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Considering Uncertainty When Testing and Monitoring WCPFC Harvest Strategies.

WCPFC-SC15-2019/MI-WP-06

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Executive Summary

Initial developments in the harvest strategies for WCPO skipjack and South Pacific albacore have focussed on the inclusion of uncertainty in the evaluations to test candidate management procedures (MPs) through the use of a reference set of plausible uncertainty scenarios (Scott et al., 2018b). The next stages will require developing additional elements to further consider uncertainty in the harvest strategy approach:

- The robustness set: the set of additional uncertainty scenarios which are less likely, though still plausible and contribute to the selection of MPs before adoption;
- Exceptional circumstances: an important component of the monitoring strategy that are considered once the selected MP is in operation.

The robustness set is used to test whether the performance of the MP is substantially worse when exposed to the additional uncertainties. Judgement can then be made on whether to retain that MP. It is recommended that the robustness set includes a smaller number of scenarios than the reference set.

In this paper we explore some of the proposed scenarios in the robustness set for skipjack, specifically more extreme effort creep and hyperstability (density-dependent catchability), and alternative movement scenarios. The results presented here are exploratory only but will inform future model development.

The role of the monitoring strategy is to confirm that key management objectives are being achieved by the MP selected by managers and implemented in the fishery. There has been limited activity on this element of the harvest strategy to date but should be subject of increased focus in future work.

A key part of the monitoring strategy is the identification and agreement by stakeholders of situations within the fishery, or stock, that are term 'exceptional circumstances'. These are events that fall outside the range of assumptions over which the adopted MP has been tested. Exceptional circumstances should be agreed prior to implementation of the selected MP and be defined in broad terms. If exceptional circumstances occur it will be necessary to revisit the MP and determine future action.

We invite WCPFC-SC15 to:

- Note the importance of continuing to develop the robustness set;
- Agree with the proposed staged approach for applying the robustness set as described here;
- Note that the identification and agreement of exceptional circumstances will require discussions between SC and the Commission, and should include input from stakeholders;
- Renew focus on the development of the monitoring strategy for WCPO tuna stocks.

1 Introduction

A key feature of the harvest strategy approach is the explicit consideration of uncertainty. Throughout the harvest strategy approach, uncertainty must be considered in a number of ways. During the process of selecting a management procedure (MP), candidate MPs will be tested against a range of plausible scenarios to determine if they are likely to achieve agreed management objectives. Once an MP has been selected and is being applied to the fishery, it will then be necessary to monitor its performance, through the monitoring strategy. Understanding the range of uncertainty considered in the modelling framework when testing an MP will be an important consideration when evaluating its actual performance in the real world. As part of the monitoring strategy it will be necessary to define 'exceptional circumstances' (see Section 3.1) to identify those situations that fall outside of the range of scenarios against which the implemented MP has been tested.

The uncertainty scenarios considered for testing and selecting an MP are divided into a reference set and a robustness set (see Section 2). The first step of the process for selecting an MP will be to refine the list of all candidate MPs to a small selection of preferred MP options using the reference set. This small selection of preferred MPs should then be tested against the robustness set, as a secondary check of performance, after which the final selection can be made, considering all of the information available.

Initial developments in the harvest strategies for WCPO skipjack and South Pacific albacore have focussed on the inclusion of uncertainty in the evaluations to test candidate MPs through the use of a reference set (Scott et al., 2018b). The next stages will require developing additional elements to further consider uncertainty in the harvest strategy approach:

- The robustness set: the set of additional plausible uncertainty scenarios that contributes to the selection of MPs before adoption;
- Exceptional circumstances: an important component of the monitoring strategy that are considered once the selected MP is in operation.

Development of the robustness set will help to identify and refine the definition of exceptional circumstances. This report describes initial progress in the development of these elements and considers future work.

2 Robustness set

A key element of developing a harvest strategy for WCPO tuna stocks is evaluating proposed management procedures through a simulation process known as management strategy evaluation (MSE) (Scott et al., 2017). One of the main components of the MSE framework is the operating model (OM) (Punt et al., 2014). A range of OMs should be identified, each one representing a specific plausible hypothesis on uncertainty in stock biology (e.g. natural mortality, movement) or fishery dynamics (e.g. effort creep). The aim is to ensure that the OMs cover all plausible and important sources of uncertainty, against which the performance of candidate MPs should be evaluated (Scott et al., 2018a, 2019b). The preferred MP should be the one that has the highest chance of achieving the objectives while also being robust to uncertainty.

The suite of OMs is divided into a reference set, considered to reflect the most plausible hypotheses on uncertainty, and a robustness set, considered to reflect less likely but still plausible hypotheses and which may have a stronger impact on the performance of the MP (Rademeyer et al., 2007).

The relative performance of candidate MPs is evaluated from performance indicators calculated across all combinations of uncertainty in the reference set. The results should not be disaggregated by the different factors that make up the reference set because all of the OMs in the reference set are considered to be equally plausible.

The robustness set is used to give a secondary indication of performance. Instead of testing candidate MPs against all combinations of uncertainties in the robustness set, they are tested against specific uncertainties to see how it impacts their performance, i.e. the uncertainties are considered one at a time, similar to the 'one-off' assessment runs conducted for the stock assessments. This tests whether the performance of the MP is substantially worse when exposed to the additional uncertainties of the robustness set. Judgement can then be made on whether to retain that MP given that it performs poorly against a scenario that is considered less likely, though still plausible. It is recommended that the robustness set includes a smaller number of scenarios than the reference set (Scott et al., 2019a).

In this paper we explore some of the proposed scenarios in the robustness set for skipjack, specifically effort creep, hyperstability (density-dependent catchability) and movement. This report is not a full analysis of the robustness set of OMs. The results presented here are exploratory only but will inform future model development and OM conditioning.

2.1 Sources of uncertainty in the robustness set

The sources of uncertainty currently specified for the robustness set for skipjack and the corresponding scenarios in the reference set are shown in Table 1. Note that Table 1 is a subset of the full MSE uncertainty grid outlined in Scott et al. (2019b).

Axis	**Levels**		**Options**		
	Reference	Robustness	**0**	**1**	**2**
Observation Error					
Catch and effort	1	**1**	20%	**30%**	
Tag recaptures	1	**2**	status quo	**low**	**none**
Model Error					
Movement	1	**1**	estimated	**El Nino/La Nina**	
DD catchability (k) ‡	2	**1**	0	-0.5	**-0.9**
Implementation Error					
Effort creep	2	**1**	0%	2% p.a.	**3%**

Table 1: Proposed skipjack OM robustness uncertainty scenarios (in bold) and the corresponding scenarios in the reference set. Note that the full reference set includes additional scenarios and error types. ‡ Denotes those scenarios for which a dedicated fit of MULTIFAN-CL is required.

In this section the initial basis for including these scenarios in the robustness set is outlined. Initial analyses of these scenarios is presented in Appendices A, B and C.

2.1.1 Observation Error

In the current skipjack evaluation framework, variability in future catch and effort is included in the simulations by a user-specified coefficient of variation (CV) that applies to all fisheries in the model. A CV of 20% was determined from the OM conditioning process (Scott et al., 2018a,b) and used for the reference set and a slightly higher value of 30% suggested for the robustness set. However, it was noted at the time that a preferred approach to introduce observation error into future catch and effort values would be to resample the effort deviates from the fitted MULTIFAN-CL model. This approach requires further development of MULTIFAN-CL and has not been considered further here.

Future tag recaptures are generated in the simulation framework conditional on the number and spatial-temporal distribution of tag releases (Scott et al., 2018a). Two scenarios for alternative tag release numbers have been proposed for the robustness set but have not yet been examined in detail.

2.1.2 Model Error

At the request of members, scenarios for moderate hyperstability (implemented using density dependent catchability) that were originally allocated to the robustness set were moved to the reference set. A new scenario, representing strong hyperstability is proposed here for the robustness set.

An initial investigation of this scenario is described in Appendix B using a limited set of OMs. The impact of hyperstability on the performance of HCRs is small in the example results, and a candidate MP might not be rejected on the basis of such performance. However, the impact of hyperstability may be more pronounced when considered across a range of alternative OMs, and it will still be necessary to conduct thorough robustness tests.

A suggested alternative movement scenario for the robustness set was to incorporate temporal variability in movement rates as a consequence of La Niña and El Niño events. The approach would be to estimate separate movement matrices for specific El Niño Southern Oscillation (ENSO) conditions and to randomly replace the movement matrix used in the MULTIFAN-CL projections to simulate appropriate oscillatory dynamics in ENSO events. An initial investigation of this approach and suggestions for further work are given in Appendix C.

2.1.3 Implementation Error

At the request of members, scenarios for effort creep that were originally allocated to the robustness set were moved to the reference set. A new scenario, representing a higher level of effort creep is proposed here for the robustness set.

An initial investigation of this scenario is described in Appendix A using a limited set of OMs. The results demonstrate that effort creep can impair the performance of an HCR. However, the results also demonstrate that even though the performance of the HCRs is impaired under a more extreme effort creep scenario, the HCRs are still able to mitigate some of the potential impacts of effort creep.

3 Monitoring strategy

The monitoring strategy is a key element of the harvest strategy approach, as detailed in CMM 2014-06. Once an MP has been selected by managers on the basis of the MSE simulation results, there is a need to monitor the fishery and stock in relation to the key biological, economic, social and ecosystem objectives, to ensure they are being achieved in the real world in the way the simulations suggest they should be. For example, once the MP has been implemented within the fishery, is the stock assessed to be around the target reference point? Are the levels of CPUE those expected from the MSE results?

The monitoring strategy may require the collection of new information and data. For example, monitoring economic objectives may require new economic information to be gathered. The guidelines for voluntary submission of economic data is an example of this.

The harvest strategy work plan (SC15-MI-IP-01) has scheduled the development of the monitoring strategy for each stock, but there has been limited focus on this element in recent years. This is consistent with the current development of management procedures in the WCPO, but greater focus will be needed in the near future.

3.1 Exceptional circumstances

A key part of the monitoring strategy is the identification and agreement by stakeholders of situations within the fishery or stock that are termed ‘exceptional circumstances’. In general terms, exceptional circumstances are events that fall outside the range of assumptions over which the MP that has been adopted for the fishery has been tested. They may also include situations where the trajectory of the stock has not responded as expected to management action. For example, if biomass has fallen below the limit reference point, catches continually exceeded some upper threshold, or general behaviour of the fishery contrasts significantly from the range of behaviours expected through the simulation testing. Exceptional circumstances should be agreed prior to implementation of the selected MP and, to the extent possible, be defined in broad terms (Scott et al., 2019a).

An important role of the monitoring strategy is to be able to identify when exceptional circumstances are occurring. This is important as, if they do occur, it will be necessary to revisit the MP and determine future action.

The MSE expert consultation workshops have stressed the importance of discussing exceptional circumstances throughout the consultation process and to highlight that in spite of our best predictions the future remains uncertain and that the MSE should not be considered a crystal ball (Scott et al., 2016).

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A Effort creep

A.1 Background

Effort creep describes the situation where fishing vessels improve their ability to catch fish over time within an effort-managed system, and hence catch more per fishing day, i.e. it can lead to the increase in fishing power of a unit of nominal effort (Muller et al., 2018). This may create economic benefits through increased efficiency. However, effort creep may become a problem if adjustments are not made to management systems to take into account the resulting increases in fishing mortality per ‘fishing day’.

In the presence of effort creep there is an increasing difference between the ’observed’ effort and the ’effective’ effort. It is possible that this will affect the performance of candidate MPs, particularly those which aim to control effort levels. This is partly because the estimation method of the MP may not adequately detect the changing relationship between effort and fishing mortality. This may lead to an overestimate of biomass, thereby providing increasingly biased inputs to the HCR. Additionally, the HCR may set inappropriate levels of effort as it does not take into account the increase of fishing power per unit of nominal effort.

Several recent studies have tried to quantify the level of effort creep in WCPO purse seine fisheries and to identify potential indicators of effort creep (Tidd et al., 2015; Pilling et al., 2016; Muller et al., 2018). Whilst there is considerable potential for effort creep, particularly in the associated purse seine fishery, there is no clear understanding of how it manifests or what scale it might be.

For the skipjack evaluations we assume a simple linear trend in effort creep whereby effective effort increases progressively throughout the evaluation period (Scott et al., 2019b). Effort creep is assumed to apply to the purse seine fisheries in model regions 2, 3, and 5. The reference set of OMs has two levels of effort creep: 0 and 2% per annum. The robustness set has an additional level of 3% per annum, meaning that at the end of a 30 year projection, the effective effort is almost two times higher than the perceived effort.

A.2 Method

The potential impact of effort creep on the performance of two harvest control rules (HCRs) was evaluated by running MSE simulations using an OM from the robustness set. To illustrate the impact of effort creep, a base case OM from the reference set was used for comparison (Table 2). Note the selected base case OM is not considered to be more or less likely than any other OM in the reference set. The robustness set OM differed from the base case by including a high level of effort creep (3% per annum)

For each OM (the base case and robustness set), 250 MSE simulations were run using the framework described in Scott et al. (2019b). Each simulation included variability in the recruitment and in

Factor	Level
Steepness	0.8
Mixing period	1 quarter
Tag overdispersion	1.1
Hyperstability	Density dependent catchability = 0 (i.e. no hyperstability)
Recruitment autocorrelation	0
Recruitment variability	Residuals selected from the year range 1982-1941
Effort creep	0 per annum (i.e. no effort creep)
Movement	Future movement is as the past
Tag scenario	Reporting rate = 0.6, numbers released based on PTTP, release frequency = every 3 years
Catch and effort observation	error CV = 20%

Table 2: The base case scenario from the reference set of operating models.

the pseudo data generation process. The random sequence used to generate recruitment variability and pseudo data was the same for each OM meaning that the results were directly comparable.

The HCRs are shown in Figure 1. The estimated adult depletion, $SB/SB_{F=0}$, is used by the HCR to set a multiplier to be applied the fishing effort reference level.

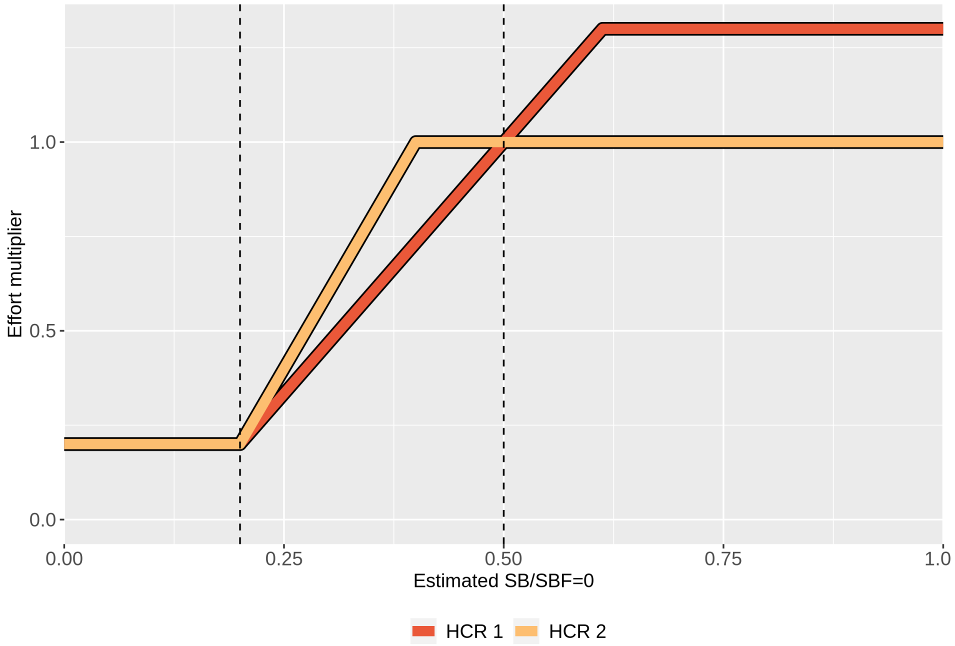

Figure 1: The shapes of the tested HCR.

A.3 Impact on HCR performance

Due to the feedback between estimated stock status and the fishing effort level that is set, untangling the impact of effort creep on the performance of the HCR can be complicated. As mentioned above, effort creep can have a positive impact on the economic performance of the fishery through increases in fishing efficiency. For the two HCRs tested here, the presence of effort creep leads to higher catches and higher CPUE over the time period of the simulations (Figures 2 and 3) even though biomass decreases (Figure 5). This arises because CPUE is measured using observed effort whereas catches and stock biomass are the result of the effective effort.

When effort creep is present, HCR 1 generally sets lower effort levels, apart from in the early periods of the simulation (Figure 4). However, due to the impact of effort creep, this reduction in observed effort does not sufficiently reduce effective effort, leading to higher than expected levels of effective effort and lower depletion (Figure 5). This effect is not seen for HCR 2 as it has a longer upper threshold for maximum effort (Figure 1).

The overall effect is that the performance of both HCRs is impaired. Although neither HCR is effective at achieving the target depletion level of $SB/SB_{F=0} = 0.5$ with or without the presence of effort creep, when effort creep is present the depletion is lower and decreases over time (Figure 5). This demonstrates that effort creep can have a detrimental impact on the stock status, even when managed using a HCR. It is therefore important that the adopted HCR is robust to possible impacts of effort creep.

With an effort creep rate of 3% per annum, under a 30 year status quo scenario, we would expect the final effective effort to be 1.9 times the effective effort at the start of the simulation (2016). For both HCRs, the final effective effort relative to 2016 under the effort creep scenario is lower than 1.9, with the maximum values of relative effective effort being about 1.25 and 1.5 respectively (Figure 6). This demonstrates that even though the performance of the HCRs is impaired under an effort creep scenario, the HCRs are able to mitigate some of the potential impacts.

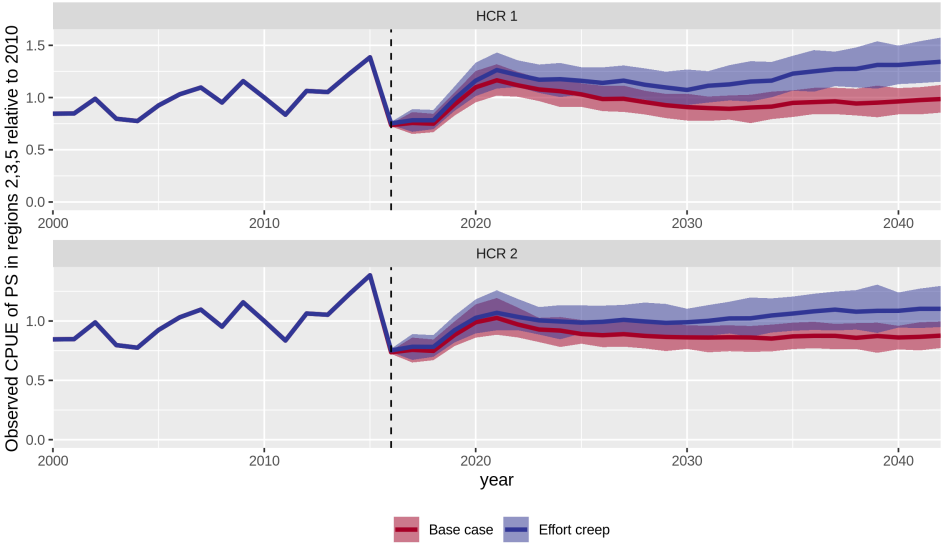

Figure 2: Time series of observed CPUE (relative to 2010) from the purse seine fisheries operating in model regions 2, 3, and 5 (excluding the associated purse seine fishery in region 5 which has been standardised) for the base case and effort creep scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

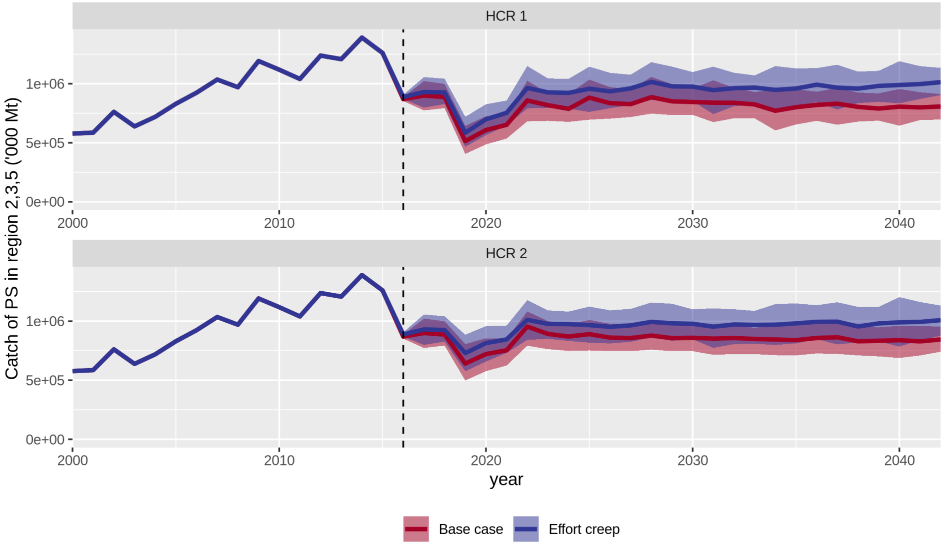

Figure 3: Time series of catches from the purse seine fisheries operating in model regions 2, 3, and 5 for the base case and effort creep scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

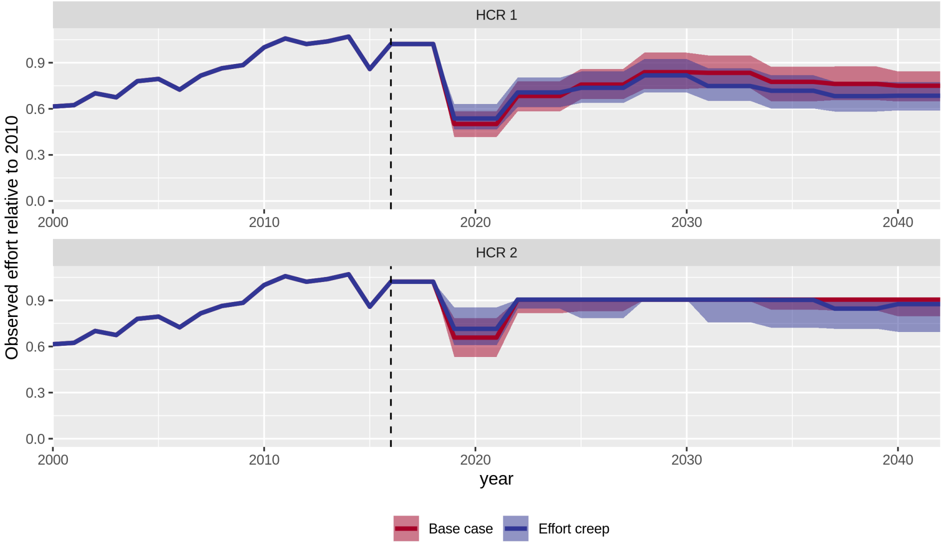

Figure 4: Time series of observed fishing effort (relative to 2010) from the purse seine fisheries operating in model regions 2, 3, and 5 (excluding the associated purse seine fishery in region 5 which has been standardised) for the base case and effort creep scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

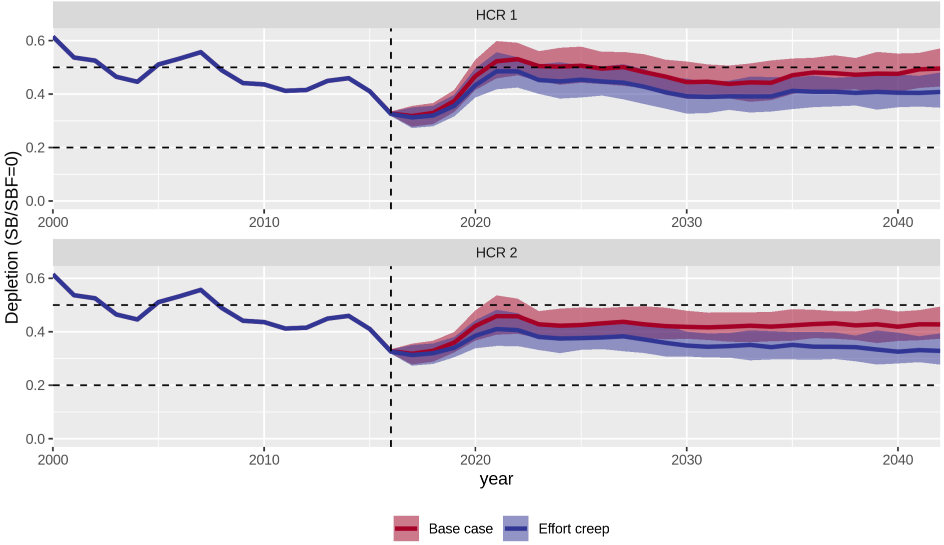

Figure 5: Time series of adult depletion ($SB/SB_{F=0}$) for the base case and effort creep scenario. Note that this is the 'true' depletion of the population and not the estimated depletion used by the HCR. The ribbons show the 20-80th percentile. The solid line shows the median value.

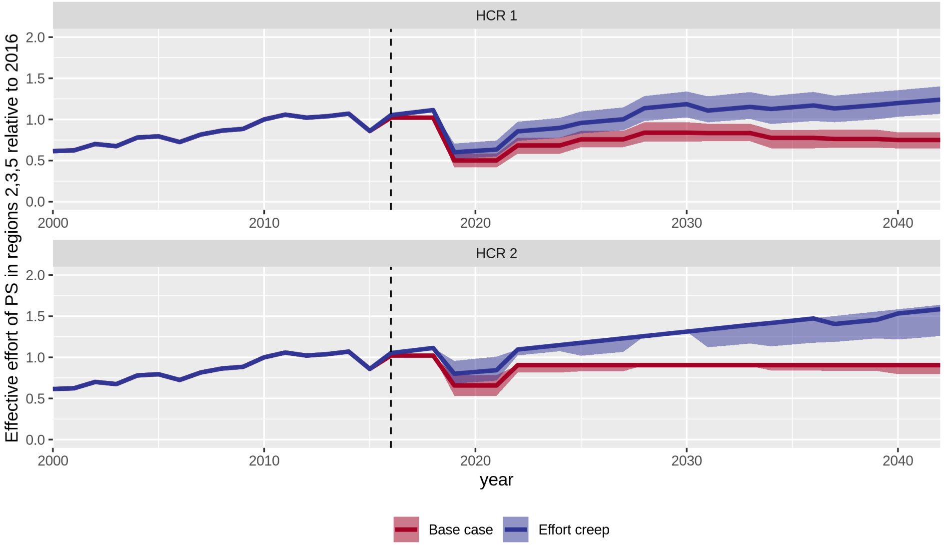

Figure 6: Time series of effective fishing effort relative to 2016 (the start of the simulations) from the purse seine fisheries operating in model regions 2, 3, and 5 (excluding the associated purse seine fishery in region 5 which has been standardised) for the base case and effort creep scenario. The ribbons show the 20-80th percentile. The solid line shows the median value. With an effort creep rate of 3% per annum, under a status quo scenario we would expect the final effective effort relative to 2016 to be 1.9.

B Hyperstability

B.1 Background

For schooling species that form aggregations, such as tunas, there is the potential that as the stock is depleted, catches and catch per unit effort (CPUE) remain high (Harley et al., 2001). This is known as hyperstability in CPUE and can impact the conclusions of analyses undertaken to inform management decisions.

Previous investigations of the potential impact of hyperstability on skipjack concluded that underestimating the extent of hyperstability in CPUE may lead to an overestimation of the necessary change in effort that is required to achieve a desired change in stock biomass (Scott et al., 2015). It is therefore possible that hyperstability in CPUE can affect the performance of an MP. However, the degree of hyperstability that might be operating in the WCPO purse seine fisheries is difficult to estimate, in particular due to potential confounding with changes in purse seine efficiency (i.e. effort creep) that occur through time.

Hyperstability is implemented in the MSE framework through density dependent catchability in the MULTIFAN-CL model , (Scott et al., 2015, 2019b; Davies et al., 2019). In the reference set of OMs there are two levels of hyperstability where density dependent catchability levels represent no hyperstability (k = 0) and moderate hyperstability (k = -0.5). For the robustness set of OMs an additional, stronger, level of hyperstability (k = -0.9) is set (see Figure 7).

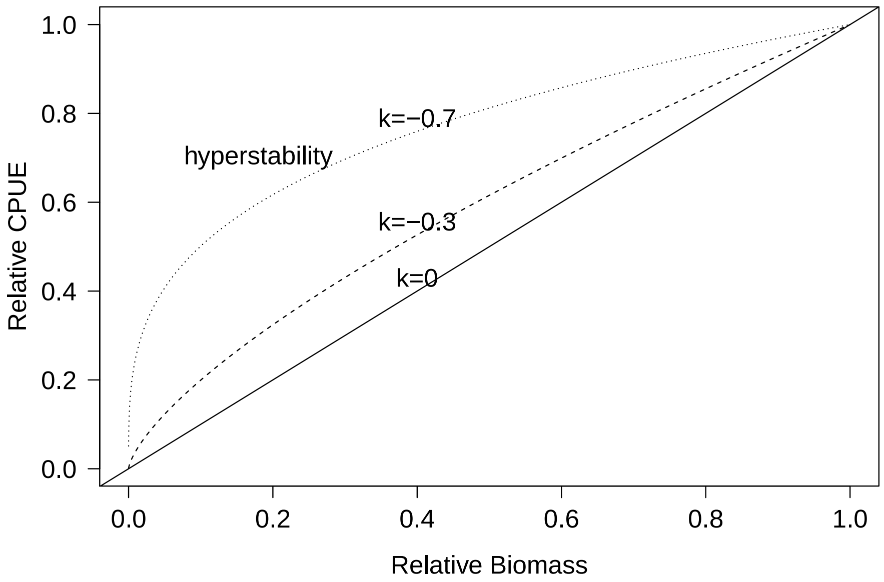

Figure 7: Conceptual plot of the relationship between CPUE and stock abundance for a range of hyperstability assumptions.

B.2 Method

The potential impact of hyperstability on HCR performance was explored using MSE. The method employed was the same as that described in Appendix A, except that in this example the robustness set OM differed from the base case by including strong hyperstability (k = -0.9).

B.3 Impact on HCR performance

The extent to which hyperstability in CPUE affects the performance of the MP depends, to a large extent, on the amount of variation in stock biomass (see Figure 7). For the two HCRs considered here, biomass changes very little throughout the simulation (Figure 11) and consequently the impact of hyperstability on the MP, in this case, is quite low. For both HCRs catches are generally slightly higher (Figure 10) and stock status slightly lower (Figure 11) for the hyperstability scenario. If the HCR performed much worse, and the stock was depleted to much lower biomass levels, a greater impact on the performance of the MP would be expected.

It is possible to see from the results how hyperstability can affect the performance of the MP. The estimation model (which does not allow for hyperstability) interprets the higher CPUE (higher catches, for the same amount of effort) as an indication of higher stock abundance and correspondingly increases allowable effort in the fishery (Figure 9). This leads to higher catches and a more depleted stock prompting the HCR to reduce allowable effort. Although the impact is small in this example, the impact may be more pronounced when considering the impact of hyperstability across a range of alternative OMs, and it will still be necessary to conduct thorough robustness tests.

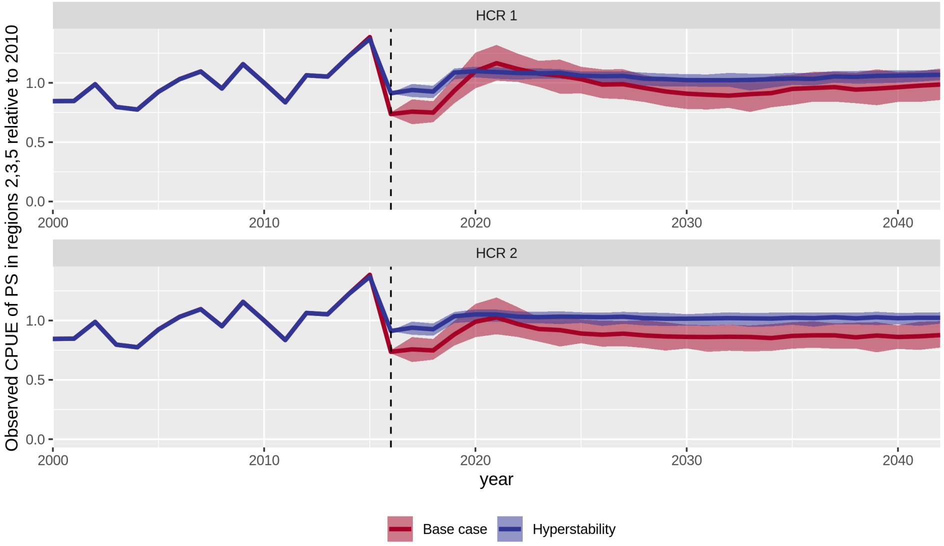

Figure 8: Time series of observed CPUE (relative to 2010) from the purse seine fisheries operating in model regions 2, 3, and 5 (excluding the associated purse seine fishery in region 5 which has been standardised) for the base case and hyperstability scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

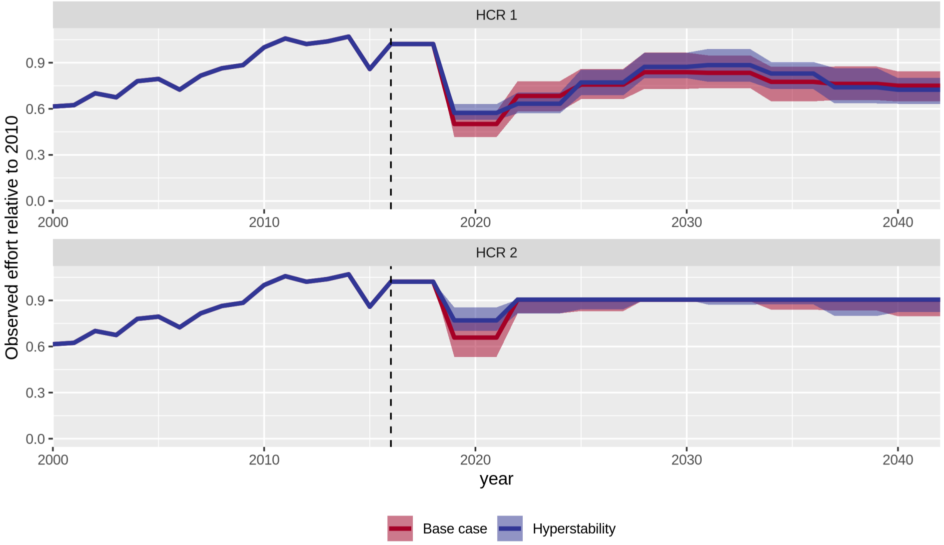

Figure 9: Time series of observed fishing effort (relative to 2010) from the purse seine fisheries operating in model regions 2, 3, and 5 (excluding the associated purse seine fishery in region 5 which has been standardised) for the base case and effort creep scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

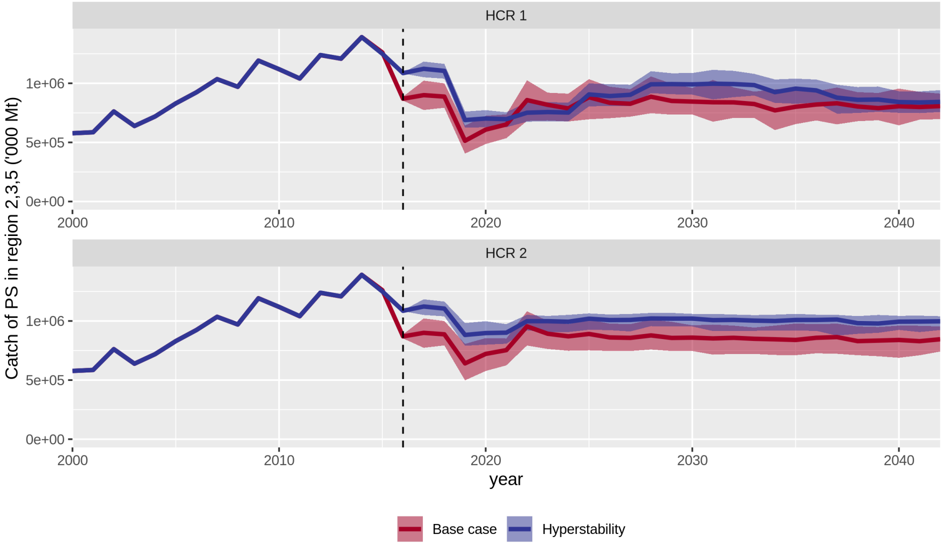

Figure 10: Time series of catches from the purse seine fisheries operating in model regions 2, 3, and 5 for the base case and hyperstability scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

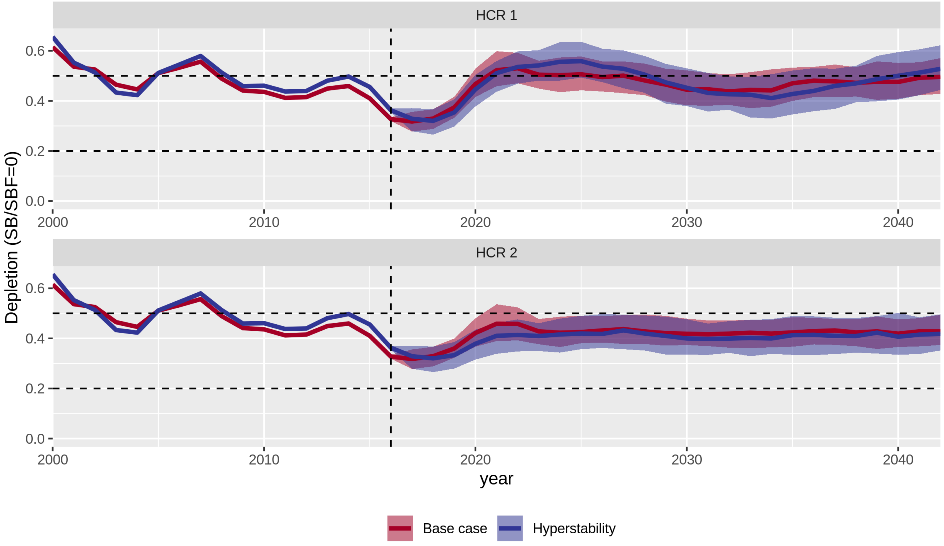

Figure 11: Time series of adult depletion ($SB/SB_{F=0}$) for the base case and hyperstab scenario. The ribbons show the 20-80th percentile. The solid line shows the median value.

C Movement and environmental effects

The 2016 stock assessment of skipjack in the WCPO was based on a spatial structure comprising 5 regions. MULTIFAN-CL distributes the population amongst these regions by estimating the relative proportion of recruitment in each region and age-specific, seasonal movement, both of which are assumed to remain constant across all years. However, movement among the assessment regions is likely to be strongly influenced by climatic conditions that are known to vary over time, most notably through the El Niño Southern Oscillation (ENSO). The occurrence of La Niña and El Niño ENSO events affects the east-west displacement of the warm pool which, in turn, affects the spatial distribution of skipjack in the WCPO and the fishing fleets that target them (Lehodey et al., 1997).

The impact of ENSO events on movement rates and the extent to which an MP is affected by mis-specification of movement rates in the EM are not fully understood. For our initial investigations we have considered two possible mechanisms for the re-distribution of the fish population due to ENSO events and outline potential approaches to test them. The first is that movement rates are directly affected by ENSO events and are the primary driver of the spatial distribution of the population. The second is that recruitment rates are affected by ENSO events and the variation in the spatial distribution of recruits is the primary driver of stock structure.

C.1 Alternative movement assumptions

In order to investigate the effect of alternative movement rates, it is first necessary to determine alternative rate scenarios. SEAPODYM (Lehodey and Senina, 2009) is a model developed for investigating the spatio-temporal dynamics of fish populations under the influence of both fishing and the environment in which movement is constrained by physical and biological environmental observations. An updated version of SEAPODYM 3.0 has been applied to skipjack tuna in the Pacific Ocean (Senina et al., 2016) to estimate stock structure and potential movement rates based on a 2° and 1 month spatial and temporal resolution.

A comparison of the time invariant, age specific MULTIFAN-CL movement rates with those determined from SEAPODYM (Figure 12) shows the time varying SEAPODYM fluxes appear broadly similar to the time invariant MULTIFAN-CL estimates. High movement rates estimated by MULTIFAN-CL coincide with high movement rates estimated by SEAPODYM, albeit with some variability. Although SEAPODYM appears to estimate higher residency for those fish with low movement rates (i.e. fish are more likely to remain where they are).

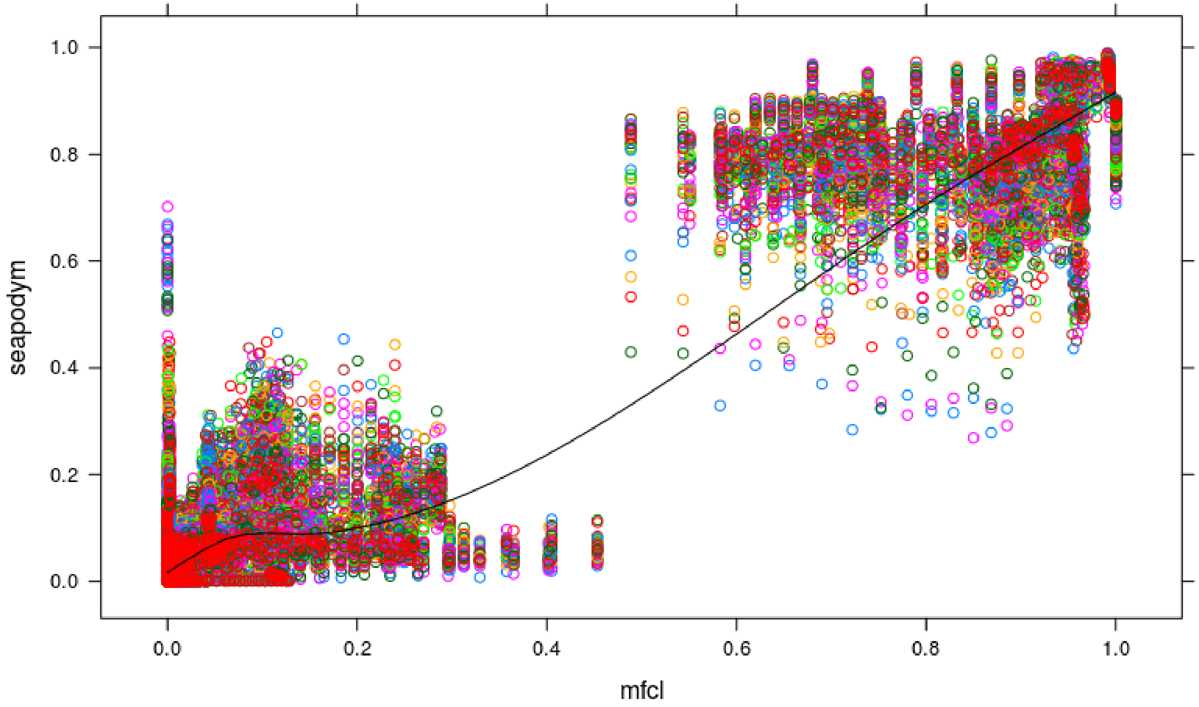

Figure 12: Comparison of estimates of skipjack movement rates and residency for MULTIFAN-CL and SEAPODYM across all years, seasons and ages. Points are coloured by age and the black line shows a loess smoother fitted to all data.

The variability between the MULTIFAN-CL and SEAPODYM estimates arises, in part, because the MULTIFAN-CL estimates are fixed while the SEAPODYM estimates can vary through time. Identification of how these differences between the estimates changes in relation to ENSO events would then provide the basis for the alternative, ENSO driven, movement rates to include in the robustness set.

Initial comparisons of the annual movement estimates (Figure 13) did not reveal any clear pattern in the differences between the two sets of movement estimates coinciding with known La Niña and El Niño events. It will be necessary to further investigate and identify plausible alternative movement rates to include in the robustness set.

The analysis has been conducted at the spatial resolution of the 2016 five region assessment model which may be too coarse to properly identify the true nature of ENSO driven movement rates. Options for repeating this exercise at a finer spatial resolution can be investigated and the new 2019 stock assessment of skipjack may be informative in this respect. We also note that previous studies have identified the potential for a lag in the response of the biomass of skipjack population to ENSO events Lehodey et al. (2003) that may be up to 1.5 years (Receveur, pers. comm.). This finding may suggest that the spatial redistribution of recruitment rather than instantaneous movement rates could be a more influential driver of stock structure.

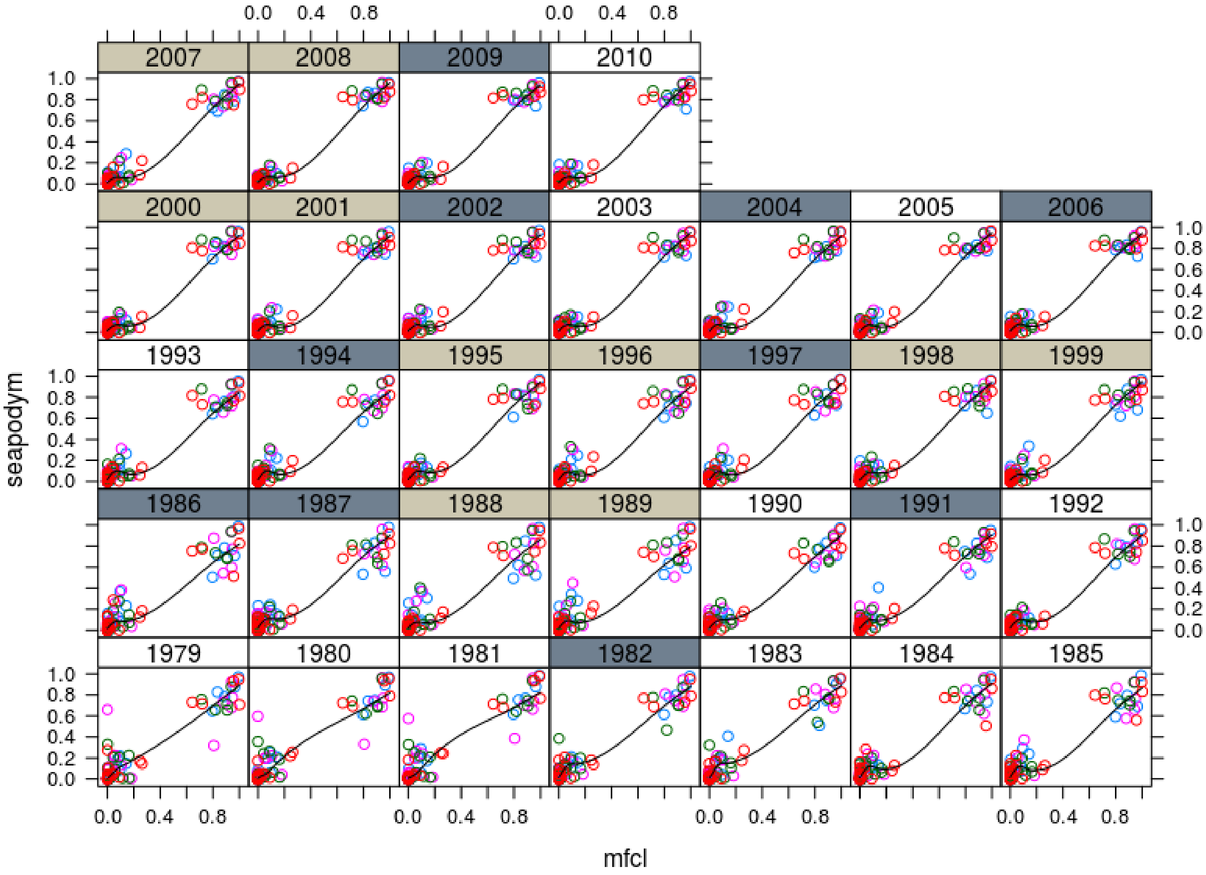

Figure 13: Comparison of estimates of skipjack movement and residency (at age 5 quarters) for MULTIFAN-CL and SEAPODYM. Grey strips denote El Niño years, beige strips La Niña and white strips are neutral. The black line shows a loess smoother.

C.2 Spatial distribution of recruitment

MULTIFAN-CL estimates recruitment from a single stock and recruitment relationship (SRR) and distributes these recruits amongst the assessment regions according to an estimated relative proportion of recruitment which does not change systematically through time (i.e. some random deviation may apply). In this way the overall recruitment level is determined from the overall abundance of skipjack. This assumption may be reasonable when considering the historical trajectory of the stock but may not be appropriate when conducting projections under varying rates of exploitation or under varying environmental conditions.

This scenario has not yet been tested but will be the focus of future work.