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Management procedure evaluation for the Indian Ocean skipjack tuna fishery : management procedure descriptions and evaluations

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Abstract

Three contrasting classes of management procedure (MP) have been implemented: BRule (a generic harvest control rule based on an estimate of stock status), FRange (a MP which adjusts effort when fishing mortality is outside a target range) and IRate (a MP which recommends a total allowable catch using a CPUE-based biomass index). Each MP is evaluated over a twenty five year period against performance statistics that include average annual yield, variability in catch, CPUE for the main region/gear combinations , average stock status and probability of stock status falling to low levels. Evaluations are performed using a range of model parameter values and the sensitivity of MP performance examined.

Outline

1 Management procedures

Several classes of management procedure (MP) are considered with each *class* having several *control parameters* which can be varied to alter it's behaviour. We refer to a particular combination of control parameters for a class of MP as an instance of that class.

The classes of management procedure used here are mainly intended to illutrate the wide variety of possible MPs: the data inputs they use, their algorithmic form and the management controls which they alter (e.g. effort versus catch). The

1.1 BRule class

The `BRule` class of MP is similar to generic harvest control rules that have been suggested in other tuna fisheries (e.g. SCRS 2011, Scott et al 2013). It assumes that an estimate of stock status is available each year (although the same MP could be altered to have less frequent updates) and uses a simple relation between stock status and fishing intensity. Here we define relative stock status as ratio of current spawning biomass over the spawning biomass associated with maximum sustainable yield, B_t/B_{msy} , and relative fishing intensity as the ratio of the current instantaneous rate of fishing mortality and the rate associated with MSY, F_t/F_{msy} . For this study we have investigated the impact of alternative levels of stock assessment precision and implementation error on performance statistics.

In each year the relative biomass is estimated through a stock assessment,

$$\hat{S} = \frac{B_t}{B_{msy}} \varepsilon$$

where ε is a lognormally distributed multiplicative error with mean of 1 and standard deviation of p ,

$$\varepsilon \sim LN(1, p)$$

Using $\hat{S}$ the recommended fishing intensity ($\overline{F}$) is calculated. If $\hat{S} < s_l$ then,

$$\overline{F} = 0$$

If $\hat{S} > s_t$ then,

$$\overline{F} = f$$

Otherwise,

$$\overline{F} = \frac{f}{s_t - s_l} \left(\hat{S} - s_l \right)$$

The recommended fishing intensity is applied to the fishery in the following year,

$$F_{t+1} = \overline{F} \varphi$$

where φ is a lognormally distributed multiplicative error with mean of 1 and standard deviation of e ,

$$\varphi \sim LN(1, e)$$

Table 1 provides a summary of each of the control parameters of `BRule` and their respective values evaluated in this study. Note that IOTC Resolution 13/10 set an interim limit target biomass of B_{msy} (i.e. $b_t = 1$) and an interim limit biomass of $0.4B_{msy}$ (i.e. b_l = 0.4). Analogous values have been tested. IOTC Resolution 13/10 also includes a limit reference point of $1.5F_{msy}$. Such a limit reference point on F is not a feature of this MP which instead is based on relative biomass reference points.

Table 1 : Control parameters of the BRule management procedure : descriptions and values evaluated.

Parameter	Symbol	Description	Values evaluated
Estimation precision	p	Precision with which relative stock status is estimated	0, 0.2, 0.4, 0.6
Threshold stock status	s_t	Relative stock status below which recommended fishing intensity is reduced	0.7, 0.8, 0.9, 1.0
Limit stock status	s_l	Relative stock status below which recommended fishing intensity is zero	0.2, 0.3, 0.4, 0.5
Target fishing intensity	f	Relative fishing intensity	0.8, 0.9, 1.0, 1.1
Implementation precision	e	Precision with which recommended fishing intensity is applied	0, 0.2, 0.4, 0.6

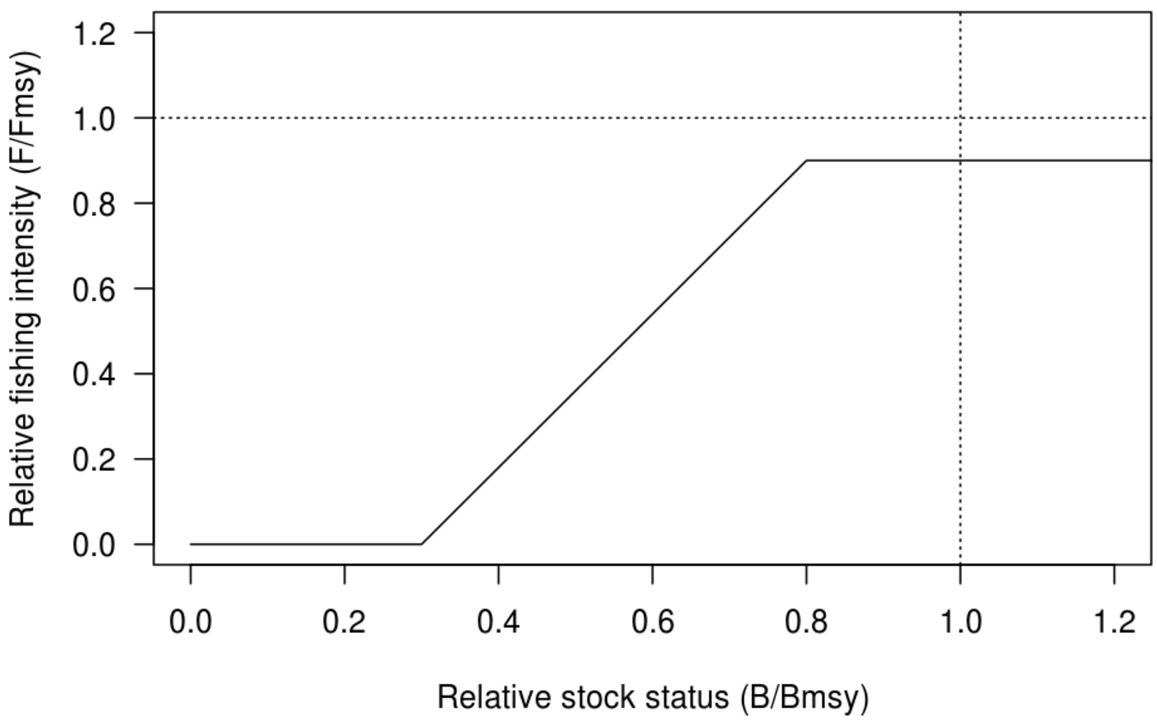

Figure 1 : An example instance of the BRule management procedure with $s_l = 0.3$ **,** $s_t = 0.9$ **,** $f = 0.9$ **showing the relation between** $\widehat{S}$ **and** $\overline{F}$ **.**

1.2 FRange class

`FRange` seeks to maintain the fishing mortality rate within a defined range. At periodic intervals, defined by the control parameter i , F is estimated (e.g. from a stock assessment or a tagging study) with a defined level of precision, p ,

$$\widehat{F} = F\varepsilon$$

where ε is a lognormally distributed multiplicative error with mean of 1 and standard deviation of p ,

$$\varepsilon \sim LN(1, p)$$

The estimated fishing mortality is compared to a range defined by two control parameters, f the centre of the range and b the buffer, or width, of the range.

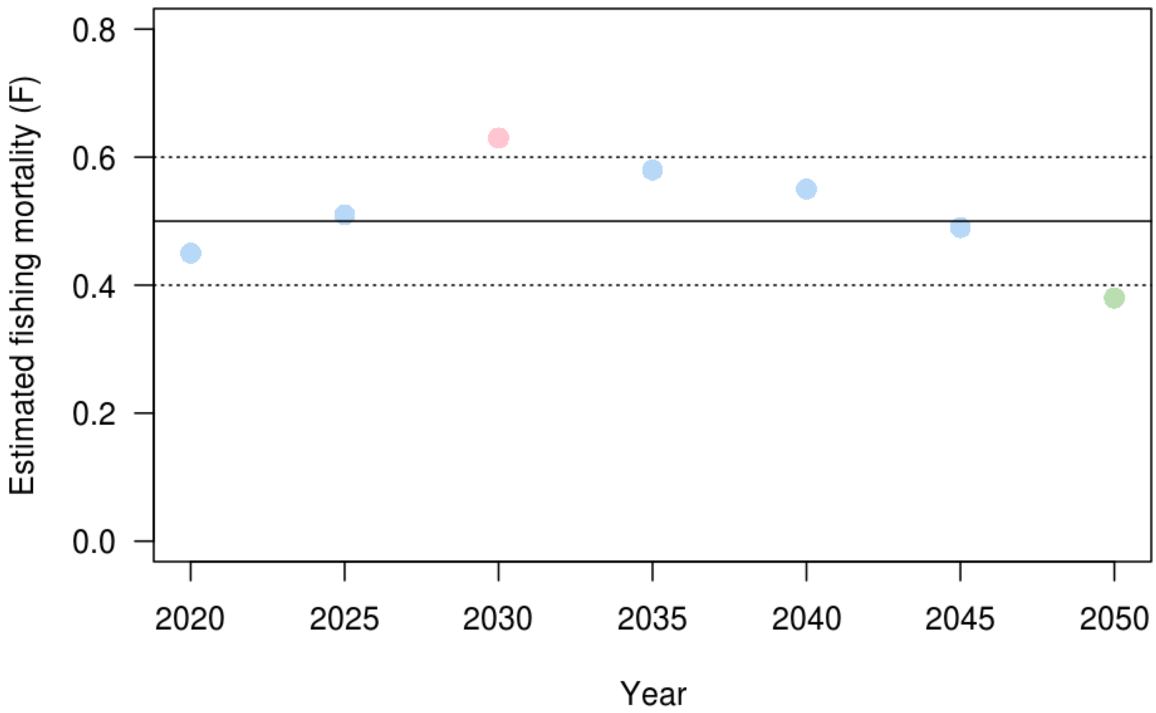

Figure 2 : An example instance of the BRule management procedure with $i = 5$, $f = 0.5$, $b = 0.1$ illustrating how total allowable catches are increased (green circles) or decreased (red circles) when the estimated fishing mortality is below or above the target range.

1.3 IRate class

This management procedure uses CPUE as an index of biomass and sets a total allowable catch (TAC) that, over most of the range of CPUE, is proportional to that index.

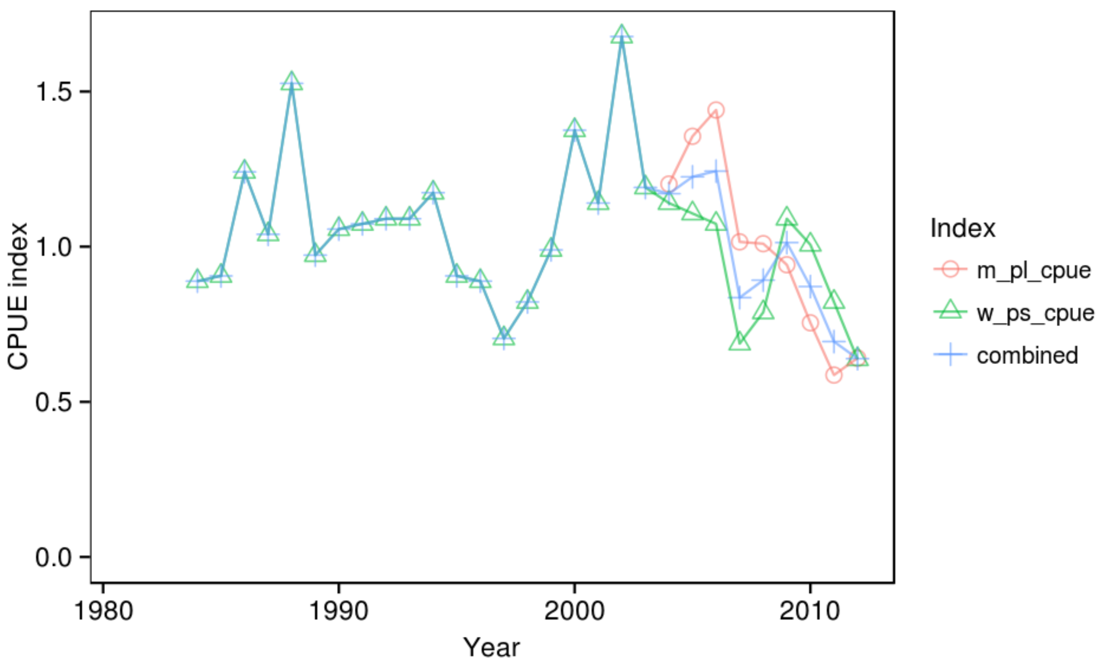

Figure 3 : Western purse seine, Maldive pole and line and combined CPUE series.

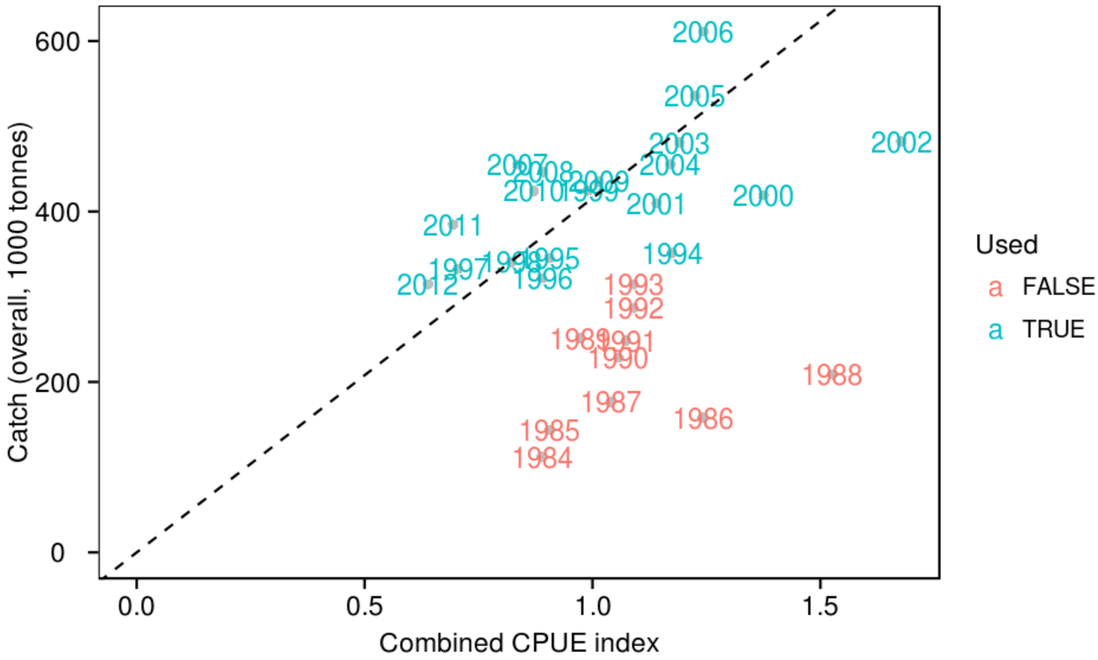

Figure 4 : Historical relation between combined CPUE and overall catch. The dashed line has a slope of the catch scalar = 415.7 (geometric mean of the ratio of catches over CPUE).

In each year, a smoothed CPUE, $\bar{I}$ is calculated using an exponential moving average with the responsivesness control parameter, r :

$$\bar{I}_t = rI_t + (1 - r)\bar{I}_{t+1}$$

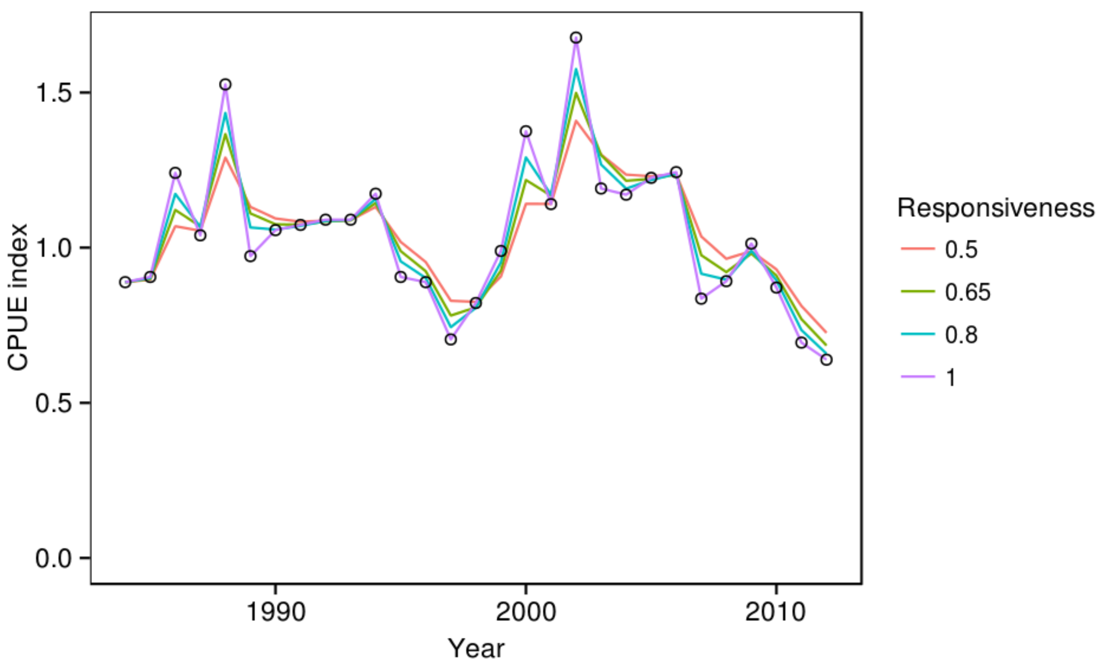

Figure 5 : Illustration of the alternative smoothing of CPUE index using the responsiveness parameter.

Higher values of r produce greater responsiveness because they put more weight on more recent values of CPUE and produce a index that is less smoothed. When $r = 1$ there is no smoothing and $\bar{I}_t = rI_t$. Smoothing may be advantageous in that it reduces the influence of annual random variation in CPUE due catchability or operational variations. However, smoothing also reduces adds a lag to the index.

Using $\overline{I}$ the recommended catch scaler ($\overline{S}$) is calculated. If $\overline{I} < i_l$ then,

$$\overline{S} = 0$$

If $\overline{I} > i_t$ then,

$$\overline{S} = m\widehat{S}$$

Otherwise,

$$\overline{S} = \frac{m\widehat{S}}{i_t - i_l}\left(\overline{I} - i_l\right)$$

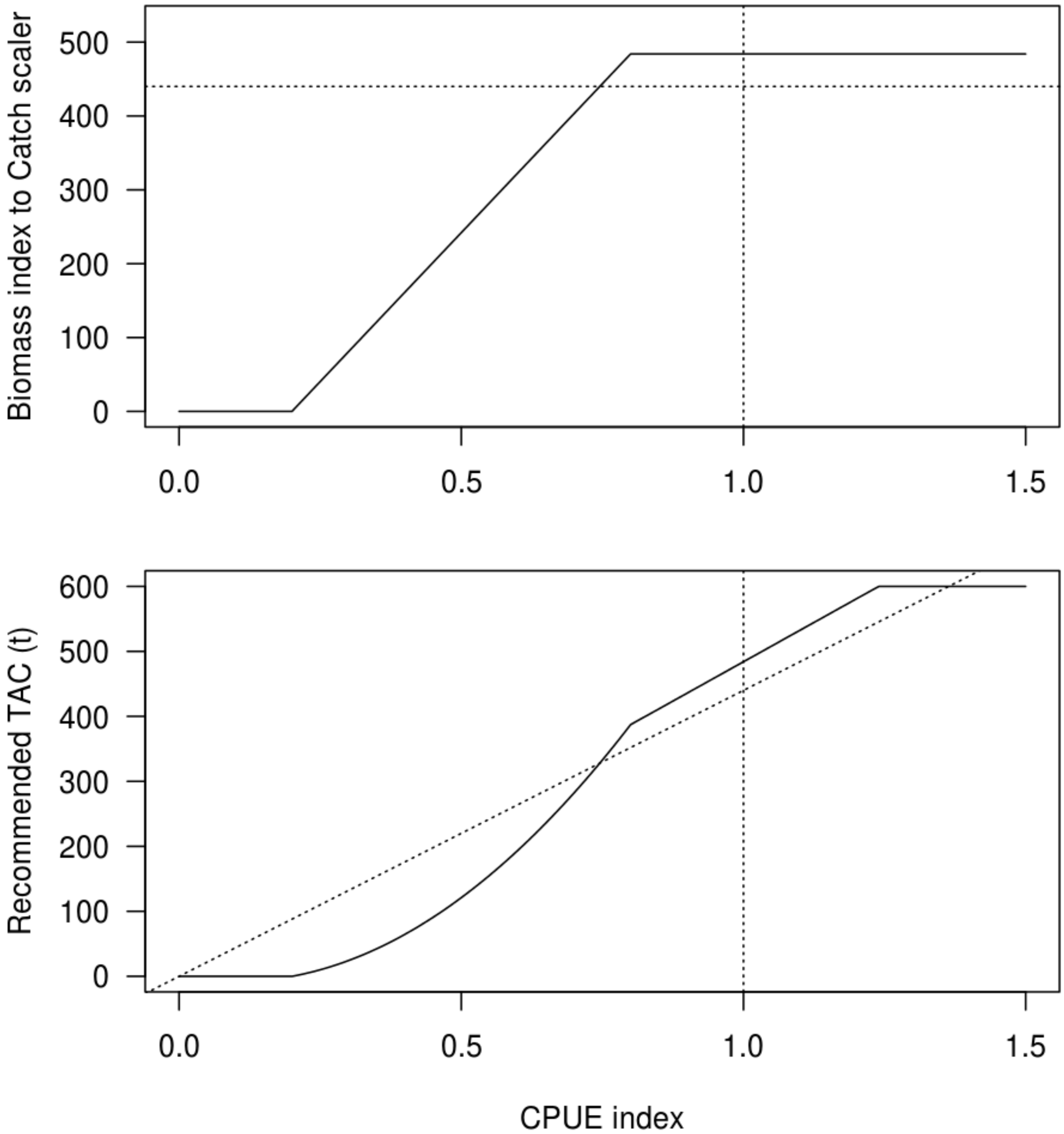

Figure 6 : An example instance of the IRate management procedure with $i_l = 0.2$ **,** $i_t = 0.8$ **,** $m = 1.1$ **,** $u = 600$ **showing the relation between the CPUE index (** $\overline{I}$ **) and the catch scalar (** $\overline{S}$ **) and the recommended TAC.**

The recommended catch scaler is used to calculate a recommended TAC, $\overline{S}$, by multiplying the harvest rate by the biomass index,

$$\overline{C} = \min\left(\overline{SI}, u\right)$$

which is applied to the fishery in the following year,

$$C_{t+1} = \overline{C}\varphi$$

where φ is a lognormally distributed multiplicative error with mean of 1 and standard deviation of e ,

$$\varphi \sim LN(1, e)$$

Table 2 : Control parameters of the IRate management procedure : descriptions and values evaluated.

Parameter	Symbol	Description	Values evaluated
Responsiveness	r	Degree of smoothing in biomass index	0.5, 0.65, 0.8, 1.0
Target harvest rate muliplier	m	Target harvest rate relative to historic levels i.e 0.9 = 90% of historic average	0.8, 0.9, 1.0, 1.1
Threshold biomass index	i_t	Biomass index at which the harvest rate is reduced relative to historic levels i.e. 0.7 = reduce harvest rate when the biomas index is at 70% of historic levels	0.5, 0.6, 0.7, 0.8
Limit biomass index	i_l	Biomass index at which harvest rate is zero relative to historic levels i.e. 0.2 = close the fishery when the biomas index is at 20% of historic levels	0.1, 0.2, 0.3, 0.4
Maximum TAC	u	Maximum total allowable catch (thousand tonnes)	300, 400, 500, 600
Implementation precision	e	Precision with which recommended TAC is applied	0, 0.1, 0.2, 0.3

2 Evaluations

2.1 Methods and terminology

This section provides an overview of the methods and terminology used for evaluating management procedures (i.e. management procedure evaluation, MPE). We provide examples of the types of figures and tables that are used in the following, more detailed, descriptions of evaluation results for each class of management procedure.

2.1.1 Evaluations and replicates

Each *evaluation* of a management procedure is based on a *replicate* . Each replicate incorporates *parameter uncertainty* through the random selection of a set of model parameters as well as *stochastic uncertainty* through the random generation of *process uncertainty* (e.g. recruitment variation) and *observation uncertainty* (e.g. CPUE error). The parameter set for a replicate is drawn from all the possible parameter sets determined from model conditioning. For each evaluation, the particular management procedure is used to determine future simulated management which affects catches, which in turn affects stock biomass and other *performance measures* (Figure 7).

The primary purpose of MPE is not to provide forecats of catch, biomass or other performance measures. Rather, it is to compare the performance, relative to management objectives, of alternative candidate management procedures. Thus, for each replicate, each of the candidate management procedures is evaluated (Figure 8). This allows us to compare the performance of alternative MPs under exactly the same set of assumptions. Notice in (Figure 8) that the biomass trajectories resulting from using alternative MPs often fluctuate in parallel. This is due to the same recruitment variations being used for each evaluation.

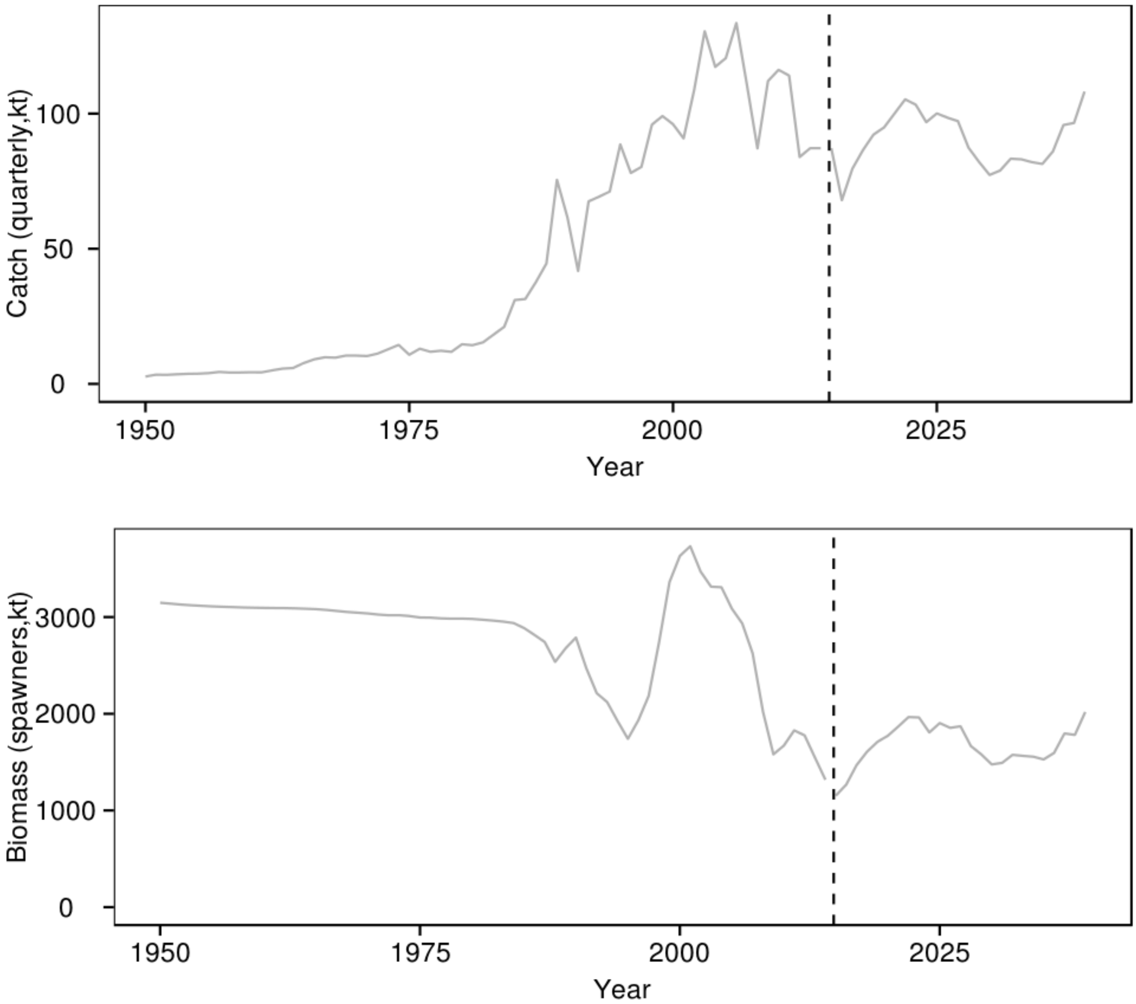

Figure 7 : Catch and biomass trajectories from a single evaluation of a single management procedure using a single parameter replicate.

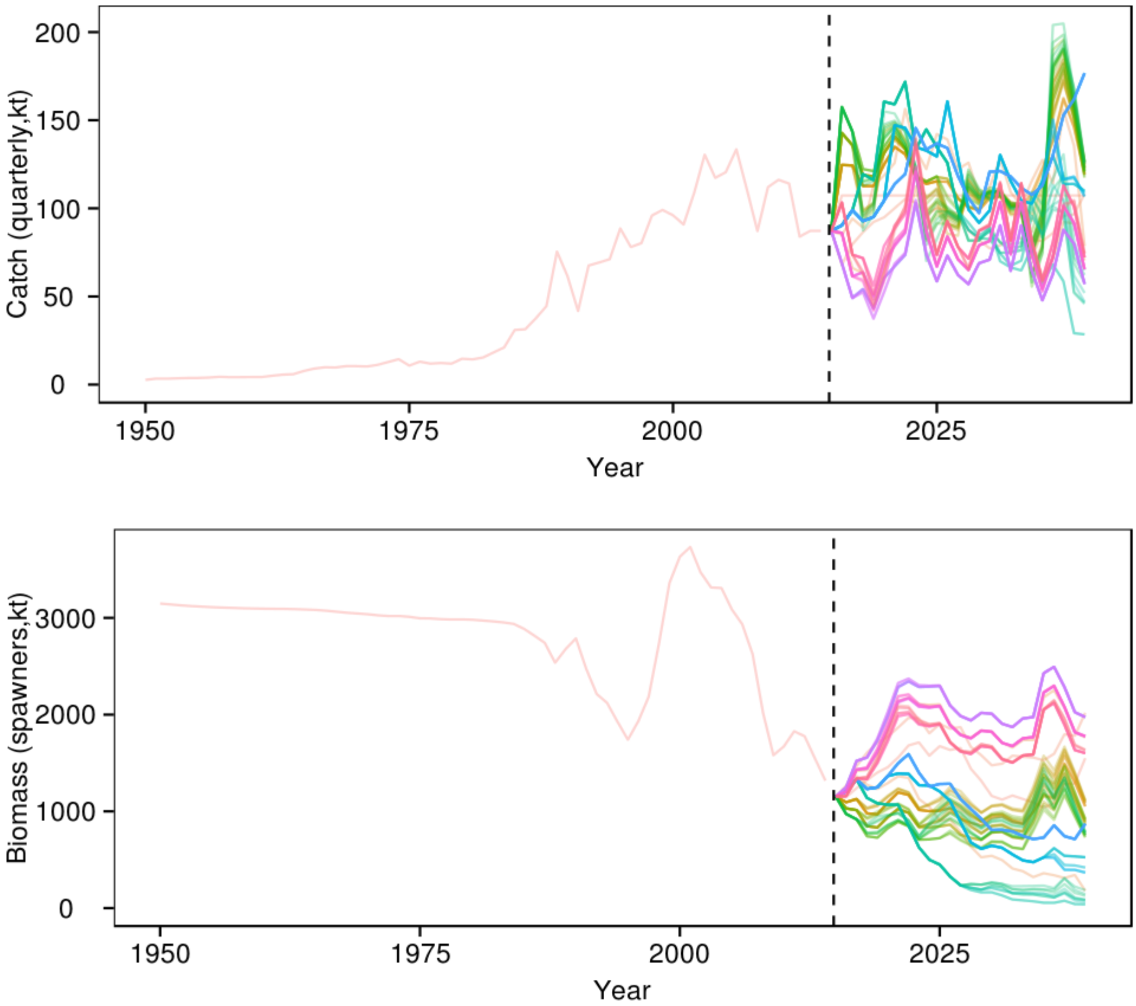

Figure 8 : Catch and biomass trajectories from multiple evaluations of multiple management procedure using a single parameter replicates. Each of the coloured future trajectories arises from applying one candidate management procedure.

To be able to assess and compare the robustness of management procedures to uncertainty it is necessary to run evaluations for many replicates. Figure 9 shows one hundred evaluations, each based on a different replicate, for a single management procedure. When presenting the trajectories from muliple evaluations, it is usually easier to ascertain both the central tendency and the variability of trajectories using quantile ribbons (Figure 10). The ribbons show the bands where 50%, 80% and 90% of trajectories fall. In addition, to indicate the expected inter-annual variability, the trajectories from three example replicates are shown separately. These example replicates were chosen as those that produced the 20th (red), 50th (blue) and 80th (green) percentile of average biomass of spawners under the constant effort management procedure. In all these plots the same three example replicates are used for ease of comparison. Figure 10 shows the same plot for a management procedure which produces higher catches but consequently, declining stock status.

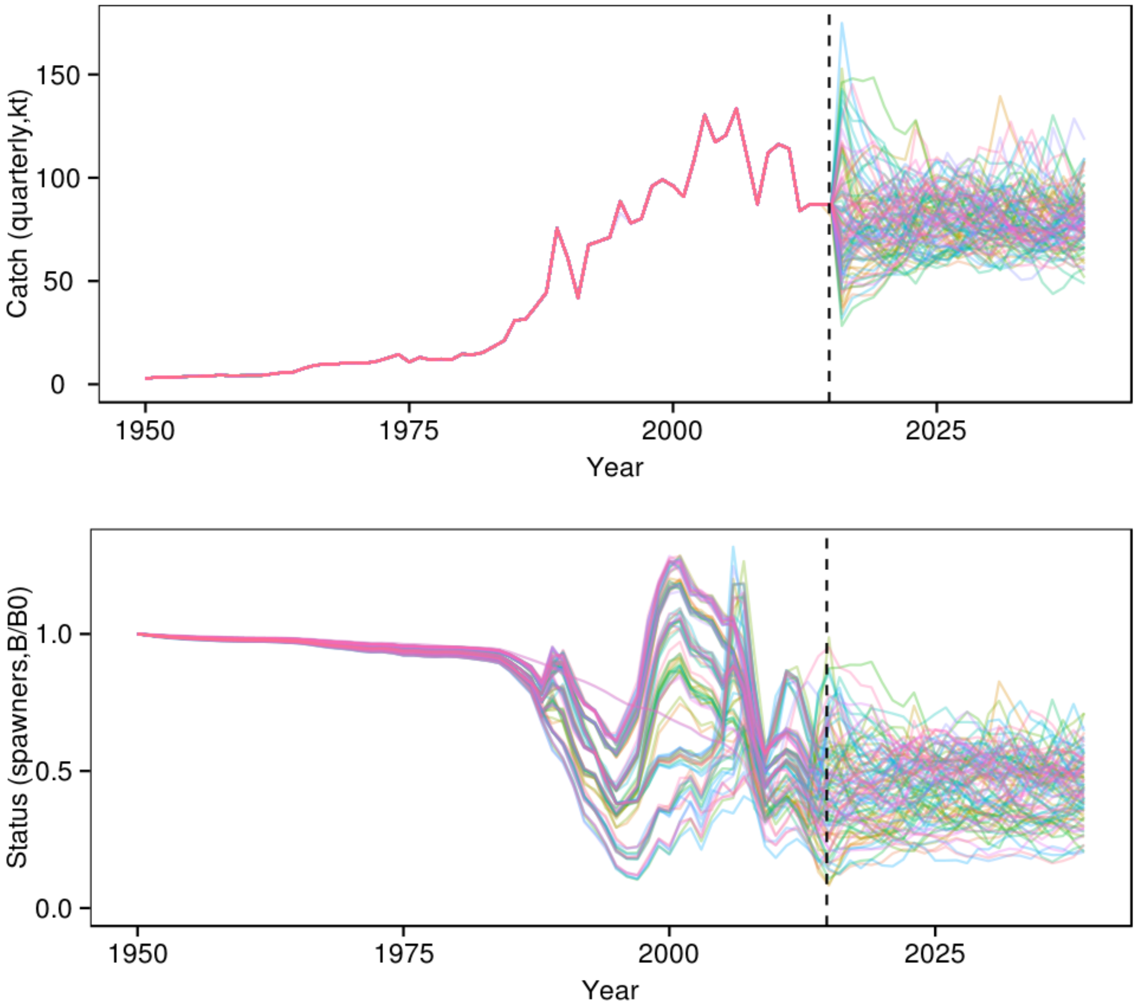

Figure 9 : Catch and biomass trajectories from multiple evaluations of a single management procedure using multiple parameter replicates. Each of the coloured trajectories arises from alternative replicate.

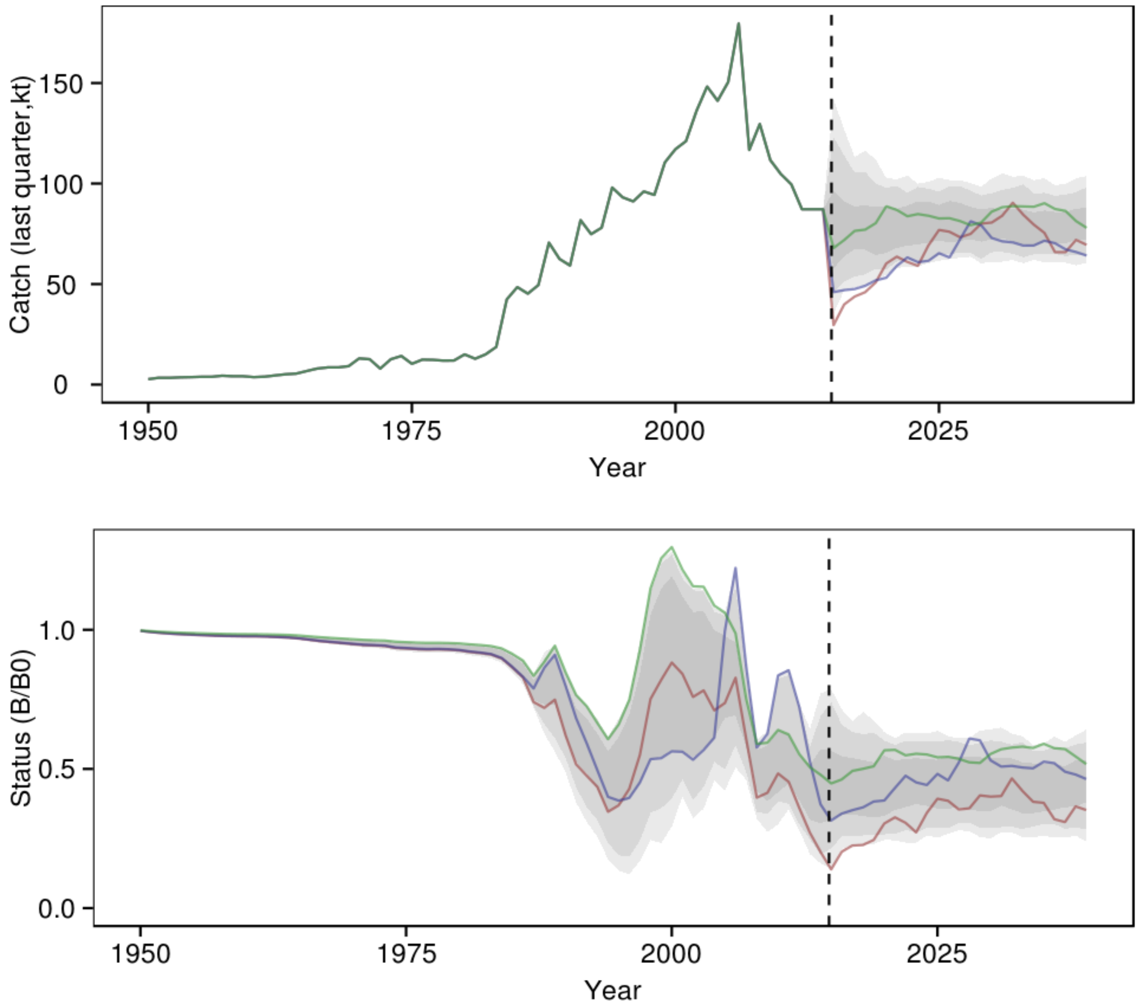

Figure 10 : Catch and biomass trajectory percentiles for management procedure ConstEffort(100) .

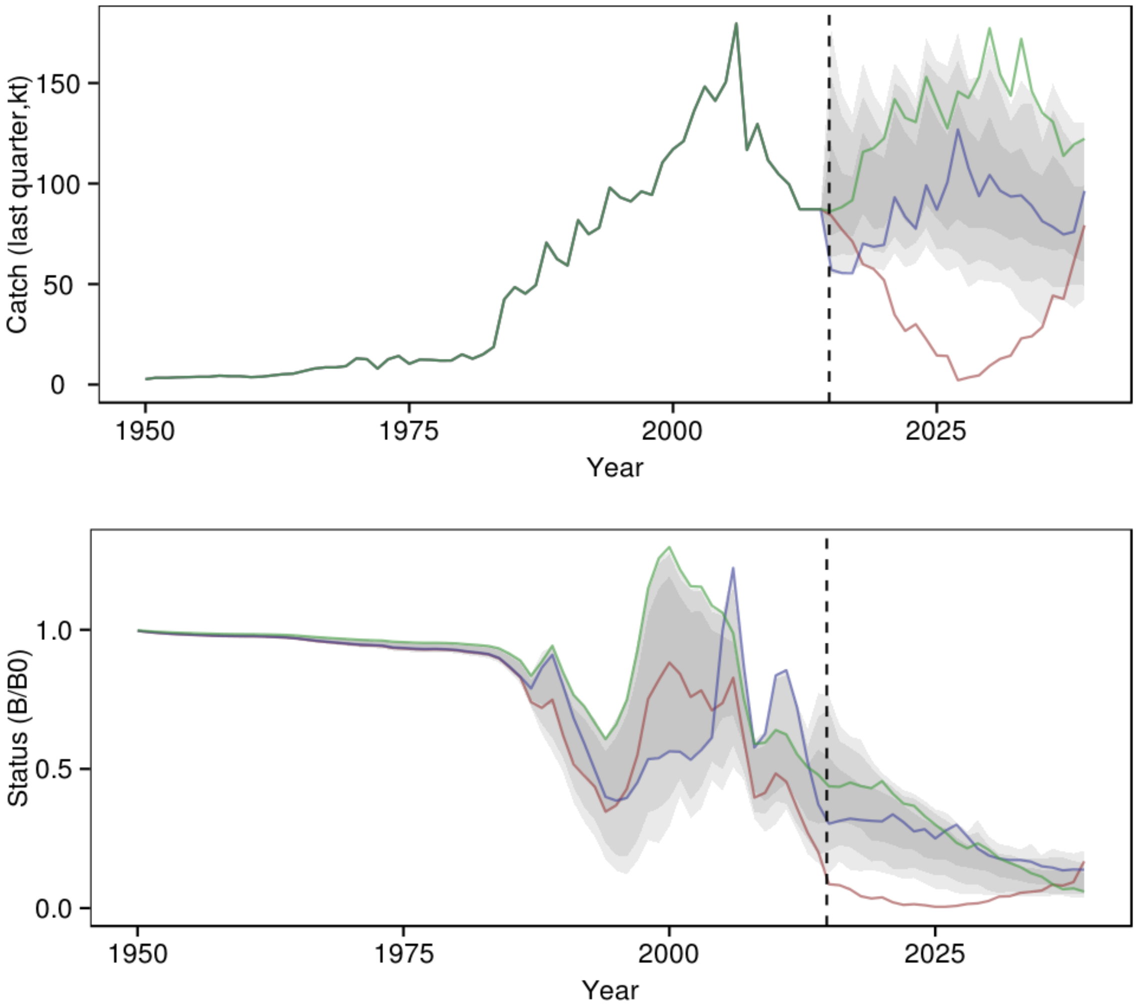

Figure 11 : Catch and biomass trajectory percentiles for management procedure FRange(3,0.1,0.25,0.05,0.3) .

2.1.2 Performance measures, performance statistics and management objectives

A *performance measure* is any model variable that is used as a basis for a *performance statistic* . That is, a performance statistic, summarises a performance measure over the evaluation period, in this case 25 years.

The main performance measures used are catches C , relative catch rates A , and mature biomass S . For convenience, where the performance measure represents a summation across all possible model dimensions (e.g. region, method) for the variable we use the bar annotation in mathematical notation. e.g.

$$\overline{C} = \sum_{r,m} C_{r,m}$$

We have grouped performance statistics according to broad categories of management objectives : yield, abundance, stability, status and safety Table 3 . We use these labels in the following summaries and for each category focus on the first performance statistic. For example, when presenting evaluation results relating to the stability management objective we mostly summarise the MAPC performance statistic. In accordance with the desire to maximise these objectives we present "positive" versions of each of performance statistics in the following figures and tables. For example, rather than presenting a "risk" related statistic such as the probability of being below 0.1S *0 we use the "safety" related statistic, the probability of being above 0.1S* 0.

Figure 12 provides an overview of the distribution of each performance measure.

Table 3 :

Performance statistic	Performance measure	Summary statistic
Yield		
Mean catch	$\overline{C}$	Mean over years
Mean purse siene catch	$\sum_r C_{r,ps}$	Mean over years
Mean pole and line catch	$\sum_r C_{r,pl}$	Mean over years
Mean gillnet catch	$\sum_r C_{r,gn}$	Mean over years
Abundance		
Mean relative catch rates for western purse siene	$A_{we,ps}$	Geometric mean over years
Mean relative catch rates for Maldive pole and line	$A_{ma,pl}$	Geometric mean over years
Mean relative catch rates for eastern gillnet	$A_{ea,gn}$	Geometric mean over years
Stability		
Mean absolute proportional change in catch (MAPC; also known as average annual variation, AAV)	$\overline{C}$	Mean over years $mean\left(\text{abs}\left(\frac{\overline{C}_t}{\overline{C}_{t-1}}\right)\right)$
Variance in catch	$\overline{C}$	Variance over years
Probability of shutdown	$\overline{C}$	Proportion of years that $\overline{C} == 0$
Status		
Mean mature biomass relative to pristine	$\frac{\overline{S}}{S_0}$	Mean over years
Mean mature biomass relative to S_{msy}	$\frac{\overline{S}}{S_{msy}}$	Geometric mean over years
Mean fishing mortality relative to F_{msy}	$\frac{\overline{F}}{F_{msy}}$	Geometric mean over years
Safety		
Probability of mature biomass falling below 10% of S_0	$\overline{S}$	Proportion of years that $\overline{S} < 0.1S_0$
Probability of mature biomass falling below 20% of S_0	$\overline{S}$	Proportion of years that $\overline{S} < 0.2S_0$

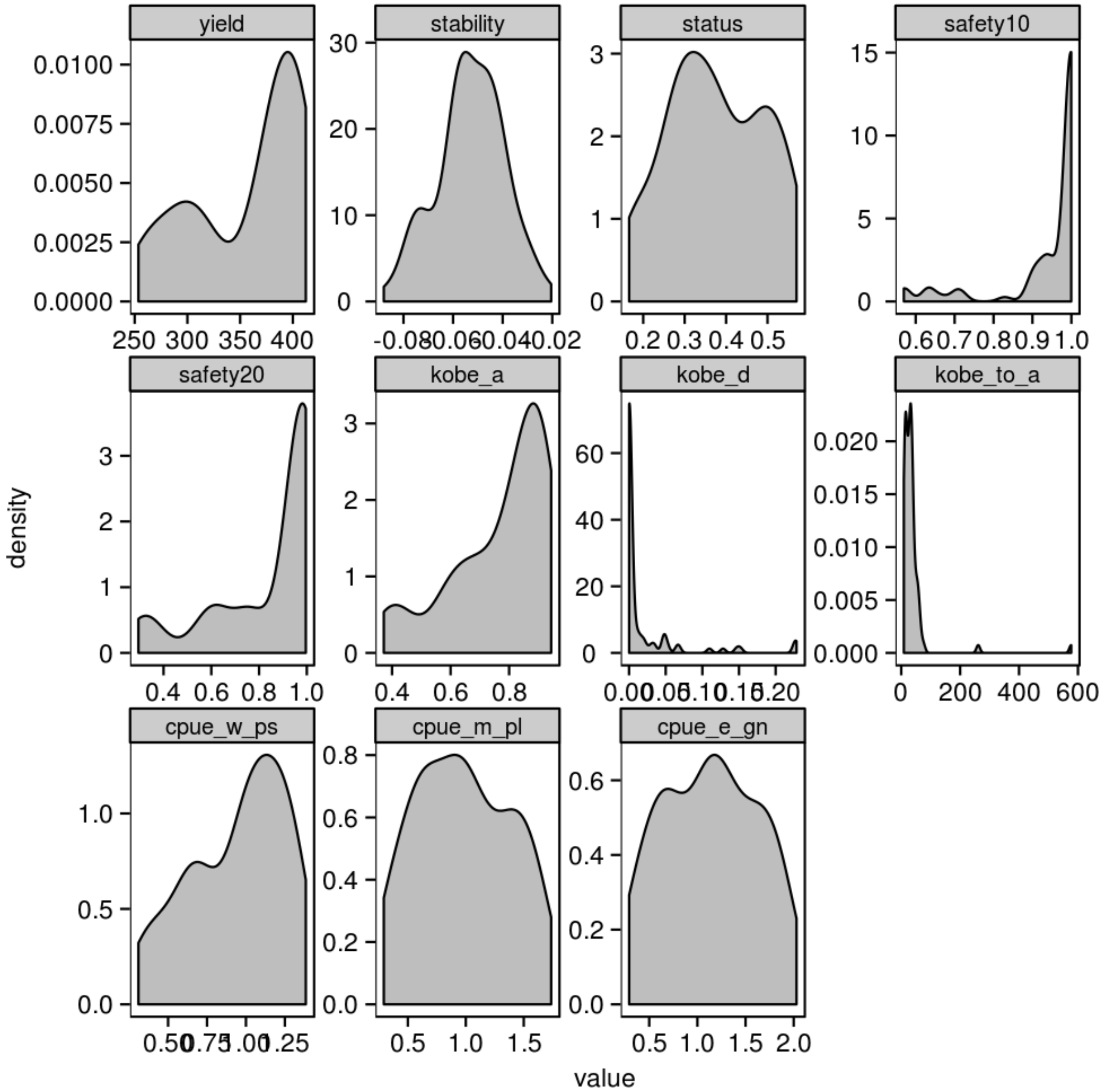

Figure 12 : Distributions of performance statistics over all evaluations. This figure is intended principally to provide an indication of the range of performance statistics outcomes across all replicates and procedures.

2.2 Results

2.2.1 Comparison of classes of management procedures

In this section we provide an overview of the performance of the three classes of management procedures evaluated. This section is also used to introduce the summary figures and tables used in following sections.

The following figures illustrate the trade offs between pairs of performance statistics:

- yield v status Figure 13
- yield v safety #figure-yield-safety-all-all
- yield v stability #figure-yield-safety-all-all
- yield v abundance Figure 16

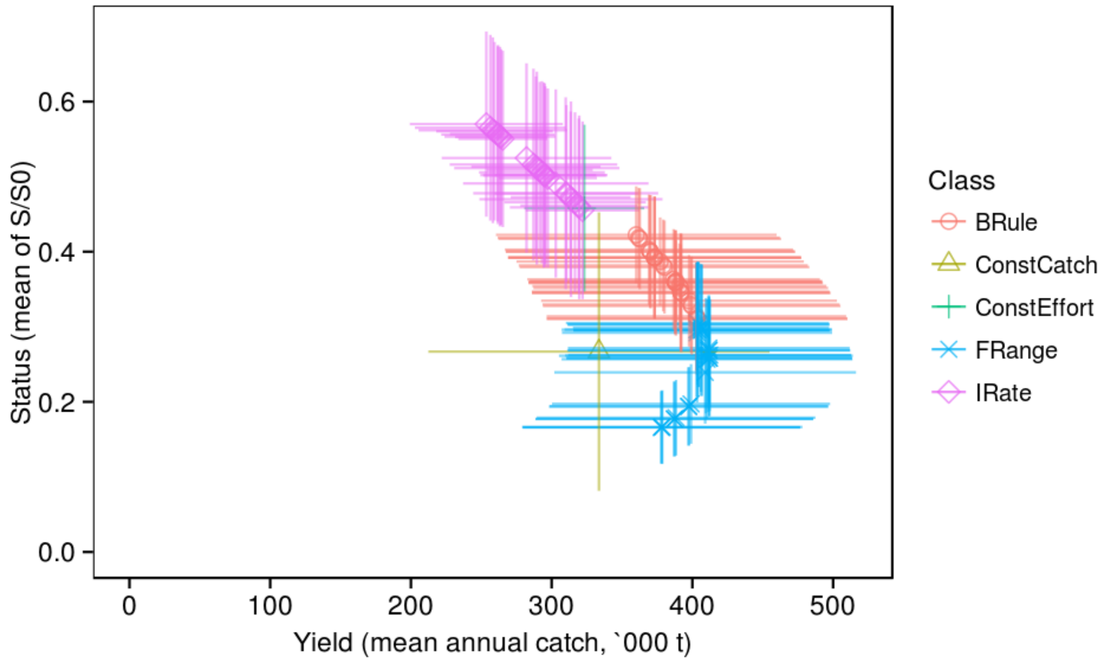

Figure 13 : Trade-off between yield and status performance statistics across all the management procedures evaluated.

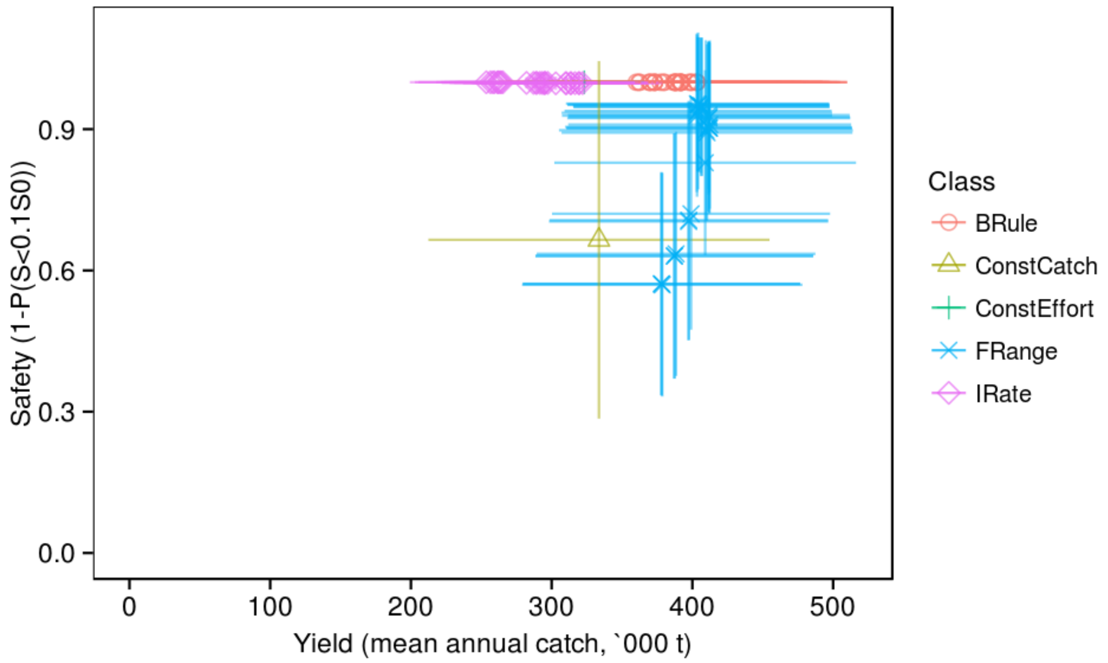

Figure 14 : Trade-off between yield and safety performance statistics across all the management procedures evaluated.

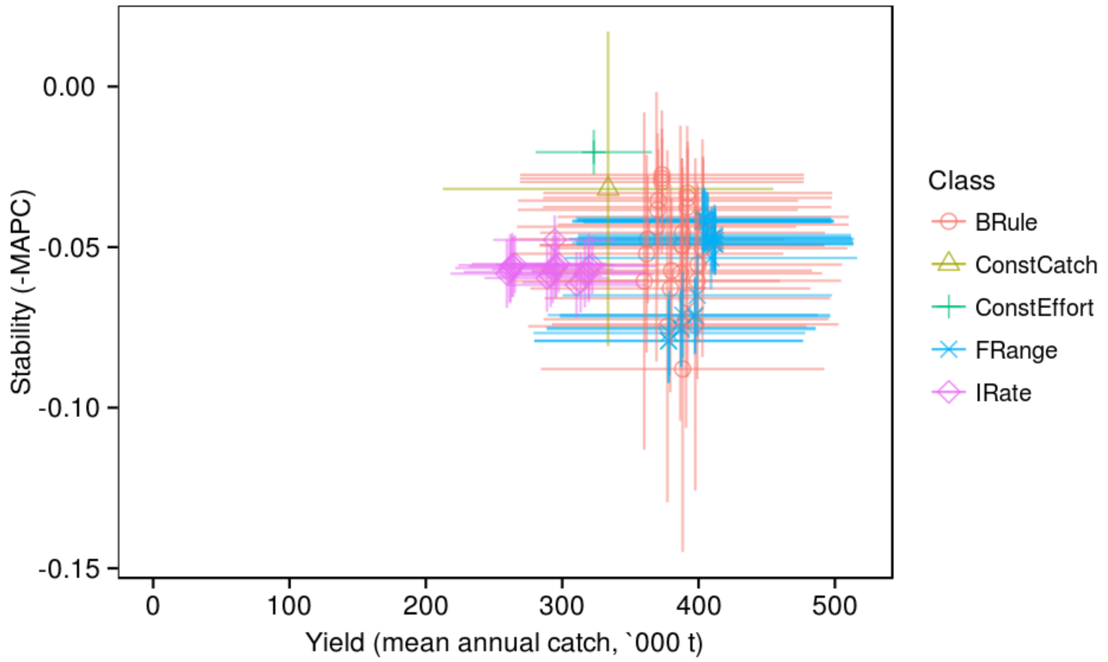

Figure 15 : Trade-off between yield and stability performance statistics across all the management procedures evaluated.

There is an unsurprising performance trade off between yield and abundance (Figure 16). In general, higher catches lead to higher exploitation rates and reduced biomass which in turn leads to reduced catch rates.

Generally there is a high correlation between the abundance performance statistics for each of the main fisheries (Figure 17). Note however, that some MPs, particularly those resulting in overall higher abundance do result in higher relative abundance for M-PL and E-GN. This is most likely a result of the lower exploitation rates under these MPs which in turn creates an increase in the biomass of larger sized skipjack which are more fully selected by these fisheries.

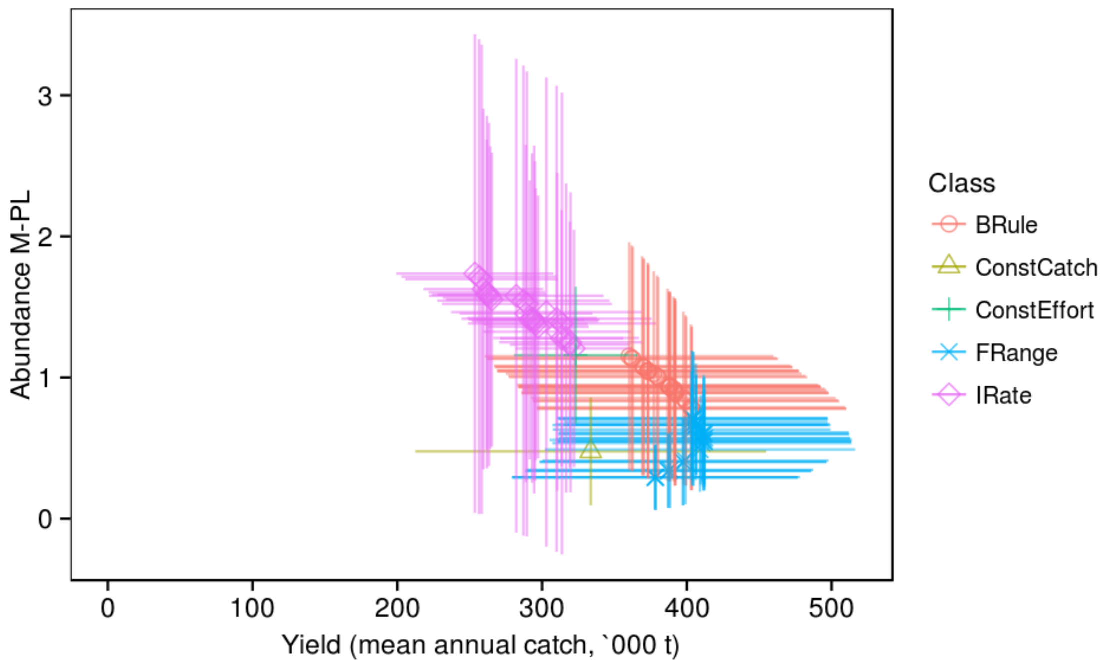

Figure 16 : Trade-off between yield and abundance performance statistics across all the management procedures evaluated.

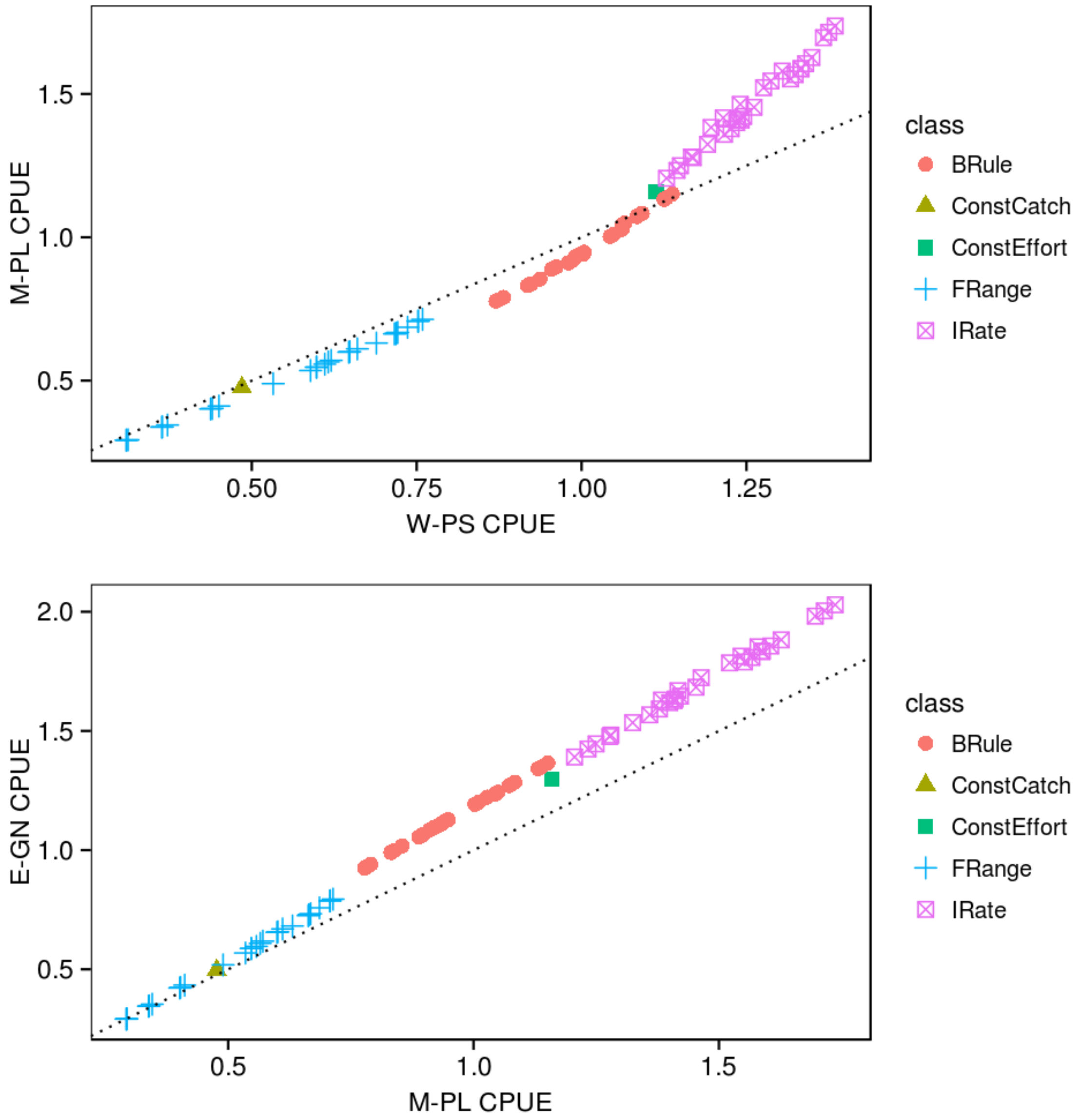

Figure 17 : Correlation between the abundance performance statistics between the three main fisheries.

2.2.2 Performance of the BRule class

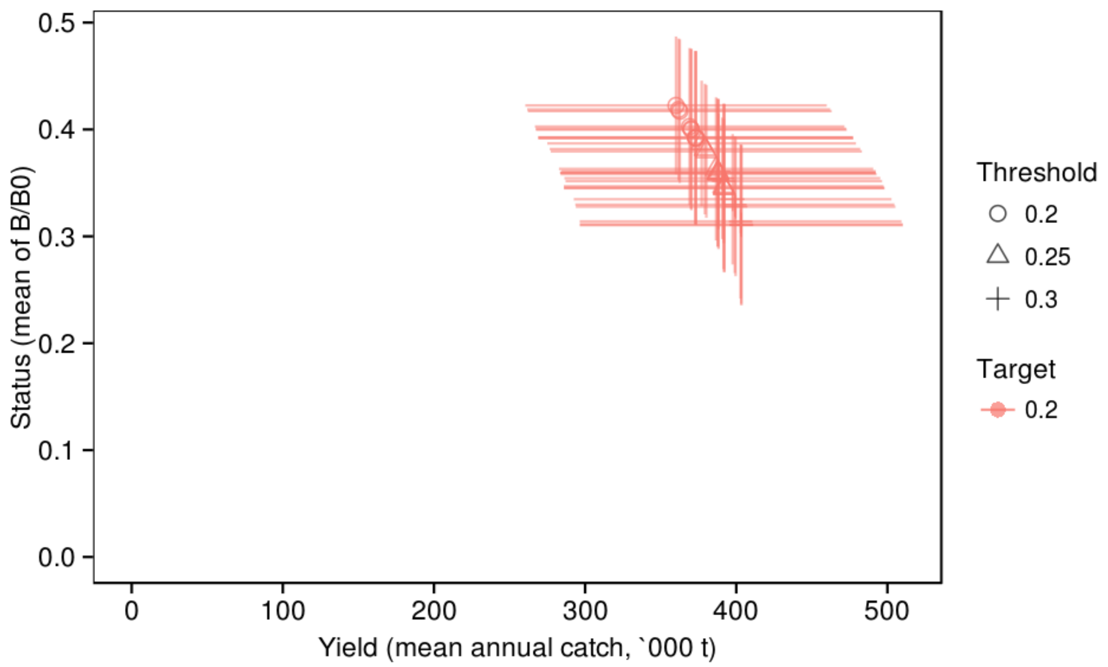

Figure 18 : Trade-off between yield and stock status for alternative instances of the the BRule class of management procedure.

2.2.3 Performance of the FRange class

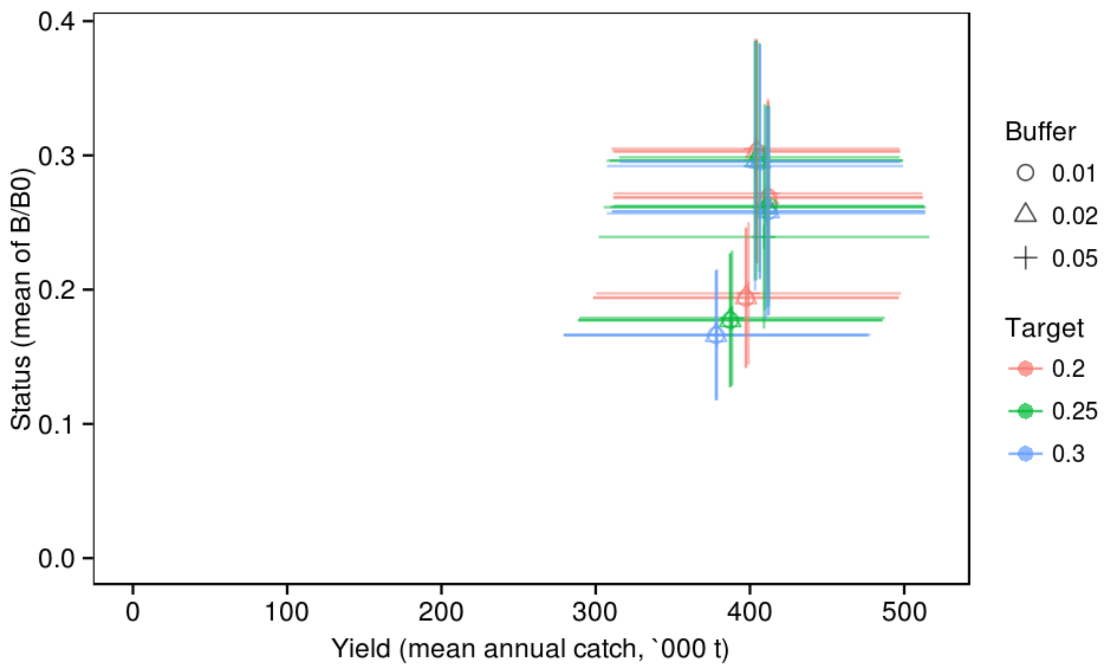

Figure 19 : Trade-off between yield and stock status for alternative instances of the the FRange class of management procedure.

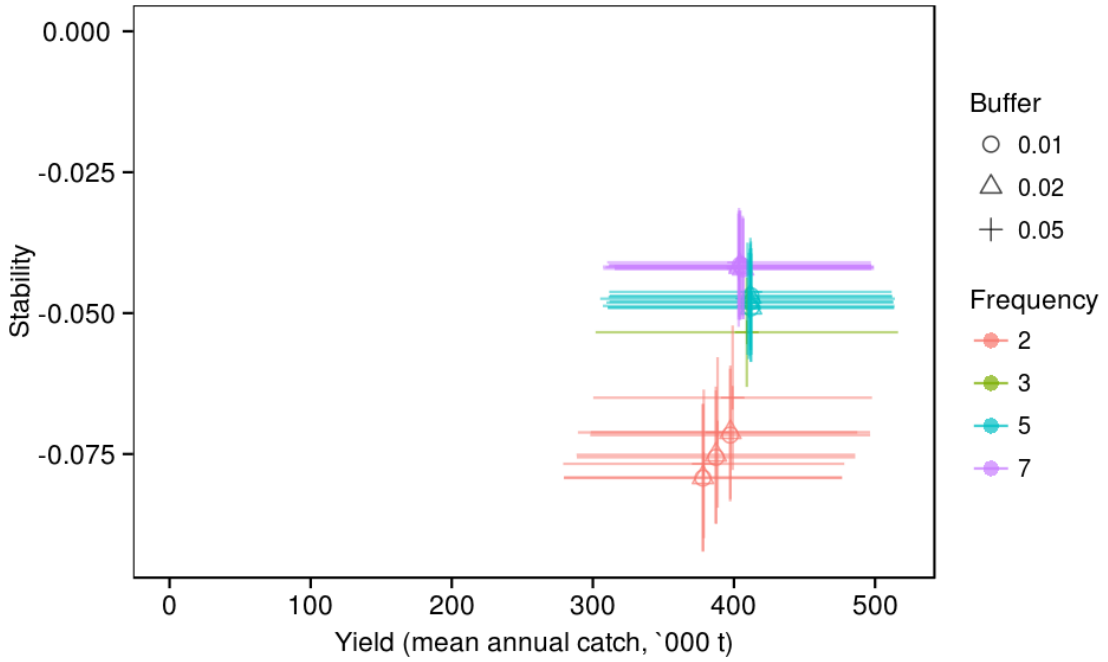

Figure 20 : Trade-off between yield and stock status for alternative instances of the the FRange class of management procedure.

2.2.4 Performance of the IRate class

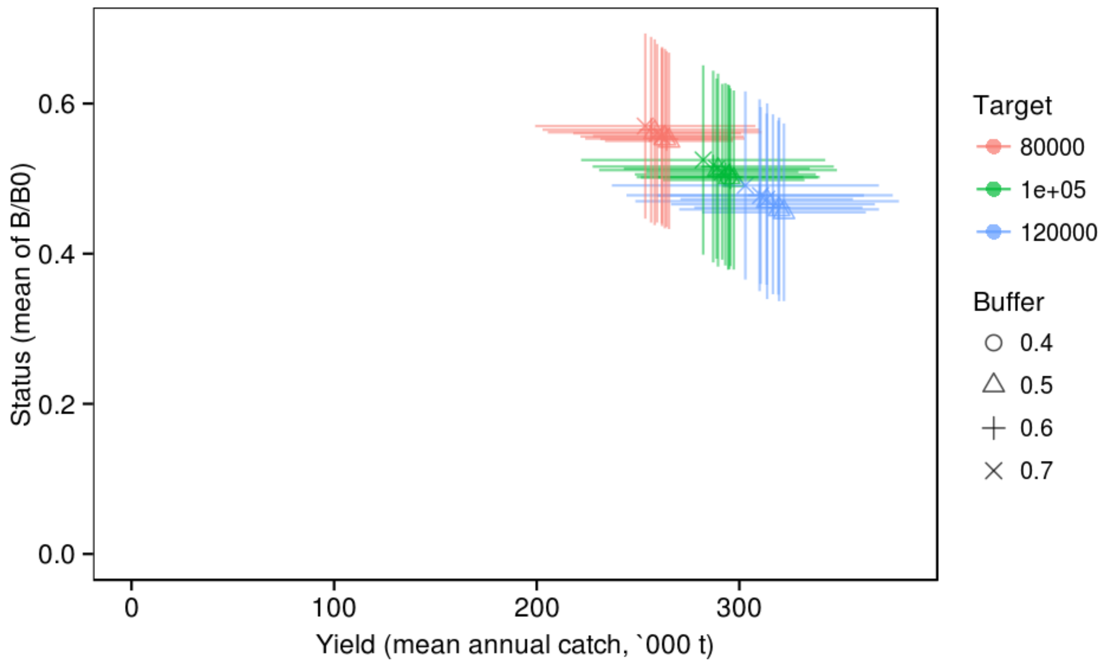

Figure 21 : Trade-off between yield and stock status for alternative instances of the the IRate class of management procedure.