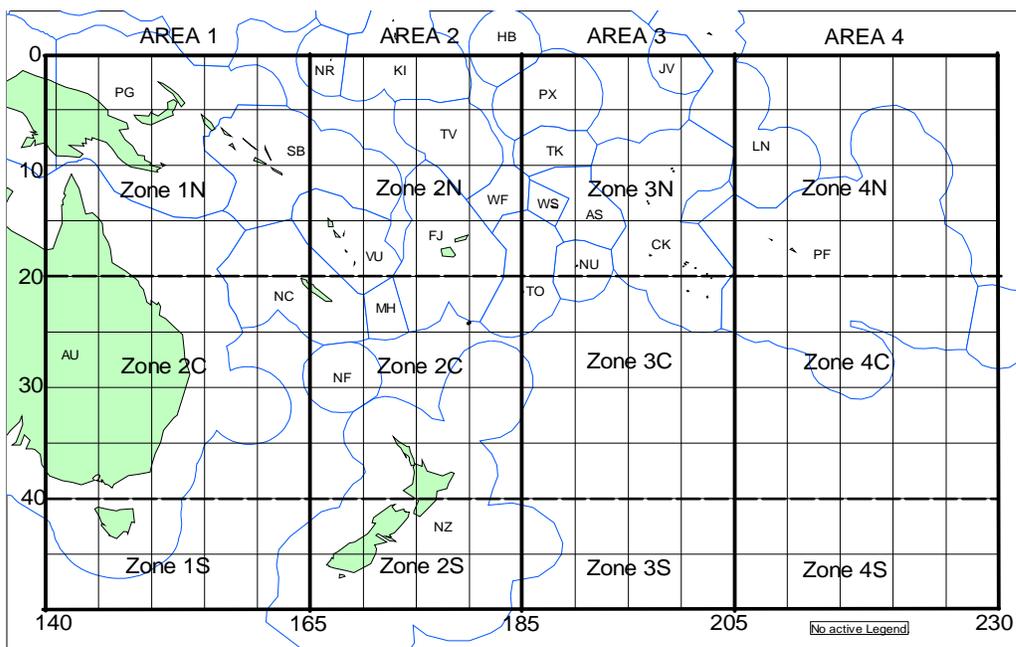


Figure 14. Swordfish assessment domain from Kolody et al. (2008). While different spatial areas were explored, only the South-West Pacific assessment (Areas 1-2) was considered successful. In the operating model, the ETBF is defined as Area 1 and non-ETBF as Area 2.

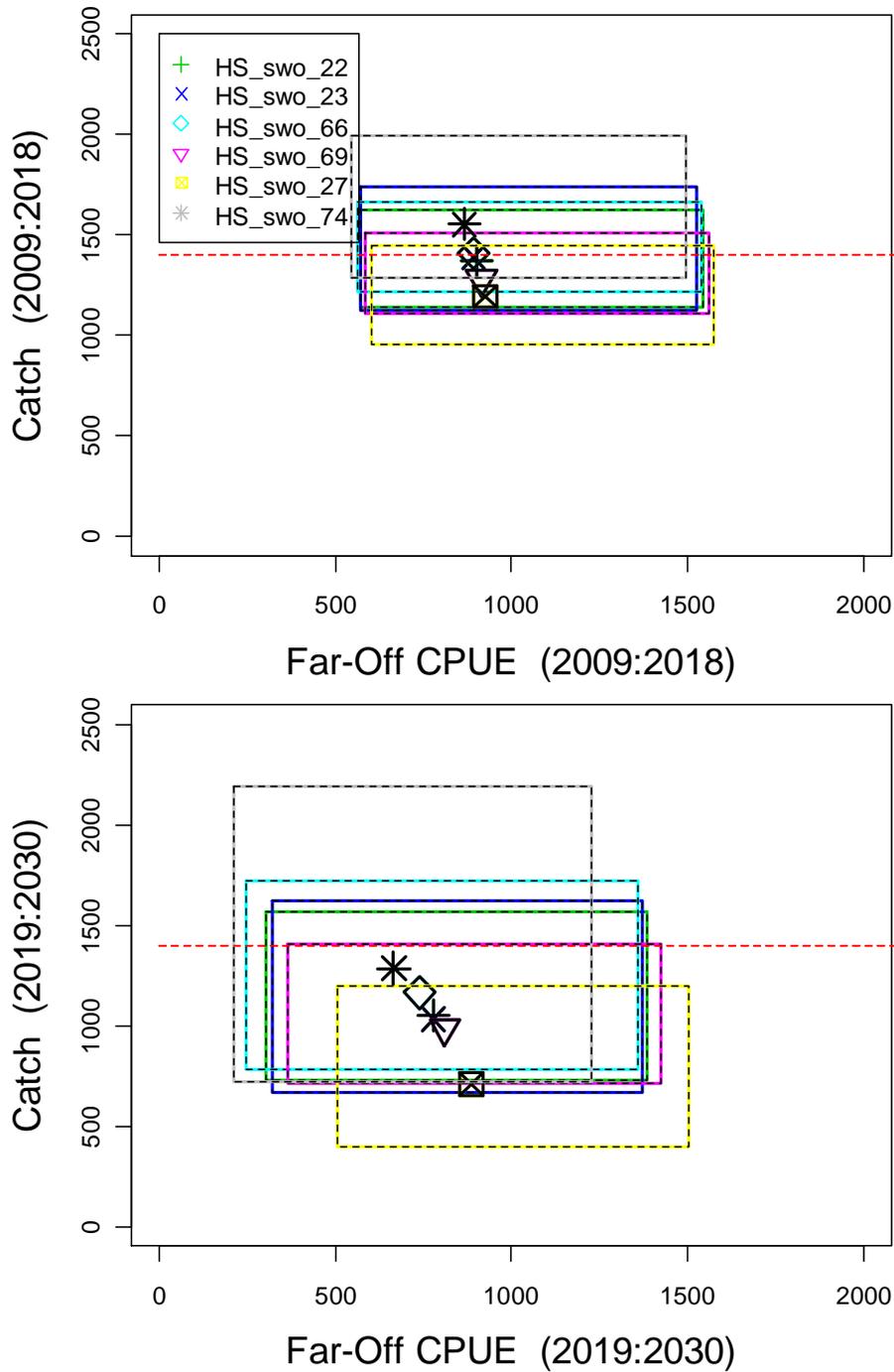


Figure 15. Swordfish trade-off plot illustrating the estimated relationship between Catch and CPUE for a range of Harvest Strategies. Symbols represent the median performance (averaged over time) for all realizations; boxes bound the 10th-90th percentile region in both dimensions. Unlike the other species, the swordfish plots are partitioned into time periods 2009-2018 and 2019-2030.

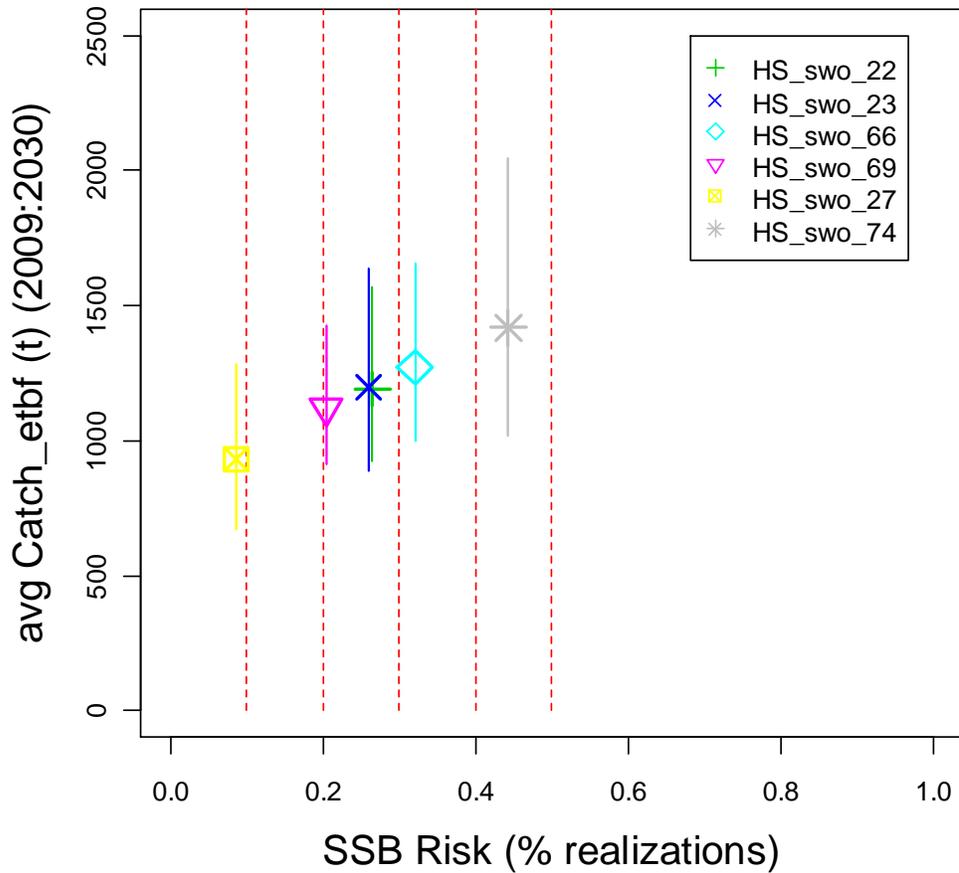


Figure 16. Swordfish trade-off plot illustrating the estimated relationship between Catch and biomass risk. Risk is defined as the proportion of stochastic projections in which spawning biomass (SSB) drops below 20% of unfished levels (0.2B0) more than 10% of the time (3 or more years). Dotted vertical lines show how specific levels of risk might be used to remove some candidate HSs from further consideration. Horizontal reference line is 1400 t (interim catch limit).

3.5 Striped Marlin: operating model and harvest strategy evaluation

The most recent striped marlin stock assessment in the region is described in Langley et al. (2006). The spatial structure consists of the whole region shown in Figure 17. In the operating model, this population was partitioned into an ETBF region and a non-ETBF region, with a dividing point approximately corresponding to 165E. Other key reference set assumptions for striped marlin:

- Non-ETBF effort is assumed to remain constant at 2003 levels.
- The ETBF region is assumed to have 36% of the operating model equilibrium population and new recruitment.
- The migration linkage between the ETBF and non-ETBF regions is assumed to be an equal mix of scenarios with 1% and 20% per quarter diffusive mixing.

Main concerns about the striped marlin operating model:

- Migration within the ETBF and non-ETBF regions is poorly understood. However, given that the largest (reported) catches have been from the ETBF region, this might be less of a concern than for the other target species.
- Only a single ‘preferred’ assessment model was adopted for the operating model, so the uncertainty is understated.
- The striped marlin assessment was considered preliminary when it was produced, and the data used are now several years out of date.

The operating model results show that there is reasonable agreement between the predicted and observed striped marlin CPUE for the ETBF. The biomass is estimated to almost triple if fishing stops, with biomass returning to levels seen around 1960 (but lower than the 1950s).

Figure 18 illustrates the estimated relationship between Catch and CPUE for a range of Harvest Strategies. The operating model estimates that the ETBF fishery has a large effect on the regional population dynamics of striped marlin, such that relatively small changes in current catches are predicted to have a large effect on CPUE. Figure 19 illustrates the estimated relationship between Catch and Biomass risk associated with the different harvest strategies. The plot indicates that the regional striped marlin stock is likely to be in the region of the limit reference point for the Commonwealth Harvest Strategy Policy, and that it is the harvesting in the ETBF that is currently having the dominant impact (i.e. CC_stm_0 indicates that the risk would be reduced substantially if the ETBF catch was zero while the non-ETBF effort remained constant at 2003 levels). The projected impact of the current ETBF harvest on striped marlin is estimated to be higher than for any of the other target species.

Primary conclusions from the striped marlin HS evaluations to date:

- The HS simulations suggest that the ETBF is the main fleet influencing the status of the regional striped marlin population, and that current catches are maintaining the biomass at a level close to the limit reference point for the Commonwealth Harvest Strategy Policy with a reasonably high level of risk.

- These observations should be tempered, however, by noting that the WCPFC assessment is preliminary, several years old, with poor spatial resolution and poor uncertainty quantification.
- Nevertheless, the implications of these results need to be carefully considered because:
 - While the spatial domain of the assessment does not resolve migration dynamics between the ETBF and non-ETBF adequately, the most substantial catches were taken out of the ETBF region (historically by Distant Water Fishing fleets). The assessment model is estimating that either i) the ETBF population represents the bulk of the population, and it is considerably depleted (while non-ETBF regions may not be depleted, but represent only a small number of fish), or ii) the population is well mixed and depleted, such that the small catches in the ETBF are sufficient to limit recovery of the spawning biomass of the whole region.
 - The short ETBF CPUE time series is consistent with the assessment even though the Australian CPUE was not actually included in the assessment model.

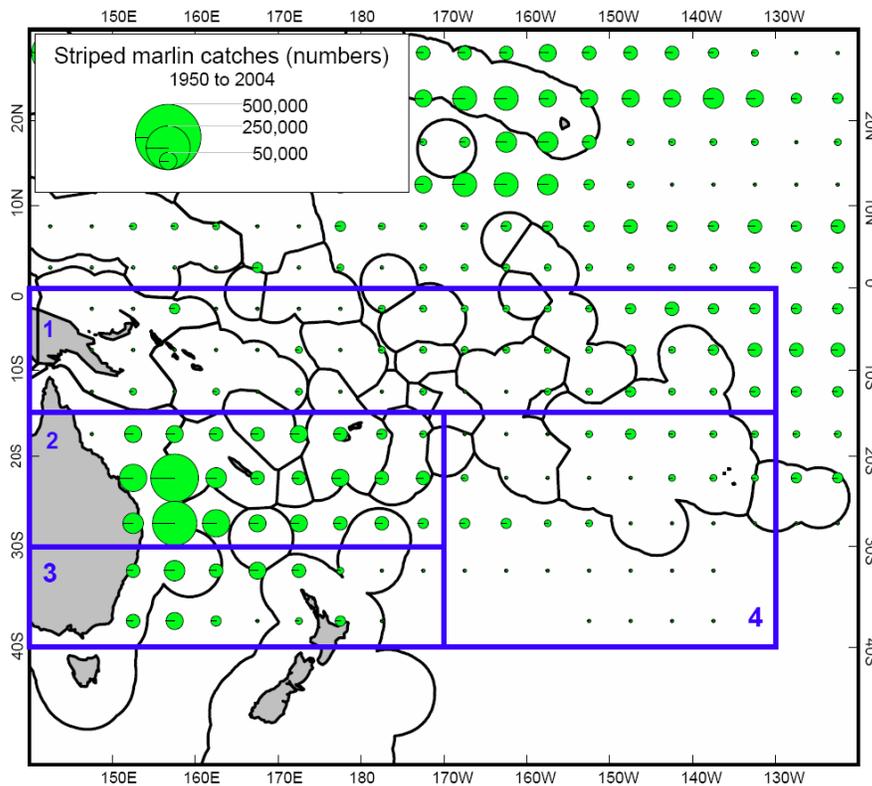


Figure 17. Striped marlin assessment domain (from Langley et al. 2006). Areas are used for fishery definitions but the fish population is aggregated across areas 1-4.

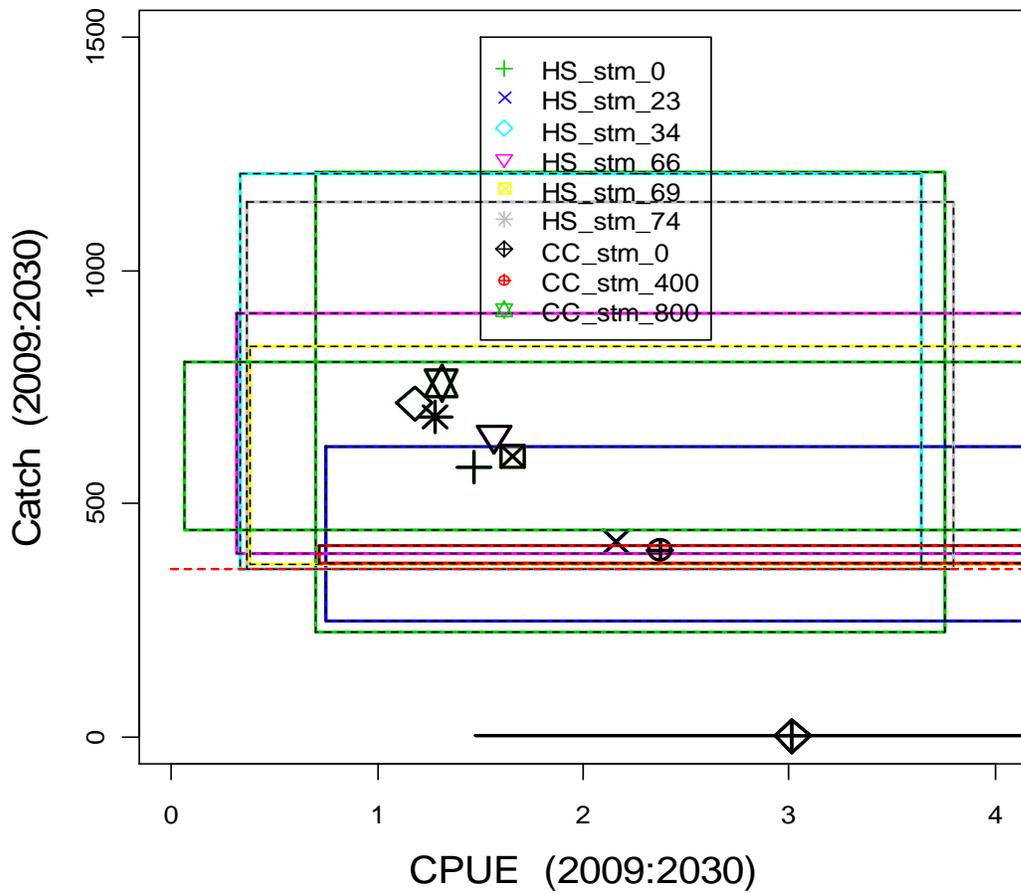


Figure 18. Striped marlin trade-off plot illustrating the estimated relationship between Catch and CPUE for a range of Harvest Strategies. Symbols represent the median performance (averaged over time) for all realizations; boxes bound the 10th-90th percentile region in both dimensions. The broken red horizontal line indicates the 2007 catch level.

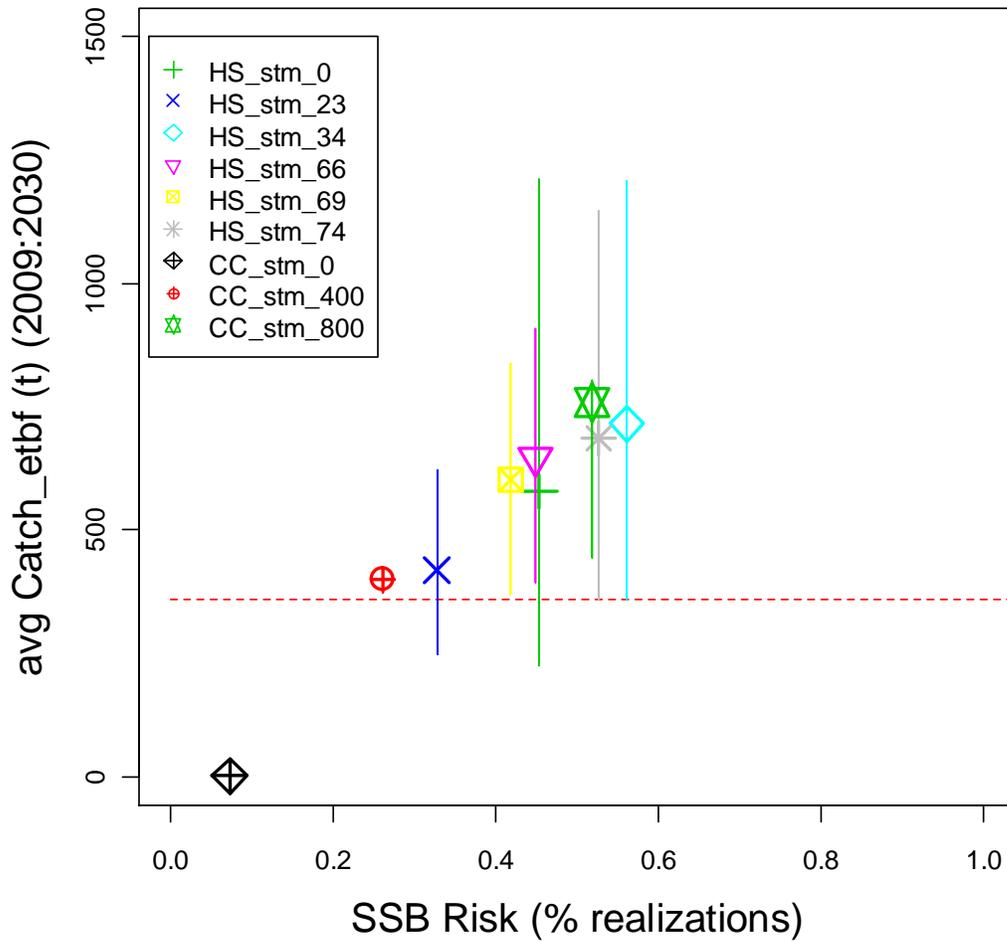


Figure 19. Striped marlin trade-off plot illustrating the estimated relationship between Catch and biomass risk. Risk is defined as the proportion of stochastic projections in which spawning biomass (SSB) drops below 20% of unfished levels (0.2B₀) more than 10% of the time (3 or more years). Dotted vertical lines show how specific levels of risk might be used to remove some candidate HSs from further consideration. The broken red horizontal line indicates the 2007 catch level.

4. Discussion

For each species, the performances of the various individual HS are shown as trade offs between biological risk and average catches and catch rates. The intention is to provide managers and the fishing industry with the basis to select a feedback harvest strategy by examining the trade off in performance between these management outcomes. On the basis of these comparisons, fishery managers will select a harvest strategy specification for each species and these will be implemented in the ETBF in Nov 2009 under the formal management plan for the fishery.

The harvest strategies evaluated are intended to be robust to the uncertainties specified in the operating models and underlying assessment models. This means that the chosen HS should perform reasonably well in terms of risk and limit reference points regardless of whether the stock is productive or unproductive. The feedback harvest strategies should allow for higher catches to be taken if the stock is productive, and prevent catch rates and the biomass from declining to very low levels. In comparison with constant future catch scenarios, the adaptive feedback harvest strategies were often able to sustain higher catches (when the stock turned to be productive), or reduce the catches to lower the biomass risk (when the stock turned out to be unproductive). However, the HSs were most effective for the simulation scenarios in which the ETBF is one of the main fisheries. If the ETBF fishery has only a minor influence on the stock, then the HSs have the potential to recommend management actions that would have substantial effects on the domestic fishery, without generating the intended reduction in risk to the spawning biomass of the regional population.

The key uncertainties that we have attempted to incorporate in the operating models cover a range of uncertainties in the stock assessments, including connectivity and migration rates, international fleet operations, future recruitment dynamics and others. The assessment uncertainty for swordfish has been the most thoroughly represented (i.e. 12 separate assessment models were tested, which spanned the stock status uncertainty from 192 different model specifications), while only a single or very few assessment models were used for the other species (1 for yellowfin, albacore and striped marlin; 5 for bigeye). The operating models included three alternative scenarios for migration rates that ranged from low mixing to rapid mixing between the two areas. In addition, three options for the international fleet future operations were explored across the 5 species. For yellowfin, albacore and striped marlin, constant recent effort in the non-ETBF area were projected into the future. For swordfish, the non-ETBF area was managed by the same HS rule operating in the ETBF, and, for bigeye, the effort was incrementally reduced down by 30% from recent levels (in an attempt to reflect the potential impact of the WCPFC Conservation Management Measure for bigeye tuna). In “robustness tests” of the harvest strategies, these alternative scenarios are evaluated for each species in combination with migration rates and other uncertainties. Stochastic variability in recruitment levels, CPUE observation error and implementation error were also incorporated. Evaluating harvest strategies across a wide range of plausible operating models, has the potential to result in higher values for absolute risk compared with more

constrained evaluations. In our view, however, it is more appropriate to consider the relative performance of alternative strategies evaluated under the same circumstances. It is for this reason that we have discussed risk in terms of relative risk.

The HS evaluations highlighted the stocks that may currently be at risk, in terms of having low biomass relative to historical levels, and the effects of unilateral management action (i.e. implementation of the HS on the ETBF) on these stocks varied by species. Bigeye and striped marlin were both estimated to be at or close to limit reference points. For striped marlin, although the assessment model is still being developed, it appears that Australian management actions can significantly impact the stock biomass. For bigeye, Australian management action would likely be less effective than if the HS were pursued in a multilateral context. Albacore and swordfish appear to currently have a lower level of biological risk than bigeye and striped marlin, with domestic management of albacore having little further impact on relative risk (though we have the least confidence in the albacore OM for a number of reasons), and domestic swordfish catches potentially having an impact in terms of increasing risk. Our level of confidence in these results varies in relation to the level of development of the stock assessment and supporting data sources. The range of results shown here illustrates domestic management sensitivity to connectivity, migration rates and the operations of international fleets.

Development of operating models that represent the ETBF and regional stocks was complicated by the mismatch in spatial structure in the underlying assessments and the spatial scales required for Australia's domestic management needs. The spatial resolution of the swordfish assessment was well matched with the need to evaluate the ETBF HS relative to the WCPO fisheries because the assessment was developed with the MSE work in mind. The assessments for the other species, however, were not. The albacore and striped marlin assessments have spatial partitions for fisheries but have a single population in each, covering large parts the Pacific Ocean. The yellowfin and bigeye assessments have spatial structure, but the Australian fishery is included in a large spatial area that also includes other fisheries. There is limited empirical information about the connectivity between the ETBF area and the greater western central Pacific stocks, which differ by species. The partitioning of the stock assessment structure to the operating model was based on estimates from the stock assessment and other available data. Planned additional work before completion of this project includes evaluating HS using alternative spatial partitioning from the WCPFC stock assessments. These will be robustness tests to evaluate whether the HS will give reasonable performance given the uncertainty in the connectivity between the ETBF and greater Western Central Pacific Ocean stocks.

These additional robustness tests are likely to be useful for identifying how sensitive the management outcomes are to assumptions about connectivity. However, they might not be very helpful for recommending a course of action in the short term if the HSs are sensitive to these results. Given that the WCPFC assessments are all tailored to this coarse spatial representation, we would expect that other countries considering the application of "in zone" management measures for their domestic fleets will confront a similar problem of local vs: regional population uncertainty. Additional research to

refine stock structure and movement assumptions would presumably help to refine these issues.

While this process is being undertaken for the ETBF fishery specifically, it illustrates the general process that might be undertaken on a broader scale if the WCPFC decided to use Management Strategy Evaluation to develop and select formal harvest strategies for regulating WCPFC fisheries. While the process to date has indicated that an ETBF-based HS might have limited capacity to influence the local stock status of some species (due to strong links with regional populations), it would be expected that a broader WCPFC-based initiative, involving all fleets harvesting a stock, would be more effective in meeting the objectives of both regional and domestic fisheries management.

5. Acknowledgements

The staff at the SPC provided most of the stock assessment results on which the operating models for this work are based. Adam Langley and Simon Hoyle gave patient explanation of the assessments. Participants from the ETBF Resource Assessment Group and ETMAC have provided critical insight, guidance on HS performance measures and behaviours and feedback throughout the project. The project is jointly funded by the FRDC, CSIRO Wealth from Oceans Flagship and Australian Fisheries Management Authority.

6. References

- Anon. 2007. Commonwealth fisheries harvest strategy policy and guidelines. Australian Government Department of Agriculture, Fisheries and Forestry.
- Campbell, R., Davies, C., Prince, J., Dowling, N., Kolody, D., Basson, M., McLoughlin, K., Ward, P., Freeman, I., and A. Bodsworth. 2007. Development and preliminary testing of harvest strategies for the Eastern and Western Tuna and Billfish Fisheries. Report to the Australian Fisheries Management Authority.
- Campbell, R. 2009. Size-Based Standardised CPUE for Target species caught in the ETBF Longline Fishery. Working Paper for the Australian Eastern Tuna and Billfish Fishery Resource Assessment Group held 25-26 June 2009, Hobart
- Hoyle, S., Langley, A. and Hampton, J. 2008. Stock Assessment of albacore tuna in the south Pacific Ocean. WCPFC-SC4-2008/SA-WP-8.
- Kolody, D., Preece, A., Davies, C., Hartog, J. and Campbell, R. 2009. Eastern Tuna and Billfish Fishery Harvest Strategy: A brief overview of management performance tradeoffs and questionnaire for RAG participants. Working Paper for the Eastern Tuna and Billfish Fishery RAG Mar 2009.

- Kolody, D., Preece, A., Davies, C. and Hartog, J. 2009. Eastern Tuna and Billfish Harvest Strategy Evaluation: Preliminary Simulation Testing Results for all 5 TargetSpecies. Working Paper for the Eastern Tuna and Billfish Fishery RAG June 2009.
- Kolody, D., Campbell, R. and Davies, N. 2008. A MULTIFAN-CL Stock Assessment of South-Pacific Swordfish 1952-2007. WCPFC-SC4-2008/SA-WP-6 (Revision 1).
- Kolody, D., Dowling, N., Preece, A. and Davies, C. 2007. Application of a harvest strategy evaluation approach to the Australian swordfish fishery. WCPFC-SC3-ME SWG/WP-5.
- Langley, A., Hampton, J., Kleiber, P., Hoyle, S. 2008. Stock assessment of bigeye tuna in the western and central Pacific Ocean, including an analysis of management options. WCPFC-SC4-2008/SA-WP-1 Rev.1
- Langley, A., Hampton, J., Kleiber, P., Hoyle, S. 2007. Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. WCPFC-SC3-SA SWG/WP-01
- Langley, A., Molony, B., Bromhead, D., Yokawa, K, and Wise, B. 2006. Stock assessment of striped marlin (*Tetrapturus audax*) in the southwest Pacific Ocean. WCPFC-SC2-2006/SA WP-6.