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Implementation of alternative CPUE/abundance dynamics for purse seine fisheries within MULTIFAN-CL with application to effort-based projections for skipjack tuna

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Executive Summary

A common assumption in most stock assessment models is that catch per unit of effort (CPUE) scales in strict proportion to stock abundance. However, for purse seine fisheries in particular, this assumption may not hold. As a stock is depleted, catches can remain high as abundance decreases. This is known as hyperstability in CPUE and can impact the conclusions of analyses undertaken to inform management decisions.

This paper describes the implementation within MULTIFAN-CL of an alternative and more flexible approach to modelling the relationship between CPUE and abundance which allows for hyperstability (and hyperdepletion) in both the past and in the future. We demonstrate the potential impact of this new approach with deterministic projections for the skipjack tuna stock under a range of effort multipliers and degrees of hyperstability.

Our simple demonstration indicates that underestimating the extent of hyperstability in CPUE will likely lead to an overestimation of the necessary change in effort that is required to achieve a desired change in stock biomass. However, the degree of hyperstability that might be operating in the WCPO purse seine fisheries is likely to be difficult to estimate, in particular due to potential confounding with changes in purse seine efficiency that occur through time (i.e., effort creep).

Further development of this approach will be important to consideration of reference points and harvest control rules, and it is likely that a Management Strategy Evaluation framework will provide the best basis for further consideration of this work given the likely difficulty in accurately estimating the degree on hyperstability.

We invite the scientific committee to:

- Note that potential implications of these results for managing to TRPs and the subsequent development of HCRs;
- Note the difficulty in estimating the degree of hyperstability in CPUE from purse seine fisheries; and
- Note that further work will be undertaken with this approach for presentation at the 4th Management Objectives Workshop (MOW4).

1 Introduction

Purse seine fishing in the western central Pacific Ocean (WCPO) has increased dramatically over the last 30 years and currently accounts for more than 70% (by weight) of all tuna caught in the region (Williams and Terawasi, 2014). Purse seine fisheries in the WCPO catch a range of different species but the majority of the catch is skipjack. In 2013 more than 80% of the skipjack catch was taken by purse seiners (Williams and Terawasi, 2014).

In the absence of fishery independent information on stock abundance (e.g.,. research surveys), fishery dependent catch per unit effort data (CPUE) are a key source of information on stock status for WCPO stocks. However, although purse seine fisheries account for the majority of the skipjack catch, purse seine CPUE is not used as an index of abundance within the skipjack stock assessment.

For assessment purposes, it is commonly assumed that CPUE scales in strict proportion with abundance. However, the strong schooling nature of tuna and resulting aggregations of purse seiners on productive fishing grounds can generate high catches associated with high levels of effort but only moderate CPUE, yielding a weak and potentially non-linear link between stock abundance and CPUE. For this reason industrial purse seine CPUE is considered unsuitable for use within the assessment. The shortcomings of CPUE in this respect are well documented (Bannerot and Austin, 1983; Quinn and Deriso, 1999; Hilborn and Walters, 1992).

Several studies have investigated the potential for a non-linear relationship between CPUE and abundance (Harley et al., 2001; Gaertner and Dreyfus-Leon, 2004; Maunder et al., 2006a). For schooling species that form aggregations, such as tunas, it is considered that, as the stock is depleted, CPUE will decline at a slower rate than abundance. This is known as hyperstability in CPUE. The converse where CPUE declines more rapidly than abundance is termed hyperdepletion (see Figure 1).

The potential for hyperstability in CPUE is an important consideration for the assessment and management of fish stocks. The erroneous assumption of a linear relationship with stock abundance when a non-linear relationship actually exists, can lead to an underestimation of the extent to which a stock is being depleted through fishing. From a fisheries management perspective it can also lead to bias in the estimated magnitude of effort change required to manage a stock to biomass targets.

In this paper we describe the implementation within MULTIFAN-CL of an alternative and more flexible approach to modelling the relationship between CPUE and abundance which allows for hyperstability (and hyperdepletion) in both the past and in the future. We then demonstrate the potential impact of this new approach with deterministic projections for the skipjack tuna stock under a range of effort multipliers and degrees of hyperstability.

2 Methods

2.1 Non-proportionality in CPUE and abundance

A typical assumption in most stock assessment models is that CPUE (C/E) scales in proportion to stock abundance in accordance with Equation 1.

$$\frac{C}{E} = qB \tag{1}$$

where catchability (q) is a fixed parameter that relates the CPUE to the abundance of the stock (B) such that as stock abundance increases so the quantity of catch attained for a given level of effort increases in a linear fashion. A non-linear relationship between CPUE and abundance can be implemented by applying a biomass dependent scalar to catchability (Equation 2)

$$\frac{C}{E} = q\left(\frac{B}{B_{ref}}\right)^{k} B \tag{2}$$

where B_{ref} is some reference biomass level against which current biomass is compared and k is a fixed value that determines the extent of non-linearity between biomass and CPUE (see Figure 1). When k is negative CPUE remains high as stock biomass reduces (hyperstability). For positive values of k the opposite occurs (hyperdepletion).

2.2 Revised assessments based on alternative hyperstability scenarios

Direct estimation of the value of k is computationally difficult because the increased number of free parameters prevents the assessment model from finding a unique solution. Instead a range of fixed values for k have been considered and the results compared in relative terms.

A modified version of the MULTIFAN-CL stock assessment programme was developed that allowed for a non-linear relationship between stock abundance and catchability following the formulation described in Equation 2. The assessment model was run with a range of fixed values of k (0, -0.1, -0.3, -0.5, -0.7) to obtain revised assessment outputs corresponding to a range of increasingly severe scenarios for hyperstability in CPUE. For each of these runs the estimated trends in biomass were compared with those derived from the 2014 reference case assessment (Rice et al., 2014) to ensure that the modified assessment model was achieving a consistent fit to the data. In all cases the trends in adult biomass were almost identical to that of the reference case assessment model such that each of the projection runs started from the same biomass level.

It should be noted that whilst trends in population abundance up to 2012 from the modified assessment method are consistent with those of the reference case assessment, estimates of average catchability may differ because in the modified assessment catchability varies with changes in the underlying biomass.

2.3 Projections

For each of the scenarios described above, deterministic projections were run for a 20 year period for a range of future effort multipliers corresponding to 3 hypothetical effort scenarios:

- Status quo, where future effort was maintained at 2012 effort levels;
- A reduced effort scenario, where future effort was half of the 2012 effort level;
- An increased effort scenario in which future effort was twice that of the 2012 effort level.

The effort multipliers were applied only to the purse seine fisheries within the model, all other fisheries were maintained at 2012 effort levels (i.e.,. an effort multiplier of 1.0).

Future recruitment was taken from the Beverton and Holt stock-recruitment relationship as determined from the stock assessment. Future effort scenarios that resulted in a decline in stock abundance would incur reduced recruitment and conversely those that resulted in an increase in stock abundance would incur higher recruitment. Variability about the stock-recruitment relationship was not included in these deterministic projections.

Throughout the projection period catchability for each fishery was set to the assessment terminal year level and then scaled with biomass in accordance with Equation 2. This is in contrast with the standard approach for projections where catchability is held at a constant value throughout the projection period.

3 Results

Population trends from the effort based projections are presented for each effort and hyperstability combination (Figure 2). The results show that for all hyperstability scenarios a reduction in fishing effort results in an increase in adult biomass from 2012 levels, and an increase in fishing effort results in a decrease in adult biomass, as would be expected. For the status quo effort projection, future adult biomass is maintained at levels close to the 2012 level.

As the extent of hyperstability increases the relative change in adult biomass increases for each effort scenario. At an effort multiplier of 0.5 biomass increases for all hyperstability scenarios, but increases the most for the most severe (k= - 0.7) instance. Similarly for an effort increase (effort multiplier = 2) the greatest reduction in adult biomass corresponds to the most severe (k= - 0.7) hyperstability assumption.

The difference in the adult biomass levels for different hyperstability assumptions is greater for an effort increase than for an effort reduction. This is because of the effect of the stock-recruitment relationship. As effort is reduced and biomass increases, future recruitment is drawn from the region of the SRR curve closer to the asymptote. Conversely, as effort is increased and biomass reduces, future recruitment is drawn from the region of the SRR curve closer to the origin where the gradient of the curve is steeper and the difference in recruitment for given change in biomass is greater.

4 Discussion

Our results show that hyperstability in CPUE is an important consideration when calculating the fishing effort required to meet biomass based management targets. Underestimating the extent of hyperstability in CPUE will likely lead to an overestimation of the necessary change in effort that is required to achieve a desired change in biomass. For example, for a doubling of effort when a linear relationship exists, the adult biomass is reduced to around 2.7 million tonnes at the end of the projection period (Figure 2, plot 3). If a non-linear relationship exists, however, CPUE remains high as the stock declines and for the same effort increase adult biomass is reduced further to 2.2 million tonnes (for the case of k= -0.7). Therefore to achieve 2.7 million tonnes a smaller effort increase would be required.

Direct estimation of the parameter k is computationally difficult and the true extent of hyperstability in the purse seine fisheries for skipjack remains unknown. It is unclear at this stage whether the true extent of hyperstability in CPUE can be determined analytically. Whilst our results are indicative of the potential effect of non-linearity in the CPUE to abundance relationship we are not able to determine the exact change in effort required to manage the stock towards biomass levels that are distant from current levels if non-linearity in CPUE and abundance is present, although the impacts can be bracketed within plausible bounds of alternative hyperstability assumptions. Further work in this area is planned prior to MOW4 to determine the sensitivity of candidate skipjack biomass TRPs to different levels of hyperstability.

Purse seine fisheries are also susceptible to effort creep, whereby fishing efficiency, and hence catchability, progressively increase over time through continuous technological advances (Tidd et al., 2015). We have not included effort creep here and have restricted our analysis to the potential consequences of a non-linear relationship between CPUE and abundance that is fixed through time, but this phenomena is likely to contribute to difficulties in accurately determining the level of hyperstability.

Throughout this analysis we have focused on the potential bias in the necessary effort changes required to manage a stock towards biomass targets for alternative assumptions about the extent of hyperstability in CPUE. It should be noted that both F based management targets and catch based projections would be equally susceptible to such bias given that fishing mortality is intrinsically linked to catchability (q).

If the true extent of hyperstability in CPUE cannot be determined, an alternative approach is to develop harvest strategies that are robust to such uncertainties. Maunder et al. (2006b) proposed a number of fisheries management approaches that could be implemented to address some of the problems associated with non-representative CPUE information including management strategy evaluation and adaptive management approaches.

5 Conclusion

Non-linearity in the relationship between stock abundance and CPUE is an important consideration when determining the fishing effort required to manage a stock towards biomass based management targets. Estimation of the true relationship is computationally difficult, however now that this approach is implemented within MULTIFAN-CL, simulation analyses can be used to investigate the sensitivity of management action to alternative, plausible scenarios.

Whilst our results are considered indicative of the general trends and behaviour that might be expected under various levels of hyperstability in CPUE, this work will be further developed with a view to submitting a more detailed results to MOW4 later this year.

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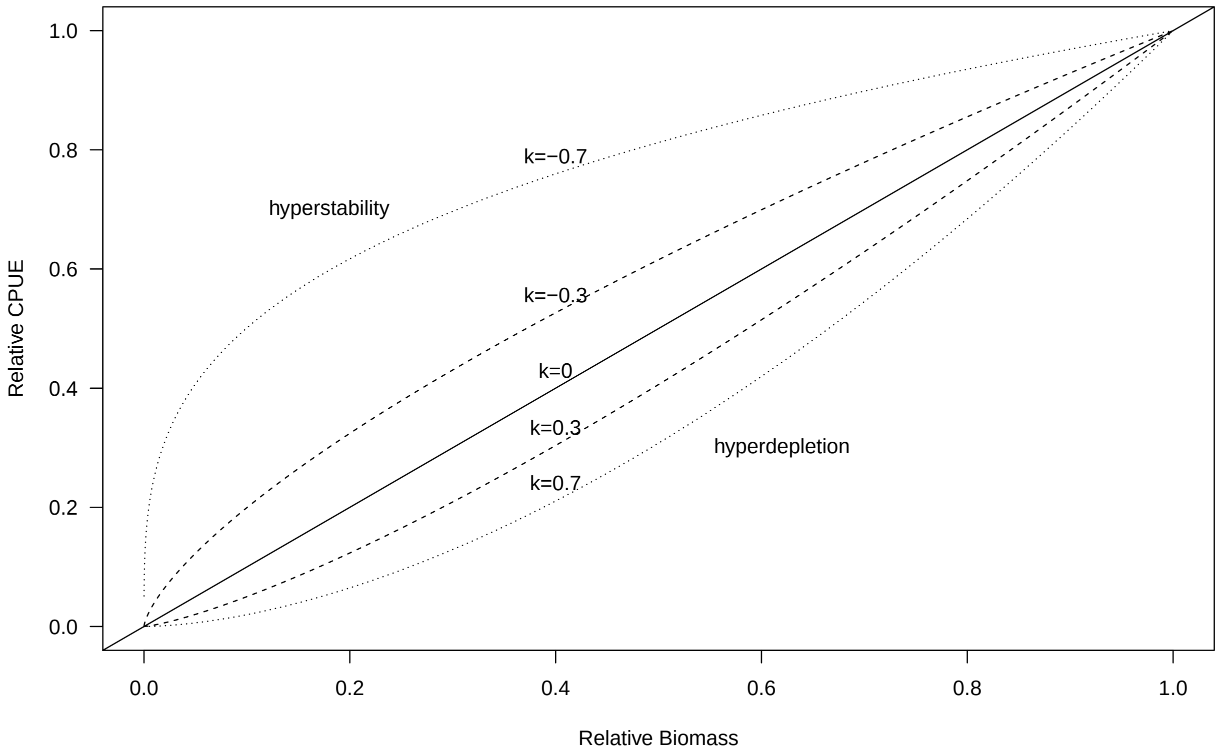

Figure 1: Conceptual plot of the assumed relationship between CPUE and stock abundance for varying values of k in Equation 2. For -ve values of k CPUE remains at high levels with decreasing abundance resulting in hyperstability in CPUE. Conversely for +ve values of k, CPUE declines faster for a given reduction in stock abundance, resulting in hyperdepletion in CPUE.

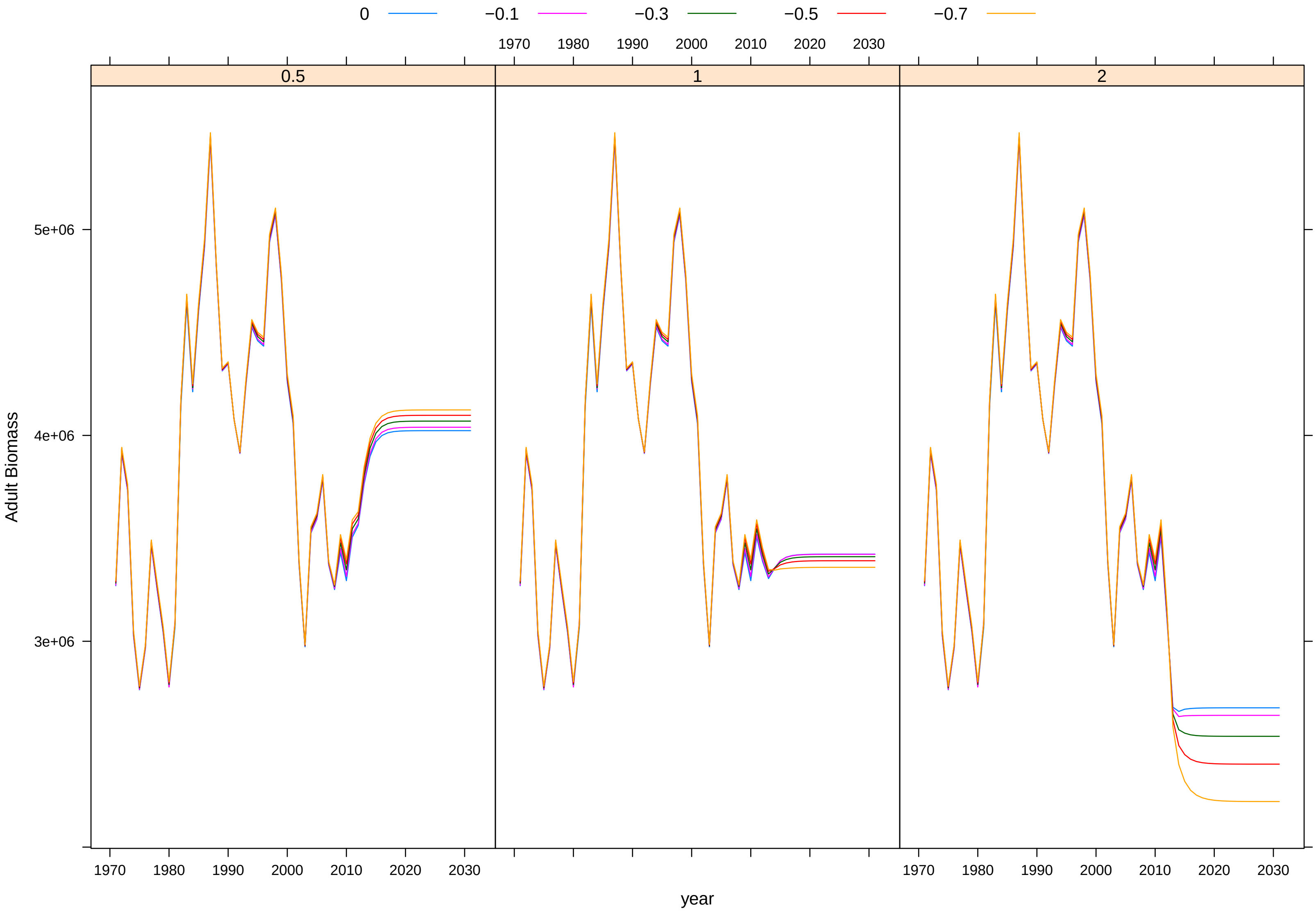

Figure 2: Results of the 20 year deterministic projections for alternative effort scalars under a range of hyperstability scenarios. Plots are shown for effort scalars of 0.5 (half of the 2012 effort level), 1.0 (status quo effort) and 2.0 (twice the 2012 effort level) and for increasing levels of hyperstability (no hyperstability, blue lines k=0, to the most severe hyperstability, yellow lines k=-0.7).