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Cover photographs

Front cover: left- blue-eye trevalla; from top - orange roughy, eastern school whiting, tiger flathead

Evaluation of new harvest strategies for SESSF species

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LIST OF ABBREVIATIONS

AFMA	Australian Fisheries Management Authority
CHSP	Commonwealth Harvest Strategy Policy
CSIRO	Commonwealth Scientific and Industrial Research Organisation
HCR	Harvest Control Rule
HSF	Harvest Strategy Framework
ISMP	Integrated Scientific Monitoring Program
MAC	Management Advisory Committee
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
MEY	Maximum Economic Yield
RAG	Resource Assessment Group
RBC	Recommended Biological Catch
SESSF	Southern and Eastern Scalefish and Shark Fishery
SETFIA	South East Trawl Fishing Industry Association
SS2	Stock Synthesis 2 (a stock assessment software package)
TAC	Total Allowable Catch

1. Non-Technical Summary

Evaluation of new harvest strategies for SESSF species

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OBJECTIVES:

- Collate the experience with the first year of adoption of the SESSF harvest strategy framework, and recommend immediate improvements to the framework.
- Formally test the consistency and robustness of the harvest strategy framework using simulation approaches (management strategy evaluation), and recommend longer term improvements to the framework.

1.1 Outcomes Achieved

Summarising recent experience of the adoption of the SESSF harvest strategy framework (HSF), a discussion paper was produced that outlined its current issues and potential problems, along with nine recommendations for modifications to this framework. This document provided the catalyst for further improvements to the HSF.

Formal testing of the SESSF harvest strategy framework using a management strategy evaluation (MSE) approach was successfully achieved. Improvements to the Tiers 3 and 4 harvest control rules followed and these were then tested using the MSE procedure. The development of the MSE software was a key output of this project. Given the successful testing of the new rules, the improvements were presented to and approved by the RAGs during 2008, and applied (where appropriate) to setting the RBCs for 2009. The MSE approach was also used to evaluate rules for changing the total allowable catch in response to the most recent year's catch per unit effort.

The results from this study provide direct benefits to management and industry, due to improved TAC setting procedures. The formal testing of the SESSF harvest strategy framework has demonstrated that the framework is consistent with, and meets the requirements of, the Commonwealth Harvest Strategy Policy. This provides all stakeholders with confidence that the fishery is being managed in accordance with agreed sustainability objectives.

1.2 Synopsis of the SESSF Harvest Strategy Framework in 2007

The issues and problems with the SESSF harvest strategy framework (as at mid-2007; the beginning of the project) are discussed in Section 5. This section also proposes interim solutions to these problems.

The issues discussed are:

1. Choice of targets and thresholds
2. Precaution between Tiers
3. Ratchet effects at Tiers 3 and 4
4. Assumptions about future discards
5. Choice of base case CPUE

The recommended modifications from this initial evaluation of the HSF are:

1. For Tier 1, B_{LIM} is maintained at B_{20}
2. For Tier 1, two Recommended Biological Catches (RBCs) will be calculated in 2007 based on both a 20:40:40 and a 20:40:48 harvest control rule applied to 2008 projected biomass
3. Tier 2 reference points will be the same as for Tier 1

4. Tier 3 reference points will be calculated as F_{20}, F_{40} and F_{48} corresponding to the limit, MSY and MEY levels respectively
5. Tier 4 reference points be calculated as CPUE levels corresponding to B_{20}, B_{40} and B_{48} (limit, MSY and MEY) levels, to be determined by RAGs
6. Introduce precaution into the HSF by applying Tier specific multipliers G^x to RBC calculations. In the absence of better information, set $G^1 = 1$, $G^2 = 0.9$, $G^3 = 0.8$, $G^4 = 0.75$
7. The Tier 3 harvest control rule be changed to a form similar to Tier 1
8. The Tier 4 harvest control rule be changed to a form similar to Tier 1
9. Assumptions about future discard rates continue to be based on recent observer data, at least until it can be shown that discard rates for quota species have declined substantially

This document was provided to the RAGs for discussion in July and August 2007. Since this initial evaluation, further modifications to the Tier rules have arisen either directly or indirectly as a result of the work conducted from this project. These changes are outlined in the sections that follow.

1.3 Tier 1

The Tier 1 harvest control rule applies to species where there is a robust quantitative assessment that provides estimates of current biomass levels. Section 6 shows the results of MSE testing of the Tier 1 harvest control rule for three species types – flathead-like, school whiting-like and orange roughy-like. Application of the Tier 1 HCR leads to all stocks stabilising at the target level. The time taken to reach the target depends on the initial stock status, and the species' biological characteristics.

1.4 Tier 3

Tier 3 species are those that do not have a formal stock assessment, but do have information available on the age frequencies of annual catches, annual total catch, and knowledge of basic biological parameters. This information is used to estimate current fishing mortality (F_{CUR}), which is then applied within the harvest control rule to calculate the RBC. A number of problems were identified with the original Tier 3 procedure used in the SESSF harvest strategy framework (HSF). Section 7 describes an improved method of estimating F_{CUR}, and an alternative Tier 3 control rule. MSE testing is used to demonstrate the improvements in the procedure.

The three main issues causing problems with the behaviour of the original Tier 3 method were:

- a mismatch in the period used to calculate current catch (C_{CUR})
- the catch curve method for estimating F_{CUR} does not take selectivity into account, and
- the rule does not use concepts of target and limit F levels, as does the Tier 1 rule.

The MSE procedure is used to test appropriate matching of estimation periods; an alternative F_{CUR} estimation method; and an alternative control rule similar in form to the Tier 1 harvest control rule. MSE testing is performed for both flathead-like and whiting-like species, with different depletion levels at the start of the projection period. All three components of the revised procedure are tested separately. The revised Tier 3 method is also tested for robustness to mismatches between the biological parameters used in the assessment procedure and those used in the operating model, and for the ability to deal with the possibility of the catch not being equal to the TAC.

The results show that when all three components of the Tier 3 method are changed, application of this method leads to both the species tested stabilising close to the target biomass. The method is shown to be relatively robust to situations where catch is not equal to TAC. The performance of the method is fairly insensitive to using the wrong value of the steepness parameter, but using the wrong value of natural mortality in the assessment rule leads to poor outcomes.

1.5 Evaluation of harvest strategies for blue-eye trevalla

A management strategy evaluation (MSE) approach is used to evaluate the performance of Tier 3 HCRs that only use information from the age-composition of the catch as a means of calculating future Recommended Biological Catches (RBCs). Section 8 describes the application of the MSE using an operating model parameterized for blue eye trevalla (*Hyperoglyphe antarctica*), a long-lived, late maturing scalefish species. Within the SESSF, blue eye trevalla is exploited by multiple gear types, and exhibits spatial and seasonal variability in availability to the fishery, possibly further complicated by spatial structure in the population dynamics. Several versions of the Tier 3 HCRs are tested, which vary in both the types of reference points used to calculate RBCs, and in the manner for which spatial variability in the fishery is accounted for when setting RBCs for the entire resource. Results suggest that implementation of HCRs which use age-composition data, such as those examined, can be used to effectively manage a species such as blue eye, given appropriate choice of reference points.

Spatial disaggregation of data leads to uncertain estimates of current mortality. However, appropriate weighting of regional estimates of the levels of fishing mortality leads to improved conservation of the resource compared to approaches which pool data spatially, when the resource exhibits spatial population structure. Care and common sense needs to be taken when applying the Tier 3 HCRs, because simulated outcomes are sensitive to many of the uncertainties inherent to an information-poor, spatially-heterogeneous resource. As a result, automated 'blind faith' management of such species through application of the Tier 3 HCRs is perhaps unwise. Application of HCRs under Tier 3 should result in lower RBCs than under Tier 1, thus achieving larger stock sizes, as uncertainty regarding stock status increases given a precautionary approach to management. The performance of Tier 3 HCRs for blue eye relative to that for more data-rich scenarios suggests that additional considerations besides the HCR, such as estimation uncertainty, alternative reference points, and RBC discounts might be warranted to achieve desired precautionary results in line with the harvest policy.

1.6 Tier 4

The Tier 4 harvest control rule applies to species with no reliable information on either current biomass or current exploitation rate. The original Tier 4 control rule determined an RBC by using the trend in recent CPUE to scale average recent catches. This rule resulted in RBC recommendations that maintained catch rates, and consequently stock biomass, at about current levels. Section 9 describes an alternative Tier 4 harvest control rule that is similar in form to the Tier 1 and revised Tier 3 harvest control rules.

The MSE procedure is used to test the alternative Tier 4 harvest control rule. The biological component of the operating model is conditioned on the biology of flathead or school whiting. Different depletion levels at the start of the projection period in which the harvest control rule was implemented are considered. Variations on the proposed Tier 4 harvest control rule included different historical reference periods from which the CPUE and catch targets were derived, and the maximum value that the control rule could take. We also perform scenarios where the target catch is calculated annually based on the average catch of the most recent four years, and where it is fixed at the average catch taken from the historical reference period.

The results show that the harvest control rule using the historical catch works better than the rule using recent average catch, because there is no lag effect that would lead to either a “ratchet effect”, (e.g. a series of low catch years, as a result of some external factor such as market forces) or to oscillatory behaviour in the fishing dynamics.

It is important to remember when considering the results of the Tier 4 harvest control rule, that the relationship between the management reference level of 0.48 B_0, which is an implicit management target, and the target CPUE, which is the explicit target, is not known. For example, we do not know if the target CPUE, to which the harvest control rule is aiming, will lead to desired relative biomasses that approximate 0.48 B_0. An estimation of B_0 requires a Tier 1 assessment.

These results stress the importance of selecting CPUE targets and the associated target catch appropriately. The revised Tier 4 harvest control rule will tend to guide the fishery to its state during the reference period, therefore it is imperative to select a reference period during which the fishery is thought to have corresponded to the management goal, and been economically and biologically stable.

1.7 Post-assessment rules

The current method of calculating TACs in the SESSF does not utilise information from the most recent fishing year, as a full stock assessments is only able to have complete data up to the end of the previous year. Section 10 describes and examines two rules that adjust the TAC from a stock assessment based on the most recent trend in standardised CPUE, in order to incorporate information from the most recent fishing year. The first rule gives a linearly proportional change in TAC with changes in CPUE, and the second gives a multiplicative proportional change. The first rule lacks symmetry in that it increases the TAC in response to an increase in CPUE more strongly than it decreases it, whereas the second rule is symmetric in this regard and therefore likely to be more conservative.

The post-assessment rules are tested using the MSE procedure for two types of species characteristics (flathead-like and whiting-like) at various starting depletion levels with the Tier 1, 3 and 4 harvest control rules. For all scenarios tested, the application of both versions of the post-assessment rule does not significantly alter the performance of the harvest strategy procedures in terms of risk to the stock or overall catch levels, but it does significantly increase the year-to-year catch variability. The first rule leads to greater catch variability than the second. The expected difference in the behaviour of the two rules (namely, that the first rule leads to greater utilisation of the stock than may be desired) is dampened by additional restrictions applied to the change in TAC. The maximum change in TAC due to the application of the post-assessment rule was capped at 25%, and the TAC is restricted from changing by more than 50% from one year to the next. If the post-assessment rules only increase TAC in response to increasing catch rates, and do not decrease TAC in response to decreasing catch rates, then the risk of stock collapse is increased.

1.8 Operating model specifications

An operating model is a formally coded mathematical model of the population dynamics of the fishery. Its development is a key step in the application of the MSE approach. Section 11 contains the technical specifications for the SESSF operating model used for the MSE project. The model consists of an age-structured population dynamics model, a data-generation module, and a component to allow future projections of the population model given input from estimation methods and harvest control rules.

Two versions of the operating model have been coded – one in C++ and another in Fortran. Multiple implementations of the fairly complicated model increase the confidence that the model has been correctly coded, and hence that the results are reliable.

2. Background

2.1 The Fishery

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

2.2 Management

Management of the SESSF is based on a mixture of input and output controls, with over 30 commercial species or species groups currently under quota management. A formal harvest strategy framework (HSF) was adopted in the Southern and Eastern Scalefish and Shark Fishery for the first time in 2005. This framework includes an agreed process for fishery monitoring, stock assessment, and decision rules for translating stock assessment outputs into clear advice on Recommended Biological Catch (RBC) for each species managed under the Quota Management System.

The HSF uses harvest control rules to determine a RBC for each stock in the SESSF Quota Management System. Each stock is assigned to one of four Tier levels depending on the basis for assessing stock status or exploitation level for that stock. Tier 1 stocks have a well established and agreed quantitative stock assessment, while for Tier 2 stocks the assessment is judged to be more uncertain. Tier 3 is based on estimates of exploitation rate from catch curve analyses, while Tier 4 is based on trends in catch rates (CPUE). The original HSF, as well as the experience in implementing the framework from 2005 to 2007 is described in Smith *et al.* (2008).

2.3 Management Strategy Evaluation

Management strategy evaluation (MSE) is a widely-used approach for evaluating management decision rules (Smith *et al.* 1999). MSE attempts to incorporate not only the uncertainty in the underlying dynamics of the fish population, but also the uncertainty in the methods and data used to assess and manage the fishery (Tuck 2006). The MSE approach involves evaluating the entire management system by means of Monte Carlo simulation – performing many runs of a mathematical model where some parameters or data values are chosen at random from a known plausible probability distribution. If the model is run enough times, a frequency distribution of possible outcomes (e.g. proportion of remaining biomass) can be generated, from which the likelihood of various options (e.g. stock collapse) can be derived (Haddon 2001). The process is designed to explore, as realistically as possible, the consequences of future management of the fishery.

The steps involved in the MSE approach are as follows:

- Specify the management objectives.
- Develop quantifiable performance measures for the management objectives.
- Specify the harvest strategies.
- Develop an ‘operating model’ to represent the ‘true’ fish stock. The parameters of the operating models in this project are based on existing Tier 1 assessments, so are consistent with the available historical and biological information on the stock being evaluated.
- Simulate the future use of a harvest strategy to manage the stock. For each year of the projection period, this involves:
    - the generation from the ‘true’ population of simulated ‘data’ representing what would be collected in the fishery (e.g catch-at-age, CPUE)
    - the application of a stock assessment method (e.g. Integrated Analysis using SS2) to both the historic and future (simulated) data
    - the application of a HCR (e.g. the Tier 1 rule) to give a catch quota for the following year
    - the application of the catch to the ‘true’ population structure
- Repeat the above process many times with a different simulated data sample and future recruitment deviations each time. Combine the performance measures over all simulations to provide a summary of the performance of the particular harvest strategy for a given stock. This provides a means of comparing harvest strategies across scenarios.
- Communicate the results to decision makers.

2.4 References

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3. Need

The decision rules that constitute a key part of each Tier in the HSF were developed on the basis of prior experience with similar rules in other (overseas) fisheries, but when first applied had yet to be formally tested using management strategy evaluation (MSE) methods. In addition, the adoption and application of the Tier rules in 2005 was giving rise to a number of issues and possible inconsistencies that clearly pointed to the need for some modifications to the HSF. This project tests, refines and improves the HSF to ensure that it is indeed consistent with the principles that underlie its development.

The Commonwealth Fisheries Harvest Strategy Policy released in 2007 states that harvest strategies should be formally tested by methods such as management strategy evaluation in order to demonstrate that they are highly likely to meet the core elements of the Policy.

4. Objectives

- Collate the experience with the first year adoption of the SESSF harvest strategy framework, and recommend immediate improvements to the framework.
- Formally test the consistency and robustness of the harvest strategy framework using simulation approaches (management strategy evaluation), and recommend longer term improvements to the framework.

5. Proposed revisions to the SESSF Harvest Strategy Framework for 2007 – a discussion paper

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5.1 Background

The SESSF harvest strategy framework (HSF) was developed during 2005 and has been used as a basis for providing advice on TACs in the SESSF quota management system for fishing years 2006 and 2007. The HSF uses harvest control rules to determine a recommended biological catch (RBC) for each stock in the SESSF quota management system. Each stock is assigned to one of four Tier levels depending on the basis for assessing stock status or exploitation level for that stock. Tier 1 stocks have a well established and agreed quantitative stock assessment, while for Tier 2 stocks the assessment is judged to be more uncertain. Tier 3 is based on estimates of exploitation rate from catch curve analyses, while Tier 4 is based on trends in catch rates (CPUE). The original HSF is described in Smith and Smith (2005) and Smith *et al.* (2008).

In general, the HSF has been well accepted and has resulted in improvements in the TAC setting process from previous practice. However some problems in applying the HSF in 2005 resulted in suggested modifications to the rules and their application in 2006 (AFMA 2006). While these modifications were broadly agreed through the SESSF RAG process in 2006, not all were agreed or adopted by the AFMA Board in determining TACs for 2007 (AFMA 2007). The issues were discussed further by SESSF RAG at workshops in February 2007, and at subsequent individual RAG meetings. In the mean time the Commonwealth Harvest Strategy Policy (CHSP) and its associated Guidelines were released for public comment by the Minister for Fisheries and are nearing completion. These will also have a strong bearing on the form and application of the SESSF HSF into the future.

The purpose of this discussion paper is to outline the issues and current problems with the SESSF HSF and to propose interim solutions. The aim is to reach broad agreement in the SESSF RAG community on these changes, with a view to adopting them in providing TAC advice for 2008-09 (noting the change to the fishing year adopted for 2007). It is intended to seek AFMA Board endorsement of the changes prior to the Joint MAC meeting in November that will provide recommendations on TACs for 2008-09.

5.2 Issues

5.2.1 Choice of targets and thresholds

It is easiest to discuss targets and thresholds in the context of Tier 1 assessments and rules. The original SESSF HSF proposed that biomass (B) and fishing mortality (F) targets be set at MSY (maximum sustainable yield) levels, with a proxy for B_{MSY} in the absence of better information being B_{40}, the biomass level corresponding to 40% of unexploited equilibrium levels (often referred to as B_0). The suggested default biomass limit reference point B_{LIM} was set at B_{20}. The proposed Tier 1 harvest control rule was based on a target fishing mortality rate of F_{40}[1] where the stock was above B_{40}, with a linear decline to zero at B_{20} for stock sizes below B_{40} (Figure 5.1). For stock sizes below B_{20} RBCs would be set to zero[2].

In the initial implementation of the HSF, the target biomass for Tier 2 stocks was set at B_{50} though there was no change to the limit biomass reference point from Tier 1. Tier 3 lacked an explicit target reference point although it had an implicit target fishing mortality rate at F=M where M is the natural mortality rate for the stock. Tier 3 had an explicit limit reference point at F=2M. Tier 4 lacked either explicit or implicit reference points (either target or limit).

Uncertainty about the appropriate target biomass levels for Tier 1 stocks was introduced during 2006 as a result of the preliminary stages of development of the Commonwealth Harvest Strategy Policy. The draft CHSP proposed that target levels be set corresponding to MEY (maximum economic yield) rather than MSY. The default target biomass proposed was 20% above B_{MSY}, with a proxy at B_{48} (20% above B_{40}). RBC calculations for Tier 1 and 2 stocks during 2006 were presented assuming several interpretations of these changes including the previous default targets. Industry in particular expressed concerns about the magnitude of the reductions in RBC levels arising from the shift in target from B_{40} to B_{48}. The CHSP released for public discussion in 2007 confirmed the intention to adopt the MEY target, though there is still some uncertainty about how quickly a stock would need to reach B_{MEY} (default B_{48}) particularly where it is above B_{MSY} (B_{40}). At the moment the recovery time is implicitly defined by the harvest control rule. This uncertainty will have to be resolved quickly so that the RAGs can provide final advice to the Joint MAC meeting in November. The current timetable has RAG advice completed by late August / early September and the basis for calculations of RBCs would need to be established well before then.

5.2.2 Precaution between Tiers

The SESSF HSF is designed to be precautionary between Tiers (Smith and Smith 2005). This is meant to apply in the sense that increasing Tier levels (from 1 to 4) are selected on the basis of increasing uncertainty in stock status and so the RBCs calculated at each level should reflect this uncertainty. Put another way, applying each

[1] F_{40} is the fishing mortality rate that will maintain the stock on average at B_{40}.

[2] While the RBC determines a zero targeted catch below B_{20}, the TAC may be set greater than zero to allow for unavoidable bycatch.

Tier level to the same stock should result in progressive decreases in RBC as Tier level increases.

The current Tier rules are not necessarily precautionary in this sense. Tier 2 will result in lower RBCs than Tier 1 (because the target stock size is higher), but Tiers 3 and 4 may not. Experience to date suggests that Tier 4 in particular is not precautionary and tends to be a "status quo" strategy that will not result in rebuilding of depleted stocks. The situation is currently unsatisfactory as it has the potential to lead to "Tier shopping" to maximize the RBC.

5.2.3 Ratchet effects at Tiers 3 and 4

The RBCs for Tier 1 and 2 stocks are calculated by applying the target fishing mortality from the harvest control rule to the estimate of biomass for the year in which the TAC will be taken. There is no direct relationship between the RBC in one year and previous catch levels (except to the extent that those catch levels have influenced the estimate of stock size). However the RBCs for Tiers 3 and 4 currently involve application of a formula that multiplies a determined factor (the multiplier) by recent average catches. The intention is that the repeated application of this formula should stabilize the stock at or close to target levels. Where the multiplier in a particular year is less than one, this will result in a decrease in catch level when applied to the TAC via the RBC. This in turn will result in a lower value for recent average catch (currently the average over the past four years). If the multiplier in the next year is one (indicating that the stock is at or close to target levels) the application of the formula will still result in a decrease in RBC because recent average catch has declined. The concern is that this could result in a "ratchet" effect with continually declining TACs even when the stock is at target levels. (Note that this should ultimately be self-correcting because the multiplier will be greater than one where the stock is above target levels, but there may be a substantial delay before the correction comes into effect). A further specific concern with Tier 3 is that the indicator (exploitation rate expressed as F/M) will be slow to respond as catches are reduced because the method assumes equilibrium conditions and F values determined from catch curves will take time to alter as true F values decline, especially for long-lived species. This again will result in a "ratchet" effect that will reduce RBCs if the Tier rule is applied annually.

5.2.4 Assumptions about future discards

The RBCs calculated at each Tier level correspond to a target level of total mortality from fishing. This includes landed and discarded catch, as well as fishing from other sectors outside the SESSF, potentially including State catches, catches by foreign fleets, recreational catches and indigenous catches. The TAC derived from the RBC applies to landed catch by SESSF endorsed vessels only.

Currently, calculation of the RBC involves at least a one year projection (to the next fishing year) of all these sources of fishing mortality, including discards by SESSF vessels. To date, the projection of discards has been based on recent trends and levels in discards from ISMP reports. However AFMA has announced an intention to ban discards of quota species from 2008. It seems unlikely that this policy will be fully and effectively implemented in the near future. What assumptions should therefore be made about future levels of discard to determine future fishing mortality and therefore RBC calculations? (Note that it will be important for assessment purposes to determine whether there has been a real change in selectivity arising from application of the zero discard policy).

5.2.5 Base case CPUE

Assessment of current stock status relies heavily on trends in CPUE for many SESSF quota species. In the HSF, Tiers 1, 2 and 4 all rely on these data. To date, there has been considerable variation in the way CPUE is defined and calculated between stocks (and even within stocks where there are multiple sectors catching that species). Attempts should be made to improve the consistency with which CPUE is calculated and applied within the HSF.

5.3 Discussion and recommendations

5.3.1 Choice of targets and thresholds

The HSF will be both improved and more readily accepted if there is complete clarity about the targets and thresholds that are being used. The targets and thresholds should be consistent with the Commonwealth Harvest Strategy Policy and its Guidelines. If these are released in time, they will be the basis for selecting the targets and thresholds. At this stage it is anticipated that the limit reference point is unlikely to change from the current default used in the SESSF HSF ($B_{\mathrm{LIM}} = B_{20}$). The target is more uncertain but is likely to be B_{MEY} with a default of B_{48}. However there is some uncertainty about transition times to reach B_{MEY} from B_{MSY}.

Recommendation 1: For Tier 1, B_{LIM} is maintained at B_{20}

Recommendation 2: For Tier 1, two RBCs will be calculated in 2007 based on both a 20:40:40 and a 20:40:48 harvest control rule[3] applied to 2008 projected biomass

For reasons discussed in section 5.3.2 below, it is desirable that consistent targets and thresholds be used between Tiers. This implies setting these values at the same levels for Tier 2 as for Tier 1. Tier 3 is based on F or Z indicators (Z is total mortality including natural mortality and is the quantity estimated directly from the catch curves that are the basis of assessment at Tier 3). For Tier 3 to correspond to Tiers 1 and 2 with regard to targets and limits would involve setting F reference points at F_{20}, F_{40} and F_{48} corresponding to the limit, MSY and MEY levels respectively[4]. Tier 4 currently uses CPUE as an indicator of stock status. Application of a consistent

[3] An X:Y:Z harvest control rule has a limit at X, an inflection point at Y and a target level at Z as in Figure 1

[4] It is suggested that F reference points be calculated on the basis of spawning stock per recruit calculations corresponding to the relevant depletion level for each reference point

approach to targets and limits across Tiers will require the identification of CPUE reference points corresponding to those targets and limits. This will be difficult in the case of CPUE because there is no clear theoretical justification for choice of these reference levels. The proposal is that RAGs attempt to define these levels based on "reasonable assumptions" (effectively, best judgement). Some further notes on this issue are provided at Appendix A.

Recommendation 3: Tier 2 reference points will be the same as for Tier 1

Recommendation 3 is a change from the current strategy for Tier 2 which uses a more conservative target. As discussed in Appendix D and section 2 below, it may be more appropriate to remove Tier 2 and allocate a "precaution discount" to Tier 1 species based on level of uncertainty in the assessment.

Recommendation 4: Tier 3 reference points will be calculated as F_{20}, F_{40} and F_{48} corresponding to the limit, MSY and MEY levels respectively

Recommendation 5: Tier 4 reference points be calculated as CPUE levels corresponding to B_{20}, B_{40} and B_{48} (limit, MSY and MEY) levels, to be determined by RAGs following guidance at Appendix A.

5.3.2 Precaution between Tiers

There are at least three options to ensure that RBC levels are increasingly precautionary as Tier level moves from 1 to 4:

- Use progressively higher biomass targets (lower fishing mortality targets) as Tier level increases
- Build uncertainty levels in assessments into the calculations for the harvest control rules (e.g. RBCs are some inverse function of CVs of biomass estimates at Tier 1, with similar but more precautionary rules at other Tier levels)
- Calculate RBCs at each Tier level based on common targets and limits, but "discount" RBCs at higher Tier levels

While any of these three options might be made to work, the third option seems to be the simplest and most direct. It avoids having to set and justify different target levels (first option) and is much simpler than specifying complex functional forms for control rules based on CVs or variances (second option). It also leaves open the option of differentiating within a single Tier among stocks with more or less certainty in assessments.

The proposal would be to calculate an RBC for each stock according to the formula for its Tier level, and then multiply the RBC by a final factor G^x (less than or equal to 1) if the stock is assessed at Tier level x. For example, G could be set to 1 for Tier 1 stocks, 0.9 for Tier 2, 0.8 for Tier 3 and 0.75 for Tier 4. In essence, G^x becomes a tuneable parameter for each Tier level. In the longer term, the correct level for G^x could be determined by simulation testing, or even tuned for individual species. In the shorter term, some indication of appropriate levels for G^x could be determined empirically using stocks with Tier 1 assessments and then applying Tier 2 to Tier 4 RBC calculations to each.

Recommendation 6: Introduce precaution into the HSF by applying Tier specific multipliers G^x to RBC calculations. In the absence of better information, set $G^1 = 1$, $G^2 = 0.9$, $G^3 = 0.8$, $G^4 = 0.75$.

5.3.3 Ratchet effects at Tiers 3 and 4

As discussed under "issues" above, the ratchet problem arises where RBCs for Tiers 3 and 4 are influenced not only by the current status of the stock, but also by recent decisions (TACs) applied to the stock. Although the Tier rules should be ultimately self-correcting, this may take some time, particularly for Tier 3 where the stock status indicator (F) may take a number of years to respond to changes in stock status. A further desirable feature for improvements to Tiers 3 and 4 is to make them similar in form to Tiers 1 and 2, with responses clearly related to the status of the stock in relation to target and limit reference points.

Considering this second point first, it is worth noting first that the relationship between biomass and exploitation rate in Tier 1 and shown in Figure 5.1 can also be represented as a relationship between biomass and catch level, as shown in Figure 5.2 (for simplicity, this is only shown for the 20:40:40 strategy). The aim will be to approximate this relationship for Tiers 3 and 4 with the x-axis replaced by the indicator used for that Tier (F for Tier 3 and CPUE for Tier 4) and appropriate target and limit reference points to replace B_{20}, B_{40} and B_{48}. This is shown in Figure 5.3 for Tier 3 and Figure 5.4 for Tier 4.

The harvest control rules shown in Figure 5.3 and Figure 5.4 solve the problem of the "ratchet" effect by avoiding having the RBC formula include recent catches or TACs. They also have the advantage of being similar in form to Tiers 1 and 2 which will help ensure consistency and precaution between Tier levels (see section 2 above). The disadvantage of this approach is the necessity to scale the y-axis (the RBC itself). The way to do this proposed here is to scale the harvest control rule at the MSY break point. This involves estimating the catch at MSY (C_{MSY}) such that the break point in the curve occurs at x = the MSY level for the relevant indicator (F_{40} for Tier 3 and $CPUE_{40}$ for Tier 4), and y = C_{MSY}. Some notes on methods to estimate C_{MSY} are provided at Appendix B for Tier 3 and Appendix C for Tier 4.

Recommendation 7: The Tier 3 harvest control rule be changed to the form shown in Figure 5.3, with C_{MSY} calculated as in Appendix B.

OR

Recommendation 7A: Adopt the equilibrium approach to Tier 3 suggested in Appendix B (Andre Punt proposal).

Recommendation 8: The Tier 4 harvest control rule be changed to the form shown in Figure 5.4, with C_{MSY} calculated as in Appendix C.

Note that recommendations 7 and 8 rely on obtaining an estimate of the MSY catch level (C_{MSY}) which may be in error. To some extent the feedback control rules proposed for Tiers 3 and 4 will correct for such errors, and estimates of C_{MSY} can be updated over time.

5.3.4 Assumptions about future discards

Recommendation 9: Assumptions about future discard rates continue to be based on recent observer data, at least until it can be shown that discard rates for quota species have declined substantially.

5.3.5 Base case CPUE

Several meetings have been held during 2007 to discuss improvements to the way catch rates are used in SESSF assessments. The most recent of these meetings (25 June 2007) concluded that:

- In principle, inclusion of zero catches in CPUE standardization is to be preferred
- The best method to include zeros is not yet established for SESSF species
- For 2007, CPUE standardizations will be conducted as before while further investigation of improvements is undertaken
- All SESSF Tier 1, 2 and 4 assessments should use standardized CPUE and species summaries should also report and show agreed standardized CPUE to indicate trends

5.3.6 Other issues

A number of other issues were identified and discussed during the SESSF RAG Tier 3-4 Workshop held in Hobart in February 2007. The draft report of that workshop is shown as Appendix D. Recommendations arising from this workshop are listed below.

5.4 Feedback and adoption

Suggested process for further development of this paper:

- Initial comment by RAG chairs, stock assessment scientists and AFMA managers
- Discussion with RAGs
- Further work to clarify recommendations and road-test procedures
- For information to MACs
- Formal recommendation to SESSF RAG
- Presentation to AFMA Board for endorsement

In the longer term, the alterations and improvements to the SESSF HSF will occur through formal evaluation in the management strategy evaluation project, and through experience in implementation via the RAGs and MACs.

5.5 References

AFMA (2006) "Principles" for TAC setting 2006

AFMA (2007) Protocols for recommending total allowable catches for SESSF quota species

Smith, A.D.M. and Smith, D.C. (2005) A harvest strategy framework for the SESSF. Report to AFMA, Canberra, June 2005.

Smith, A.D.M., Smith, D.C., Tuck, G.N., Klaer, N., Punt, A.E., Knuckey, I., Prince, J., Morison, A., Kloser, R., Haddon, M., Wayte, S., Day, J., Fay, G., Pribac, F., Fuller, M., Taylor, B., Little, L.R. 2008. Experience in implementing harvest strategies in Australia's south-eastern fisheries. *Fisheries Research* 94: 373-379

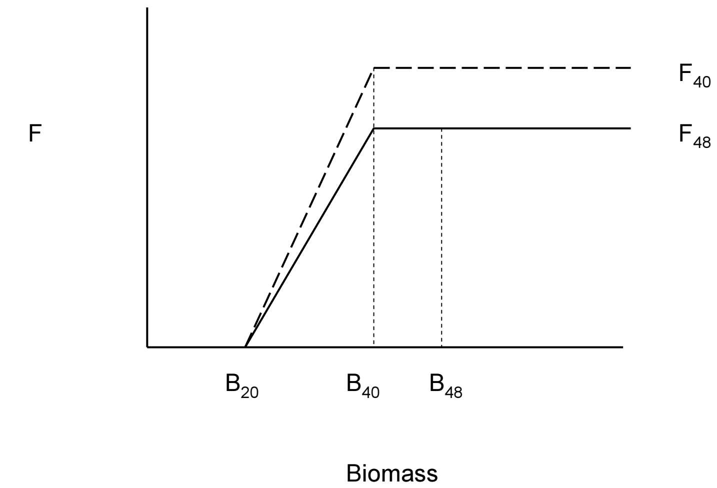


Figure 5.1. The figure shows two versions of the Tier 1 harvest control rule, with targets at B_{40} (dashed line – 20:40:40 strategy) and B_{48} (solid line – 20:40:48 strategy). B_{20} is the limit reference point.

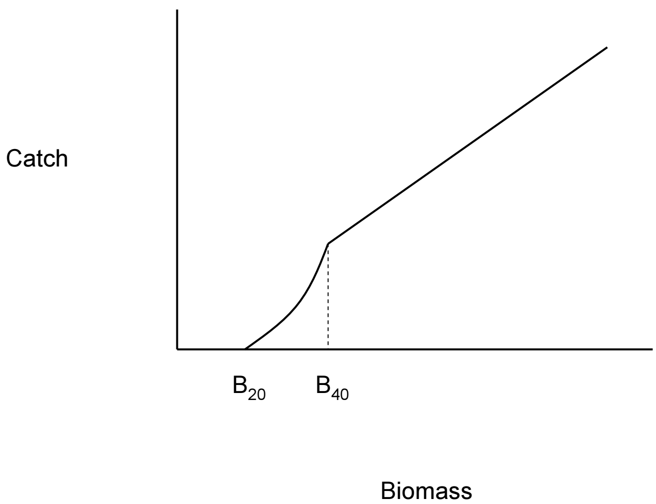


Figure 5.2 This figure shows the form of the Tier 1 harvest control rule expressed as catch versus biomass, rather than F versus biomass.

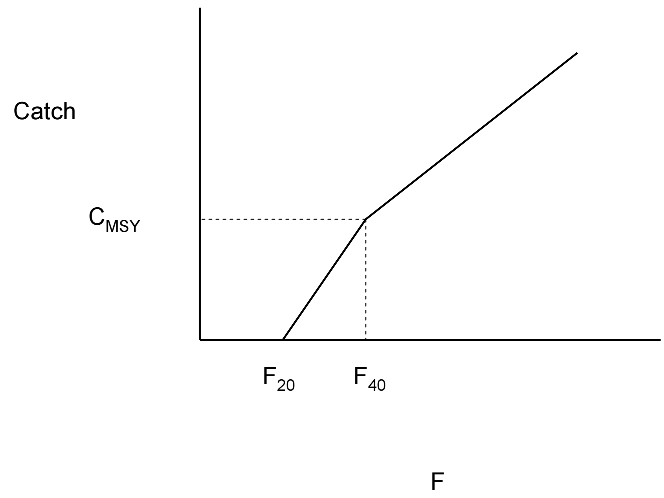


Figure 5.3. This figure shows the proposed form of the catch versus F harvest control rule for Tier 3 stocks. The break point occurs at F_{40}, where the catch level is that corresponding to MSY. An alternative version corresponding to the Tier 1 20:40:48 strategy would have the break point at the same F value, but the catch level at C_{MEY}.

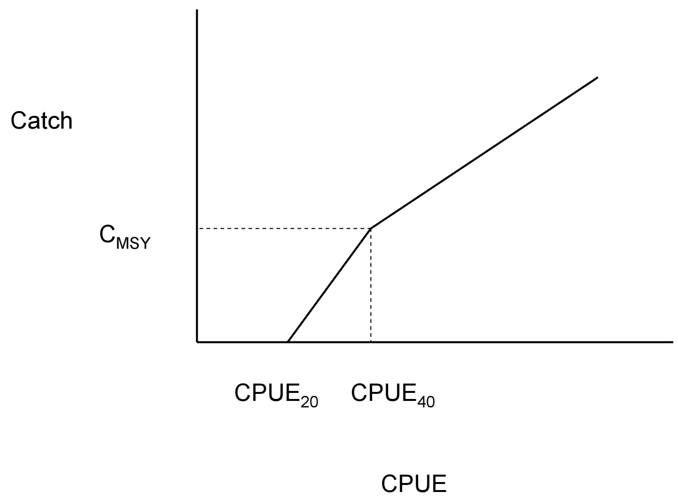


Figure 5.4. This figure shows the proposed form of the catch versus CPUE harvest control rule for Tier 4 stocks. The break point occurs at CPUE_{40}, where the catch level is MSY. An alternative version corresponding to the Tier 1 20:40:48 strategy would have the break point at the same CPUE value, but the catch level at C_{MEY}.

5.6 Appendix A: Guidance to RAGs on selection of reference points for CPUE

The requirement is to select CPUE reference points corresponding to B_{20}, B_{40} and B_{48} (limit, break point, and target reference points). The most straightforward way to do this is to assume that CPUE is proportional to stock abundance, an assumption that is already made in most SESSF stock assessments. If this were true and CPUE not too "noisy", and the CPUE time series was available for the entire exploitation history of the fishery, then assuming that the stock was close to unexploited equilibrium at the start of fishing, the initial CPUE level at the start of the time series would correspond to B_{100} (unexploited equilibrium often referred to as B_0), and the other reference points would simply be the appropriate fractions of this level (20% for B_{20} etc).

Where the full CPUE time series back to the start of fishing is not available, several other options can be considered. These will require the application of expert judgement by the RAG, and documentation of the assumptions made.

1. Assume a level of depletion at the start of the existing time series and scale to that (e.g. assume that the stock was at B_{70} or some other level). This may be feasible if there is an entire catch series but not early CPUE data.
2. Choose a period in the exploitation history where it is possible to estimate depletion level using some other source of information (e.g. F from catch curves, use of fishery independent survey data such as Kapala, etc).
3. Other suggestions???

Rather than selecting a single year corresponding to a standard depletion level, it may be more appropriate to use the average CPUE value over a range of years. This applies to any of the methods suggested.

5.7 Appendix B: Suggested approach to estimating MSY catch levels for Tier 3 stocks

Andre Punt has suggested an alternative approach for Tier 3 species along the following lines:

0. Set up a simple biological model.
1. FIT this model to the CAA data (landed+discarded over all fleets) changing F and selectivity (needed for multiple fleets). You can just base this on the catch curve if you wish but then you have all the problems of the current estimator (e.g. what to do with multiple estimates of F).
2. Compute biomass
3. Compute B0
4. I would probably apply this estimator to the last 4 years of data and inverse variance weight the outcomes. Note that this isn't too different from Mark Bravington's approach. Alternatively (and perhaps better for many species) average the CAA across years and THEN apply the estimator). Basically, given F, selectivity, Yield-per-recruit and catch biomass, you can estimate biomass.
5. Compute F20, F40, F48, etc. (easy as they are functions of steepness, selectivity, etc.) If you wanted to apply figure 3 then this is easy. I could (with a little time) build the calculation of F20, F40, etc, into the spreadsheet (or an ADMB program).
6. Compute RBC as usual.

The trick is getting "F" in a formal way (i.e. the extent to which we can believe the ABSOLUTE value of F rather than its value relative to M). This would make Tier 3 only differ from Tiers 1 and 2 in that F is estimated using an equilibrium approach. I guess one could argue that this approach can be simulation tested (and hence an appropriate value for G could be determined).

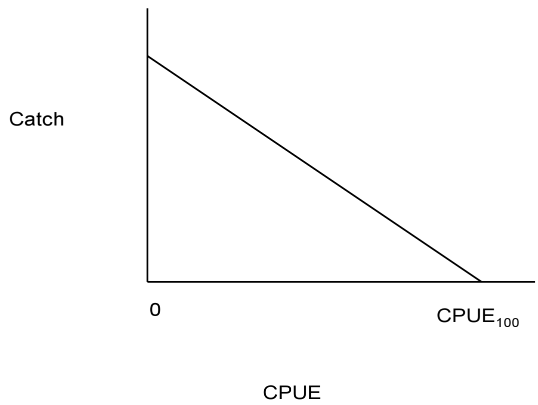
5.8 Appendix C: Suggested approach to estimating MSY catch levels for Tier 4 stocks

Where catch and CPUE data are available for a stock, the aim is to estimate an equilibrium catch level corresponding to $CPUE_{40}$ (the CPUE reference point corresponding to B_{40}, which in turn is the proxy for B_{MSY} for Tier 1 stocks).

The figure below shows the expected relationship at equilibrium between catch and CPUE. If an equilibrium catch level can be found for some level of depletion of the stock (some level of $CPUE/CPUE_{100}$), then the catch corresponding to $CPUE_{40}$ (C_{MSY}) can be estimated.

There are several options for estimating equilibrium catch at a particular depletion level. In each case, the depletion level will be determined by the CPUE relative to $CPUE_{100}$ (see Appendix A for advice on this).

1. Identify a period of relative stability in CPUE and take the average catch level during that period (so long as it has not been too variable).
2. Identify a period when the catch was relatively stable and fishing was reasonably profitable and equate the average CPUE for this period as $CPUE_{48}$ (i.e. the MEY reference point).
3. At worst, if CPUE has been declining steadily over the entire period, the average catch level over the period is likely to be in excess of C_{MSY}. Take some appropriate fraction of the average catch as the estimate of C_{MSY} (the fraction determined by the rate of decline).



5.9 Appendix D: Record of Meeting of February 2007 Tier 3/4 Workshop

5.9.1 General Issues

- *Standardization of Discards and State Catches in Assessments and Reports*
- *Definition of base case within and between Tiers*
  - *Between referred to working group*
  - *Within to be worked out in RAG*
    - *RAG only produces one RBC*
- *Change precaution level of Tier 2*
  - *Fit to structural uncertainty in model*
- *Process for AFMA sign on*
  - *Tier 4 proposal (verbal agenda item at Joint MAC)*
  - *Feedback from SESSFRAG Working Group*
  - *Detailed proposal to go to AFMA Board for endorsement*
- *Multi-year TACs and interim indicators*
  - *Tier 1 every year?*
    - *Gren vs Gummy Needs to be decided in RAG*
    - *RAG provide advice on time period without assessment before moving to Tier 2 precaution*
    - *RAG advice on indicators and performance expected during non-assessment years*
    - *Also outline monitoring program to ensure all proceeding OK*

5.9.2 Tier 3 Issues

- *Long time frame for indicator to change*
  - *Will desired effect on indicator occur?*
  - *Approach re management response in the interim*
- *Sensitivity to M*
- *Choosing analysis (F cur)*
- *Setting thresholds on sample size*
- *Smoothed vs stepped function*
- *Implicit reference points related to overfished/.overfishing categories*
- *Improved catch curve analysis*
  - *Separate by fleet? How to decide*
  - *Is four years appropriate?*
  - *Reconsider F=M rule and Z20 Z40 reference points*
  - *How do they cope with large change in TAC?*
  - *Fit growth curves carefully then use length frequency data*
  - *Need to build up equivalent age/length data*
  - *Interim*
  - *F=M target*
    - *F=2M limit*
    - *Investigate whether F=M is not appropriate for any current Tier 3 species (use lit search)*
  - *Consider Z20 Z40 reference points as part of MSE*
  - *Implicit reference points related to overfishing*

  - *Tier 3 will not be applied during 2007 to species responded to in 2006*
    - *Method of deciding when to reapply*
    - *Need justification to Board*
  - *Interim management response if:*
    - *CPUE indicator of any major unexpected shift*
    - *Other indicators (size, range)*
- *MYCCI*
  - *Fit growth curves carefully then use lfreq data*
    - *Include density dependence*
    - *Can deal with seasonal growth*
  - *Need to build up equivalent age/length data*
  - *Only use Z in last year (rather than last 4)*
  - *Need for plus group?*
  - *Ensure good input data*
    - *close to Poisson*
    - *Variability of sampling*
    - *Plausible variability estimate for recruitment and Z*
  - *Compare method with standard*
- *Sensitivity to M*
  - *Use Hoenig at exploited level*
  - *Report where Amax is derived from*
- *Choosing which fleet analysis to use for RBC*
  - *Select best selectivity first (flat in main age classes)*
  - *Choose based on number of samples*
  - *Average based on last 4 years*
- *Setting thresholds on sample size*
  - *Provisional*
    - *200 age samples*
    - *500 length*
    - *Perform if one sample available in last 4 years*
  - *Long term*
    - *Effective sample size estimates*
    - *Appropriate sample sizes*
    - *Sample size as function of number of age classes*
    - *Compare MB method with other methods*
    - *Feed back into more rigorous sampling/analysis procedures*
- *Smoothed vs stepped function*
  - *Continue to use smooth*
  - *Signoff by AFMA?*

5.9.3 Tier 4 Issues

- *Influence on restricted catch / catch rate on indicator*
  - *Market restrictions eg RRP*
- *One-way trip on RBC/TAC feedback loop*
- *Stability of the indicator*
- *Will desired effect on indicator occur?*
  - *Assessment 2 yr lag*
- *Lack of targets and limits*
- *Can't go to 0 RBC*

- *Influence on restricted catch / catch rate on indicator*
  - *Market restrictions eg RRP*
- *Choice of alpha value*
  - *Rules to decide*
  - *Larger response on declining CPUE?*
- *One-way trip on RBC/TAC feedback loop*
  - *Use of TAC (if reasonably well set)*
- *Catch rates from diff. fleets (non-trawl)*
  - *Catch-weighted combination of CPUE trends?*
- *CE Standardised?*
- *Relative to a specific year*
  - *Stability of the indicator*
- *Will desired effect on indicator occur?*
  - *Assessment 2 yr lag*
- *Lack of targets and limits*
  - *Presently target is current CPUE (status quo)*
  - *CPUE-based primary indicator*
    - *Catch composition (is it relative to TACs)*
    - *Size structure?*
  - *Target catch rate*
    - *>0.5 initial CPUE?*
    - *Median 86-94 catch rate*
  - *Averaged indicator*
  - *Include productivity indicator*
- *Issues paper to AFMA*
  - *Justifying the need to change to a more defensible target than current CPUE*
    - *This will relate better to policy*
    - *Will also relate better to other tiers*
  - *SESSFRAG working group to provide details*
    - *Standardisation*
  - *Run simple MSE on Tier 4 rules*
  - *Implementation for 2008 RBC / TACs?*
- *Run standardised CPUE series back to 1986*
- *Agree to use geometric mean on unfiltered data*
- *Use standardised CPUE where available*
  - *Need agreed standardisation process*
  - *Compare ISMP to comm catch*

5.9.4 Tier 1/2 Issues

- *High penalty from moving from Tier 1 to Tier 2*
- *Does an assessment have to be done every year to maintain Tier 1?*

6. Simulation testing of the Tier 1 harvest control rule

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6.1 Introduction

The SESSF Tier 1 harvest control rule (HCR; Figure 6.1) applies to species where there is a robust quantitative assessment that provides estimates of current biomass levels. The rule requires estimates of current relative and absolute biomass. In practice, the software Stock Synthesis 2 (SS2) is used to perform an integrated assessment to estimate these values. The SESSF management strategy evaluation (MSE) program was initially set up to test the Tier 1 HCR by simulating the actual assessment procedure used in SESSF stock assessments. This involves running SS2 to perform the stock assessment for each projected year. This was successfully implemented using the flathead example. However it soon became clear that using this method would take a prohibitively long time. For example, the flathead SS2 assessment usually takes at least five minutes of computer time. Thus 100 simulations of a 20 year projection would take at least a week to run. For a longer-lived species such as orange roughy, the time taken would be much longer.

6.2 Method

Instead of using SS2 to estimate relative stock biomass, the current stock depletion is ‘estimated’ by adding lognormal error to the true stock depletion. This ‘estimated’ stock depletion is used in the harvest control rule, using the true F_{20}, F_{40} and F_{48} to calculate the target fishing mortality, F_{TARG}. This is then applied to the true selected biomass to calculate the Recommended Biological Catch (RBC). The RBC calculated in this manner relates to retained catches only, so discards are not removed from this RBC to arrive at the TAC.

The Tier 1 HCR is applied to three species types – flathead-like, whiting-like and orange roughy-like, at three levels of current relative stock biomass – low, target and high – for each. The biological characteristics of these species are shown in Table 6.1. Whiting is a short-lived highly productive species with high recruitment variability, orange roughy is very long-lived with a very low natural mortality rate, and flathead is in between these two extremes.

While the operating models are based on the existing Tier 1 assessments it should be emphasised that these models do not represent the ‘real’ species. They are intended to be species that have the same biological characteristics and catch history as SESSF species, but in some cases the input data has been manipulated to obtain the required current stock scenario for testing. The true current depletion for tiger flathead is near the target, so a low relative biomass starting point was created by using a lower initial stock size in the operating model. Likewise, the school whiting and orange roughy initial stock sizes were manipulated to get the desired initial relative stock sizes for testing.

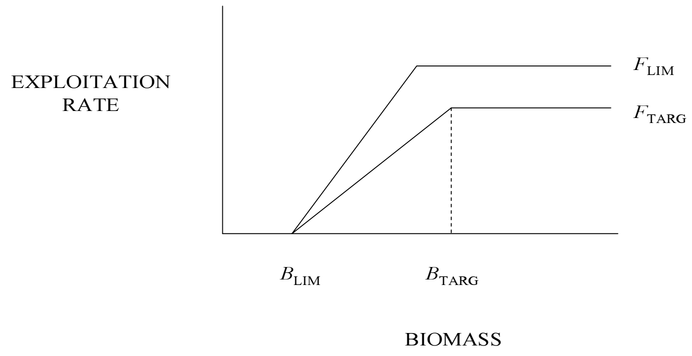

Figure 6.1 The Tier 1 HCR

Table 6.1 Biological characteristics of the three species types used in Tier 1 testing

Parameter	**flathead**		**whiting**	**orange roughy**	
maximum age	20		6	80	
growth parameters	female	male			
$L\infty$	56.03	45.7	26.0	39.06	
k	0.156	0.18	0.25	0.06	
t_0	-2.783	-3.41	-1.15	-3.18	
natural mortality, M	0.22		0.6	0.042	
steepness, h	0.72		0.75	0.75	
recruitment variability, σ_R	0.2		0.37	0.58	
length-weight parameters				female	male
a	0.0000058		0.000013	0.0000351	0.0000383
b	3.31		2.93	2.97	2.942

6.3 Results

For an explanation of the graphs see Table 6.2. For the whiting-like species, the stock reaches the target level quickly for all levels of initial stock depletion (Figure 6.2 to Figure 6.4). The flathead stocks also stabilise close to the target level, although the time taken to reach the target is longer (Figure 6.5 to Figure 6.7).

For orange roughy starting from a low current stock depletion, recovery to the target level takes almost 70 years (Figure 6.8). The dip in relative biomass after about 2030 can be attributed to the reduction in spawning biomass due to fishing. The largest catches were taken around 1990, and the age at which 50% of fish are mature is about 38. Orange roughy stocks at target and high levels of current relative stock biomass stabilise rapidly at the target biomass (Figure 6.9 and Figure 6.10).

The ability of the Tier 1 HCR to deal with the possibility of the catch not being equal to the TAC has also been examined, using the depleted stock scenarios for both flathead-like and whiting-like species. These scenarios were not run for orange roughy, as it is rare for TACs not to be taken due to the high-value and highly-targeted nature of the fishery.

If the catch is half the TAC for the first 10 years of the projection the stock increases to above the target level, but then decreases to close to the target as catches then equal the TAC for the next 10 years (Figure 6.11 and Figure 6.12). If the catch is half the TAC every four years, and equal to the TAC in the other years, this has little effect on the ability of the procedure to achieve the biomass target, for both the flathead-like and whiting-like species (Figure 6.13 and Figure 6.14).

Table 6.2 Explanation of graphs

relative biomass The black line shows an artificial historic relative spawning biomass (SB_{year}/SB_0) series. The series has been chosen to result in a current stock level as specified in the figure caption. The red line shows the relative biomass in future years, after removal of the catches as calculated by the Tier 1 HCR. The solid red line is the median of the relative biomass calculated from 100 simulations of the assessment procedure. The dotted red lines are the 2.5 and 97.5 percentiles of the simulated relative biomass values. The grey line shows the target relative biomass level (0.48).	**catch** The black line shows the actual historic catch of the species up to the year of the most recent stock assessment. The red line shows the catch in future years, as calculated by the Tier 1 HCR. The solid red line is the median of catch from 100 simulations of the assessment procedure. The dotted red lines are the 2.5 and 97.5 percentiles of the simulated catch values.
future relative biomass This graph is the same as the one above, but without the historic relative biomass series.	**RBC** This graph shows the Recommended Biological Catch (RBC) calculated by the Tier 1 HCR. The solid line is the median of the RBC from 100 simulations, and the dotted lines are the 2.5 and 97.5 percentiles.
TAC This graph shows the Total Allowable Catch (TAC) calculated by the Tier 1 HCR. The solid line is the median of the TAC from 100 simulations, and the dotted lines are the 2.5 and 97.5 percentiles. The TAC can differ from the RBC by the subtraction of expected discards, and by the constraint that the TAC cannot change by more than 50% from year to year.	**future catch** This graph is the same as the one on the top right, but without the historic catch series. The catch can differ from the TAC if the TAC is greater than the remaining vulnerable biomass, or if it has been set to be different, as specified in the figure caption.

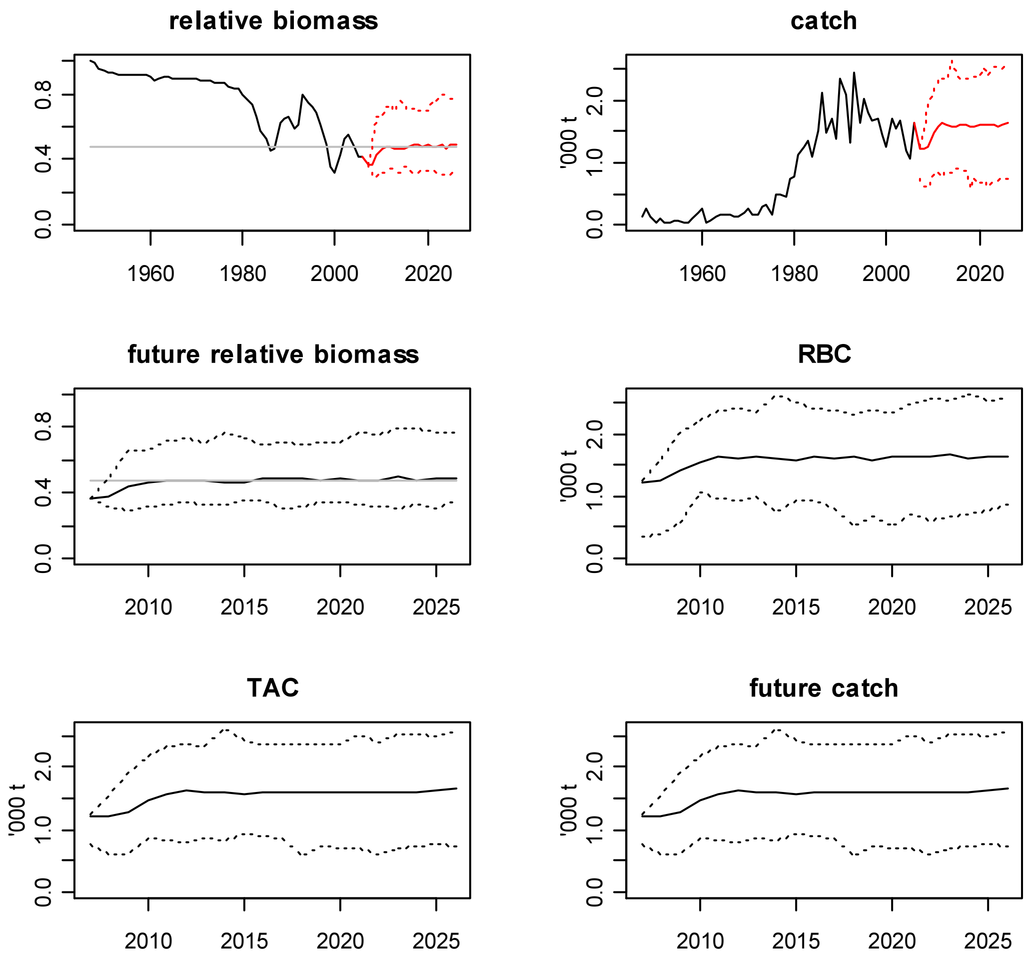

Figure 6.2 Whiting, low current relative stock

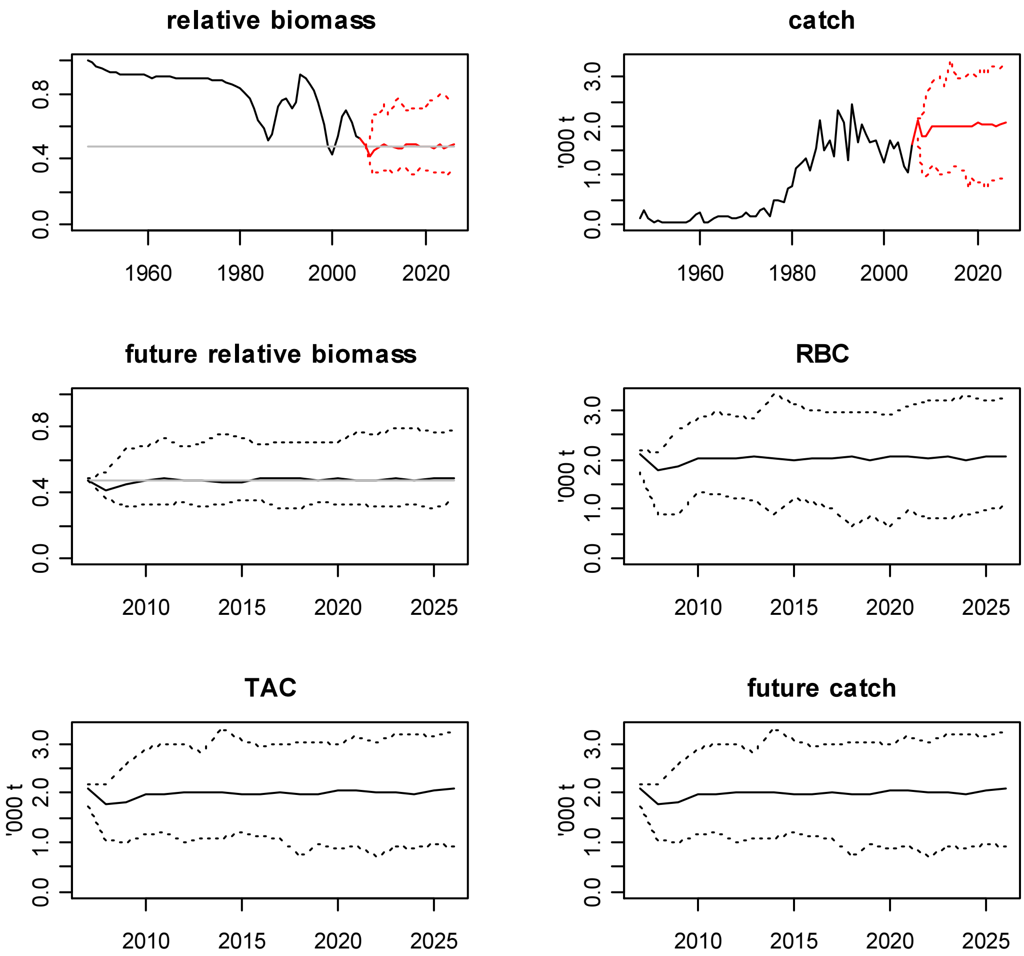

Figure 6.3 Whiting, target current relative stock

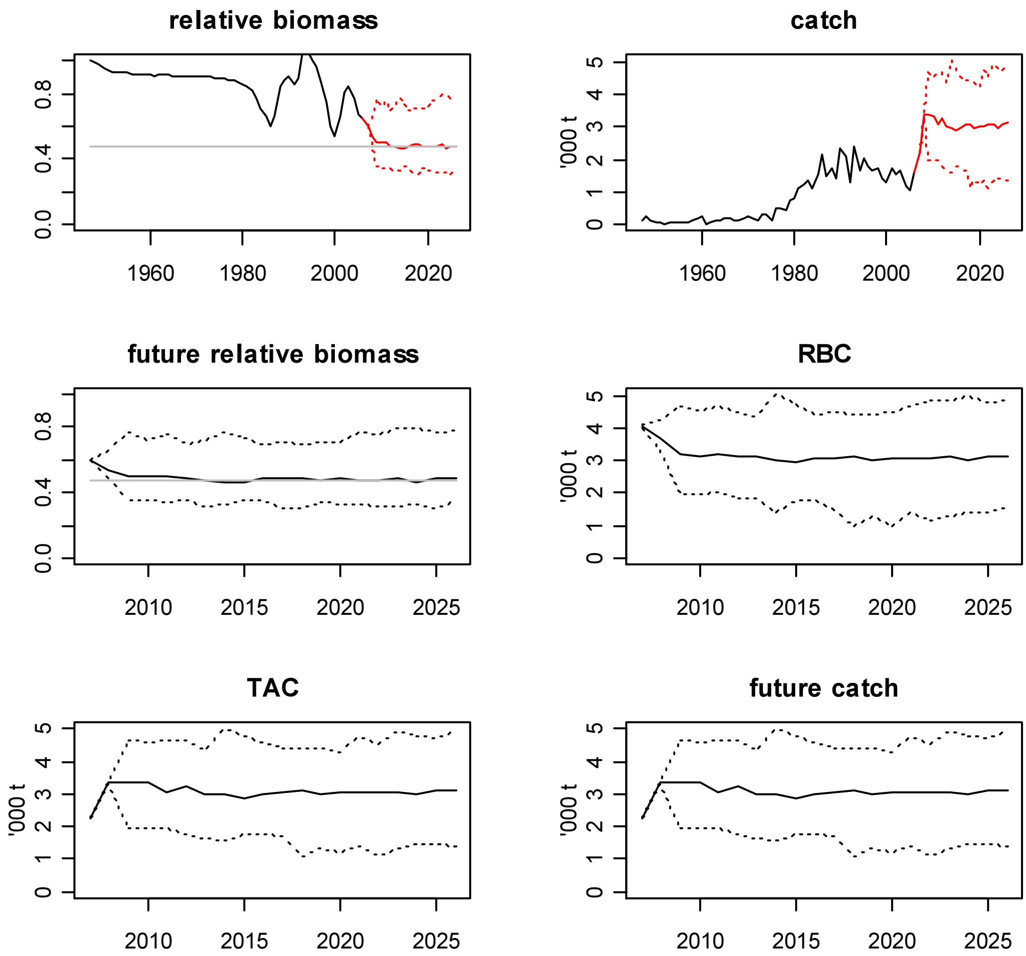

Figure 6.4 Whiting, high current relative stock

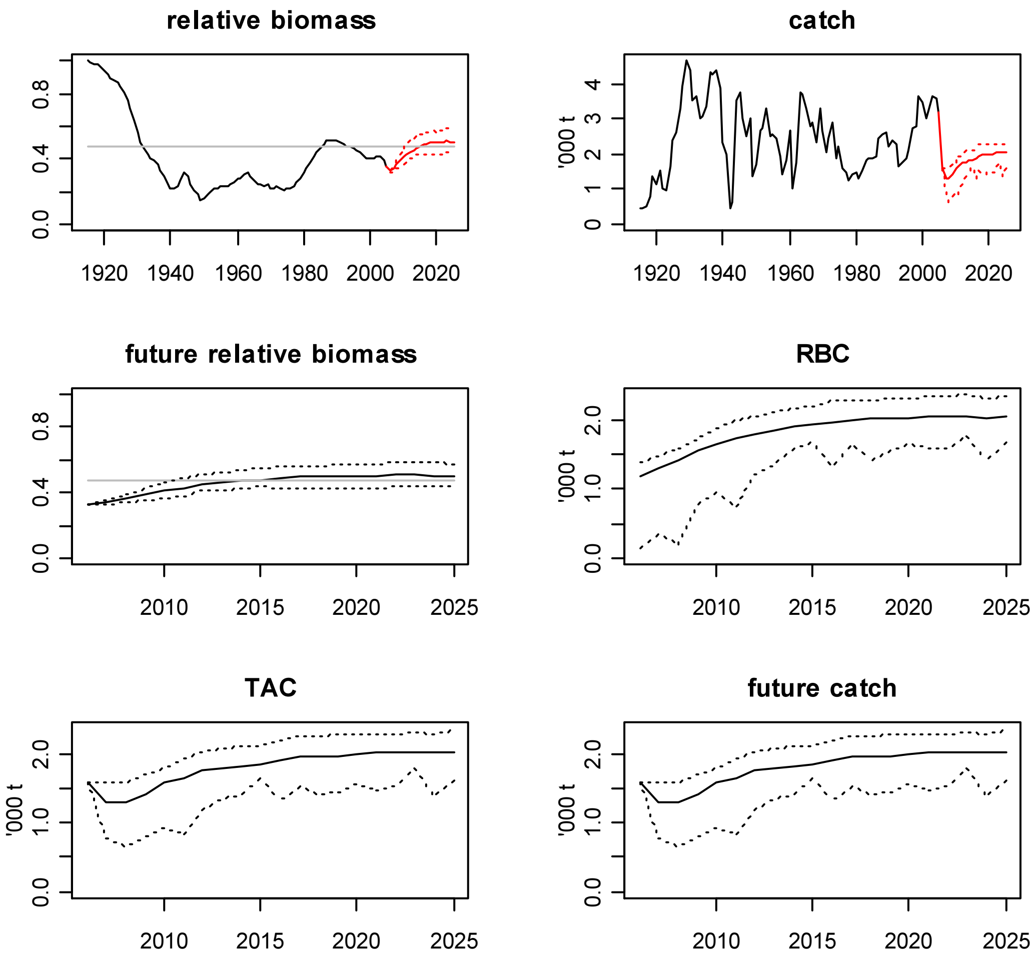

Figure 6.5 Flathead, low current relative stock

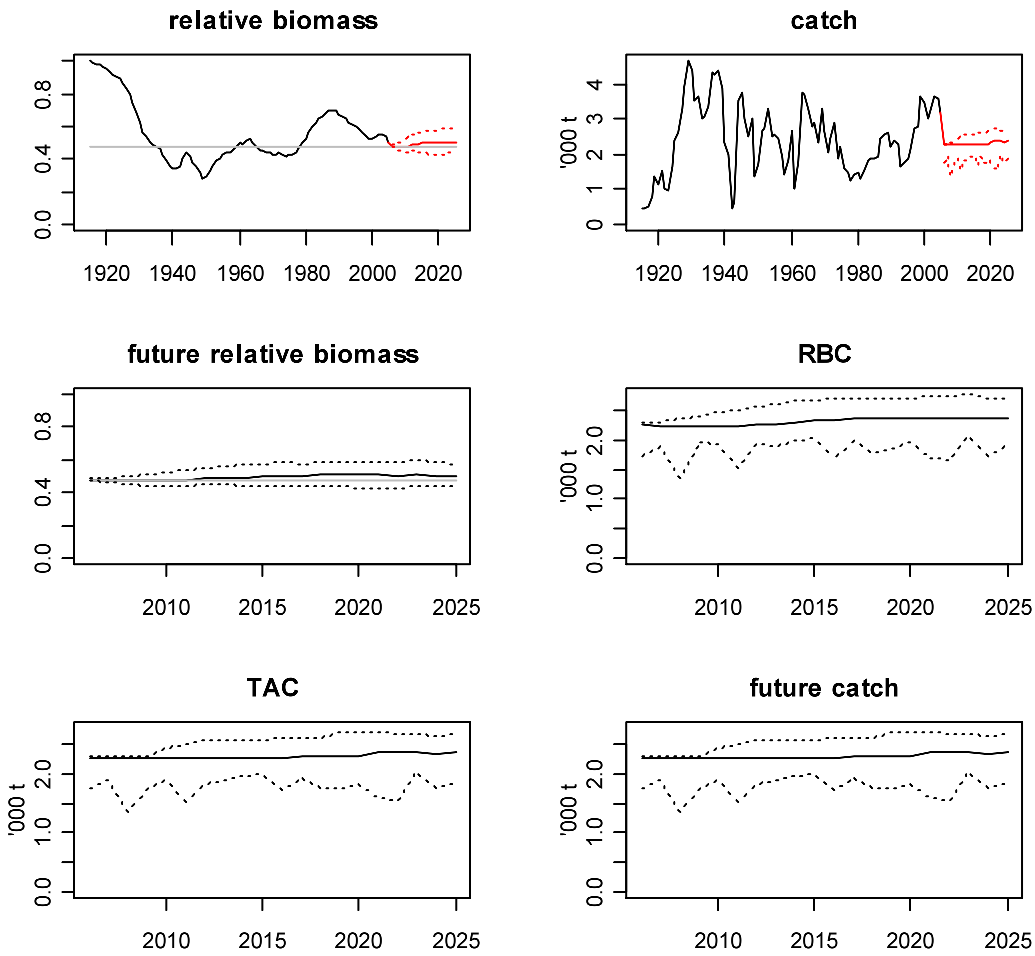

Figure 6.6 Flathead, target current relative stock

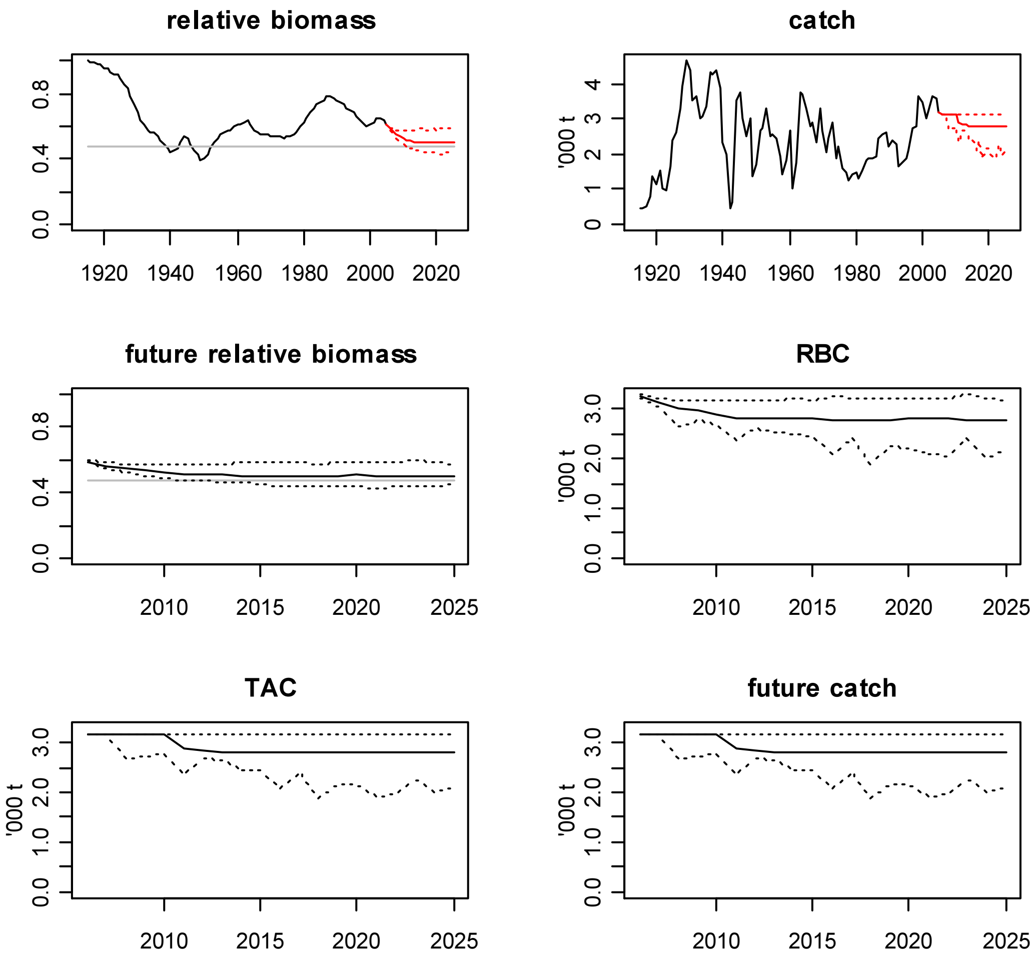

Figure 6.7 Flathead high, current relative stock

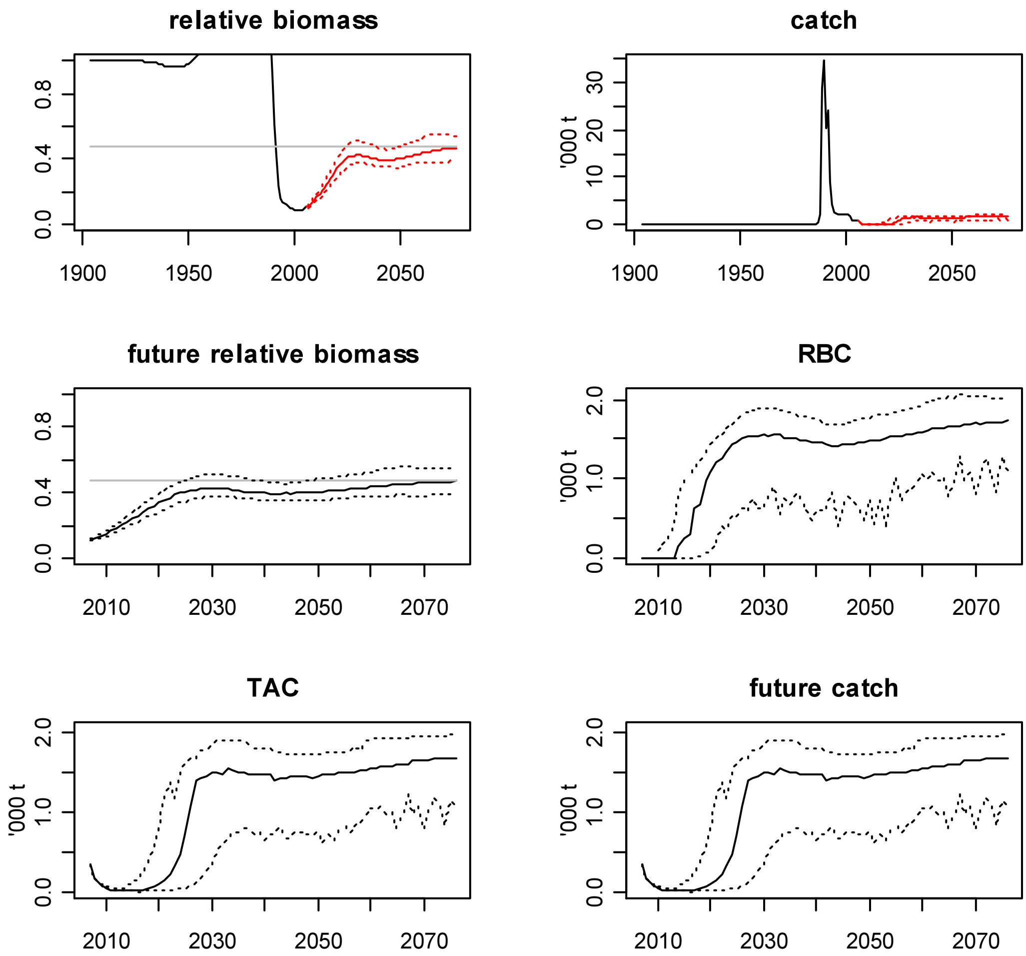

Figure 6.8 Roughy, low current relative stock

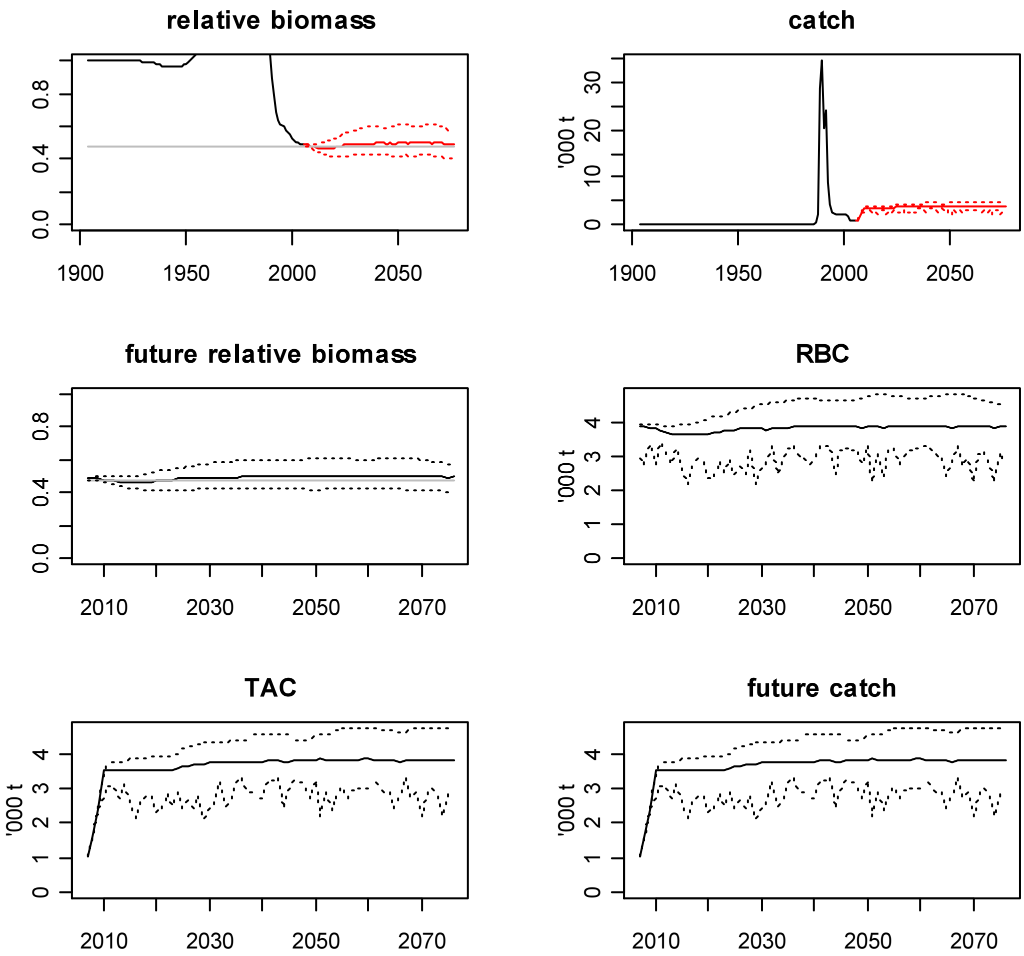

Figure 6.9 Roughy, target current relative stock

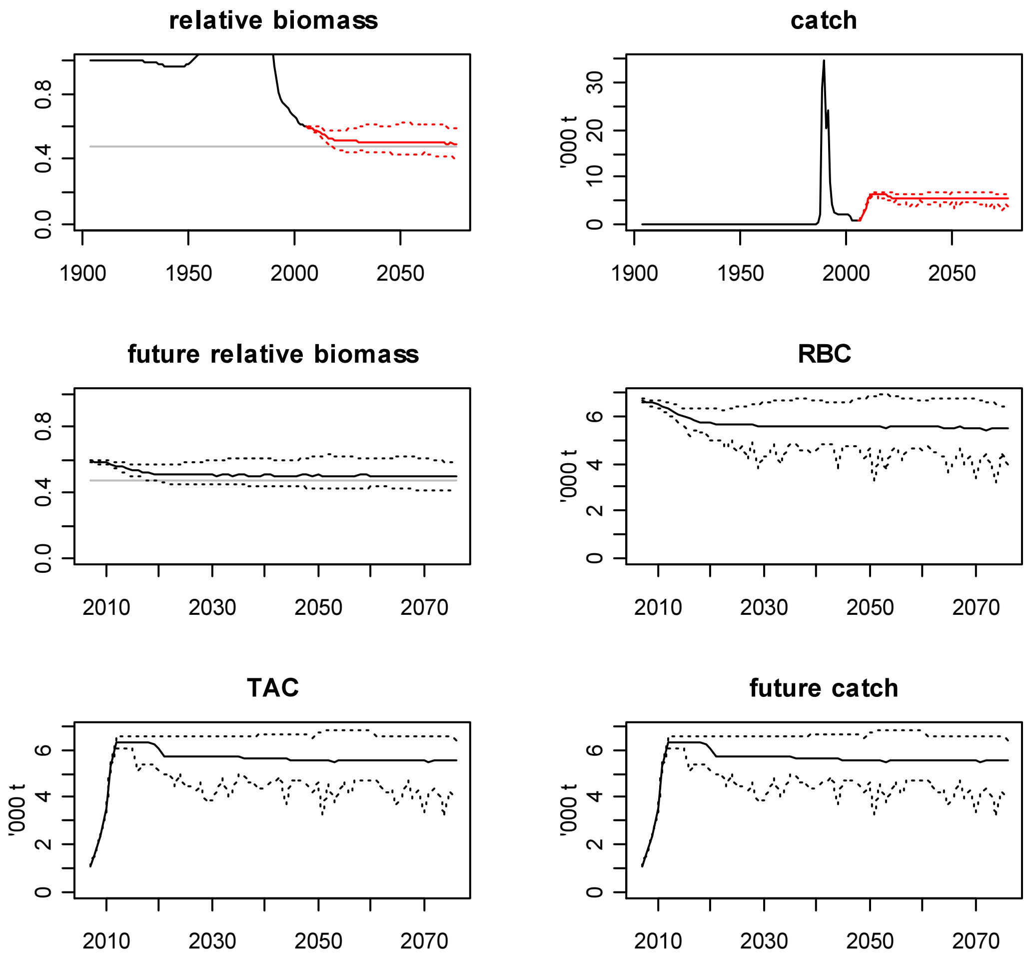

Figure 6.10 Roughy, high current relative stock

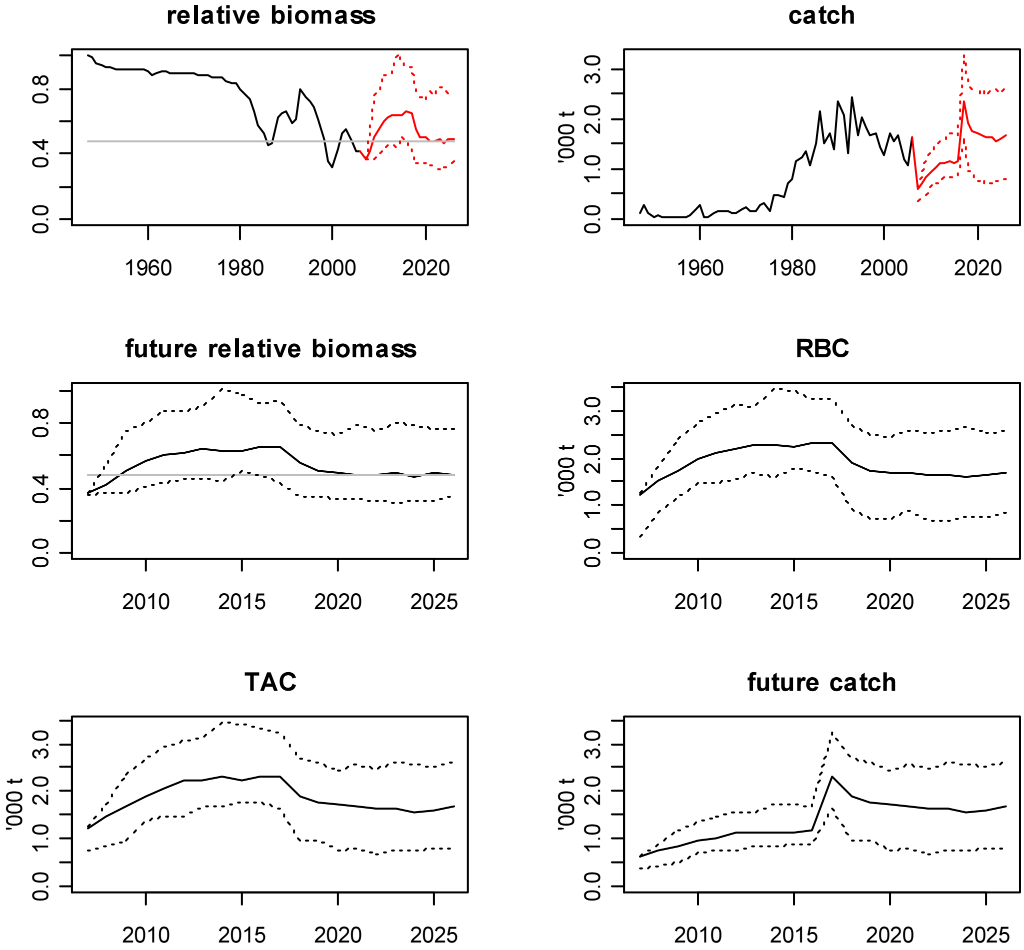

Figure 6.11 Whiting; low current relative stock; catch=0.5TAC for 10 years

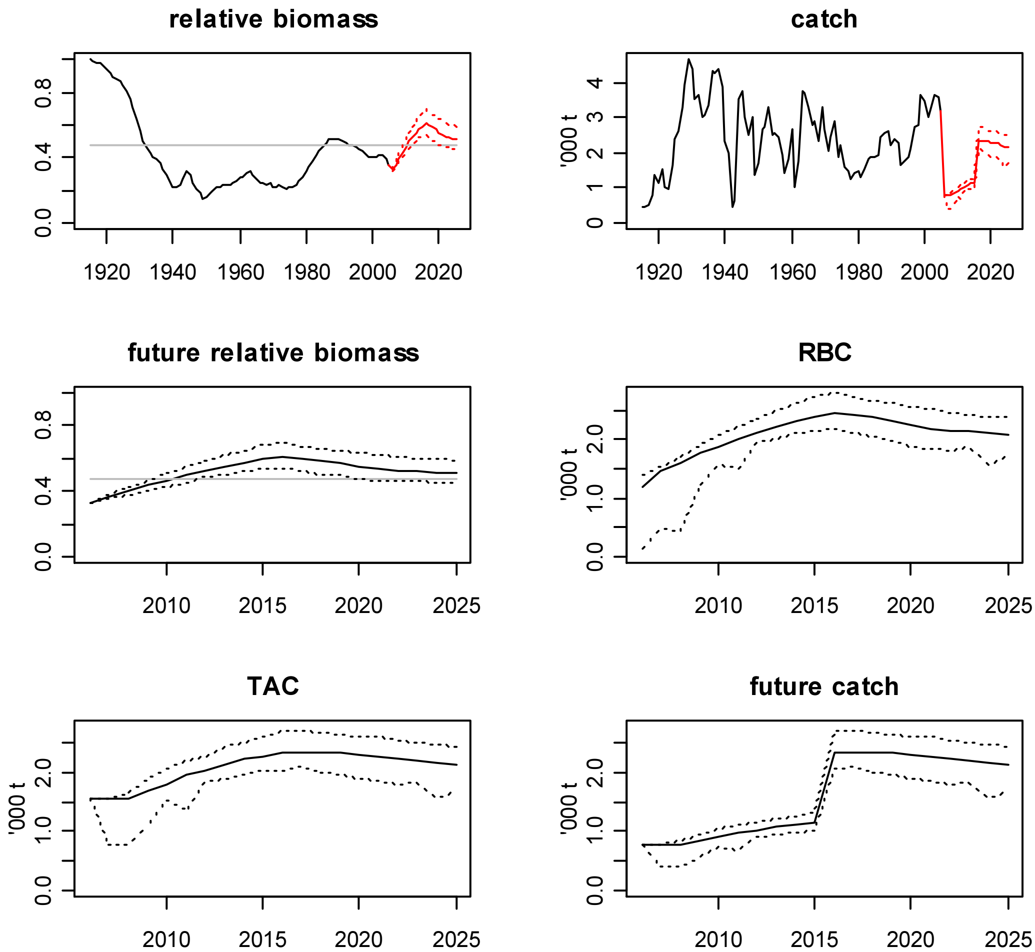

Figure 6.12 Flathead; low current relative stock; catch=0.5TAC for 10 years

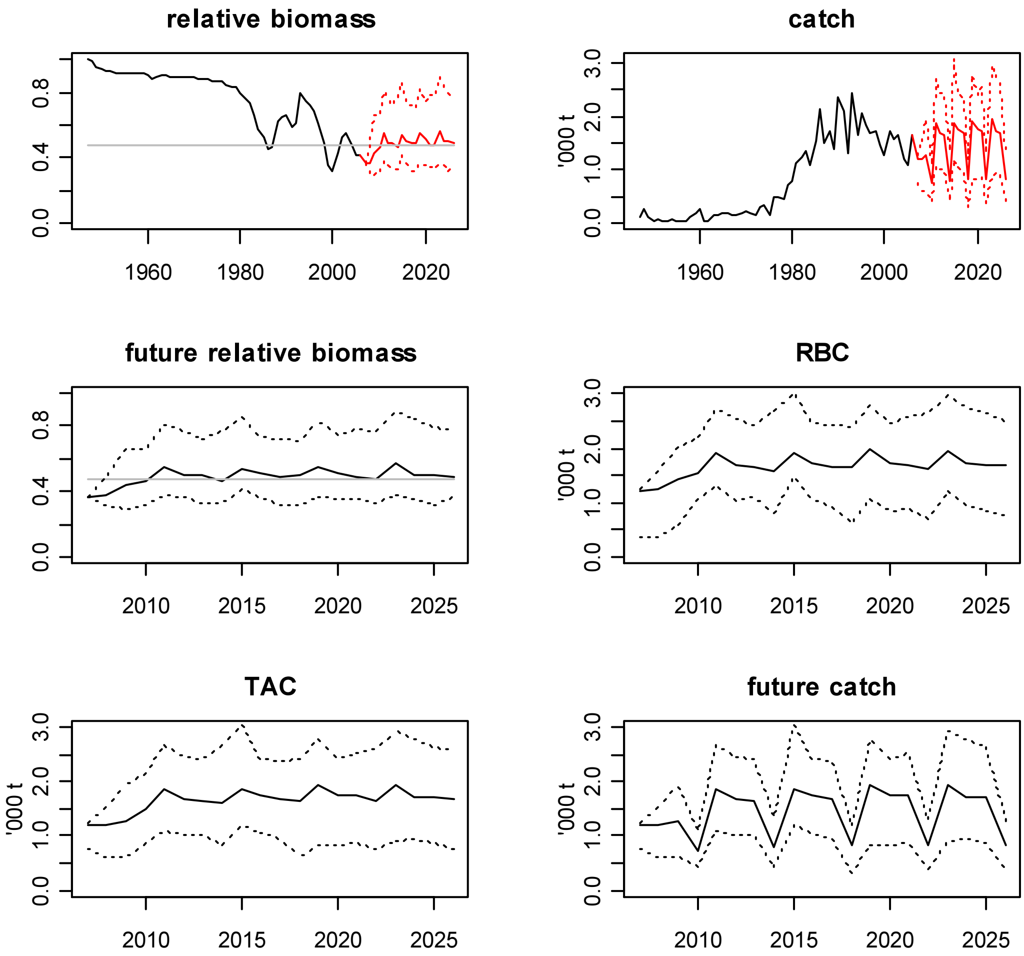

Figure 6.13 Whiting; low current relative stock; catch=0.5TAC every 4th year

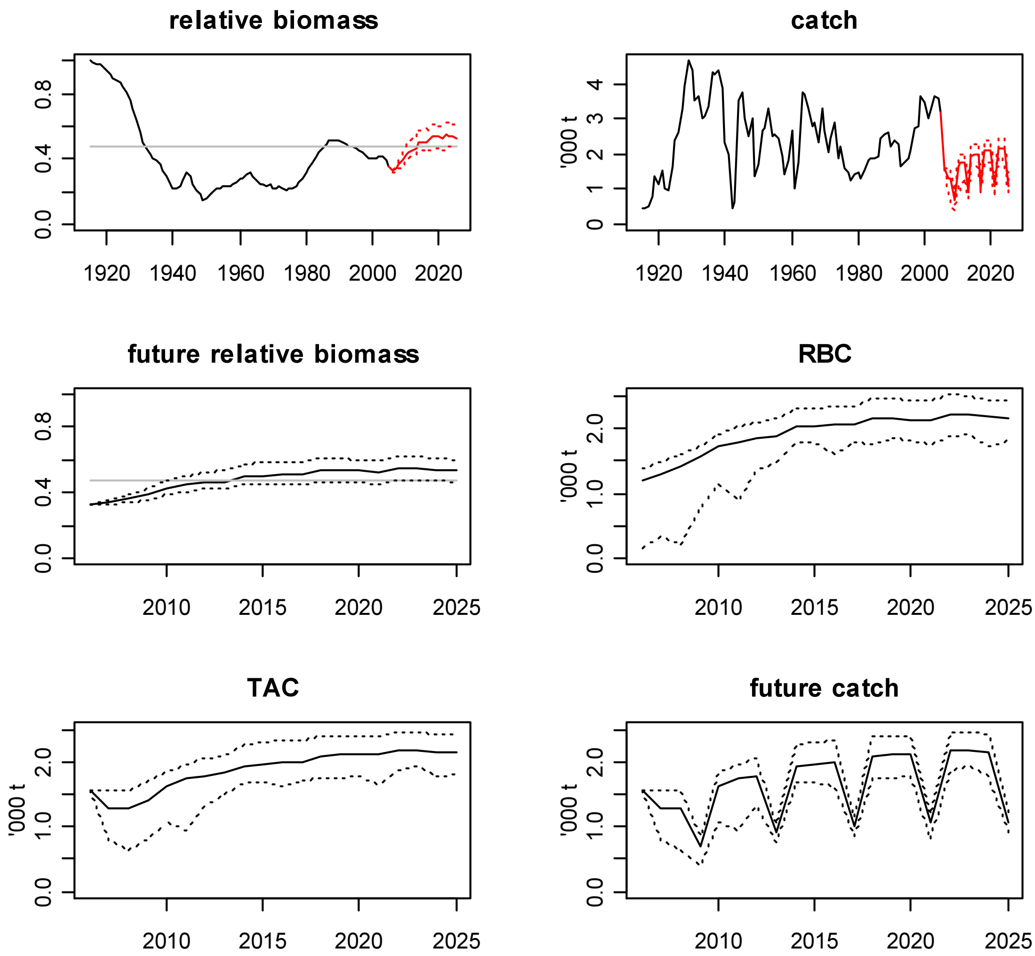

Figure 6.14 Flathead; low current relative stock; catch=0.5TAC every 4th year

7. Simulation testing of alternative Tier 3 assessment methods and control rules for the SESSF

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7.1 Introduction

This paper reports the results of simulation testing the proposed improvements to the procedure for determining a recommended biological catch (RBC) for Tier 3 species. Tier 3 species are those that do not have a formal stock assessment, but do have information available on the age frequencies of annual catches, annual total catch weight, and knowledge of basic biological parameters such as the natural mortality rate (M), age-length relationships, length-weight relationships, stock-recruitment relationship steepness, age at maturity and age at recruitment to the fishery.

The Tier 3 method of calculating an RBC is composed of two parts:

a) use an assessment method and population age structure to calculate the fishing mortality effect on the population (F_{CUR}) of recent catches (C_{CUR})

b) use a catch control rule that uses the estimated F_{CUR} and C_{CUR} values to determine an RBC for the following year.

Currently, the estimation of F_{CUR} assessment method is made using catch curves, and the catch control rule uses the ratio of F_{CUR} and M to determine the RBC (e.g. see Klaer, 2007).

There are three main issues causing problems with behaviour of the current Tier 3 control rule:

(1) there is a mismatch in the period used to calculate C_{CUR} and F_{CUR}

(2) an equilibrium assessment method[5] which can not account for transient age structure effects is used to calculate fishery influence

(3) the Tier 3 control rule does not use concepts of target and limit fishing mortality (*F*) levels as does the Tier 1 control rule.

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[5] An equilibrium model represents long-term average population behaviour and does not account for annual variations in aspects of the population including changes in recruitment or changes in catch levels.

Each of these issues is discussed in turn below, and alternative methods proposed. Results from management strategy evaluation (MSE) testing the effectiveness of the proposed methods are shown.

7.2 Alternative methods

(1) Period mismatch

The original Tier 3 control rule has a fishery influence measured as the average F over the number of fully selected age classes of the species into the past, and a reference catch C_{CUR} being the average over the past 4 years. This causes a ratcheting effect as the rule is applied each year, tending to continue to adjust catches in the same direction through time, leading to overcompensation. Ratcheting in this case could be partly avoided by either calculating the reference catch using a period appropriate to catch curves, or by using a method that calculates an average F for the past 4 years (or by using a different but matching reference period - e.g. 5 years, 1.5 generation time etc).

We propose that the same time period be used to calculate F_{CUR} and C_{CUR}. If equilibrium methods are used to calculate F_{CUR}, this implies that the fishery influence is measured over a period of at least the number of fully selected ages of the species, and possibly the maximum observed age. It may be possible to define such a time period in terms of generation time (see Caswell (2001) for definitions of generation time).

The reference catch C_{CUR} should be calculated over the years in which the fish cohorts used in the F_{CUR} estimation have been affected by fishing mortality. As F_{CUR} is calculated over the most recent five years of data (Klaer 2008), the years for calculating C_{CUR} are offset by three years from the current year in order to approximate the mid-point of this five year period. Half a year is added to the actual midpoint (2.5) because if catch is assumed to occur in the middle of any given year, the ages in that catch are more influenced by the previous year's catch, than the current year's catch. Thus:

min year = current year – 3 – (maximum age – age at 50% selectivity), and
max year = current year – 3

When the 'true' fishing mortality is used, the reference catch is the most recent catch.

In all cases a discard rate is applied to the average catch, so that C_{CUR} is a total catch figure. The discard rate applied to the average catch is weighted using a multiple of 8 for the most recent year (y), 4 for y–1, 2 for y–2 and 1 for y–3.

A separate problem from ratcheting is the responsiveness of the control rule, which is related to how far into the past we will average fishery influences and reference catch levels. Rules based on averages over long periods will cause a slow response.

(2) Use alternative assessment methods for calculating F_{CUR}

An improved catch curve method for estimating F_{CUR} has been developed. This method uses all selected ages, rather than just the fully-selected ages. F_{CUR} and two selectivity parameters are estimated by fitting an age-structured production model to the observed catches at age over the last five years. This improved catch curve method is the only additional F_{CUR} estimation procedure investigated in this paper, and is an equilibrium method.

There is also a ratchet effect in the current Tier 3 method where, for example, an overexploited species F is lowered by the rule, allowing increased recruitment, which would then lead to a steeper Z slope as calculated by catch curves. This arises because an equilibrium method is being applied to a non-equilibrium population age structure. This problem would be avoided by using a non-equilibrium method for calculating recent F values.

We suggest that non-equilibrium methods for calculating F_{CUR} be investigated, and their effectiveness tested using MSE. Candidate non-equilibrium methods that use patterns in age structure to estimate F_{CUR} are, VPA or cohort analysis (e.g. Pope 1972) and the Bravington (pers. comm) methods.

A non-equilibrium method for calculating recent F values has the following data available: catch age structure, growth curves and length-weight, total catch weight, M, age at full recruitment to fishery. Data not available for Tier 3 include CPUE, selectivity, fleet specific data, sex specific data, surveys etc.

The use of a non-equilibrium method to calculate F_{CUR} will also assist with issue (1) above because the time period that F_{CUR} and therefore C_{CUR} apply to can be as little as one year.

(3) Alternative Tier 3 control rule that has limit and target fishing levels.

From (1) and (2) above, F_{CUR} and C_{CUR} are known. Yield per recruit calculations are used to calculate F values that will reduce the spawning biomass to 20% (F_{20}), 40% (F_{40}) and 48% (F_{48}) of the unexploited level. The relationship given in Figure 7.1 is then used to assign the value of F_{RBC} using F_{CUR}. This relationship has properties similar to the Tier 1 harvest control rule, with F_{20} as the limit and F_{48} as the target fishing mortality rate.

The following formula that adjusts current catch according to the ratio of the intended and current exploitation rates is then used to calculate C_{RBC}:

$$C_{RBC} = \frac{(1-e^{-F_{RBC}})}{(1-e^{-F_{CUR}})} C_{CUR}$$

where F_{CUR} is the estimated current fishing mortality, C_{CUR} is current catch, F_{RBC} is the selected F for the recommended biological catch from the control rule, and C_{RBC} is the recommended biological catch for the following year.

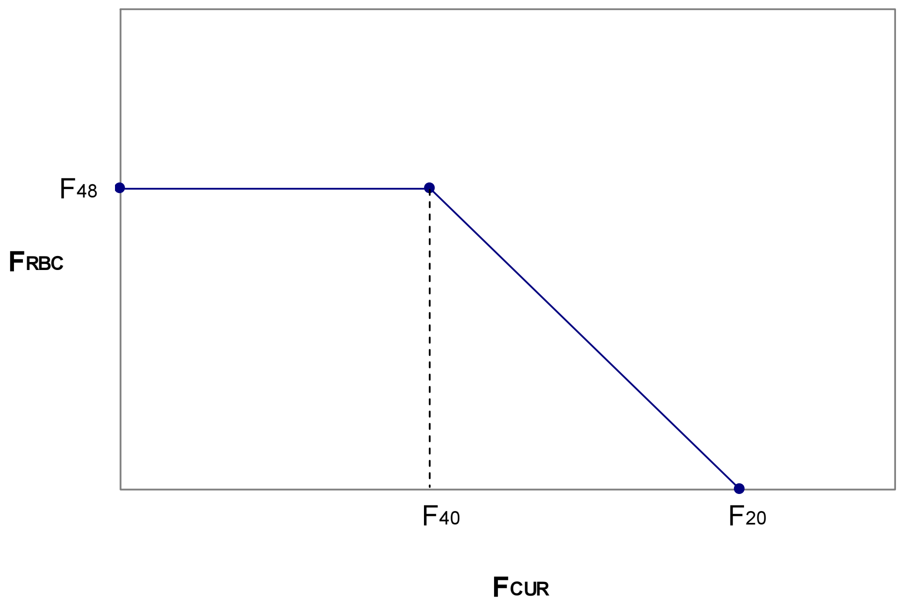

Figure 7.1 Method for selecting F_{RBC} based on estimated F_{CUR}.

7.3 Simulation tests

7.3.1 Tier 3 procedure

The performance of the revised Tier 3 procedure is simulation tested using the SESSF management strategy evaluation (MSE) procedure. A fishery population model is projected for 20 years into the future, using a detailed "operating model" to represent the future dynamics of the stock and to generate future "data". For each scenario, the future of the fishery is simulated 100 times, using different future recruitments and generating different data sets for input into the assessment procedures. The initial conditions for each scenario are based on the results of Tier 1 stock assessments for tiger flathead and school whiting.

The combinations of Tier 3 and catch options given in Table 7.1 are applied each year to set the TAC and catch in the following year. In order to test the revised Tier 3 procedure itself, biological parameters used in the assessment procedure are the same as those used in the population or operating model. Robustness to mismatches is then tested via a series of sensitivity tests.

Table 7.2 and Table 7.3 show the input parameters for each species. The length selectivity parameters are a catch-weighted average of the selectivity parameters for each fleet.

While the operating models are based on the existing Tier 1 assessments it should be emphasised that these models do not represent the 'real' species. They are intended to be species that have the same biological characteristics and catch history as SESSF species, but in some cases the input data has been manipulated to obtain the required current stock scenario for testing. The true current depletion for tiger flathead is near the target, so a low relative biomass starting point was created by using a lower initial stock size in the operating model. Likewise, the school whiting initial stock size was manipulated to get the desired initial relative stock sizes for testing.

The original catch curve method does not work for school whiting, because when using the average selectivity parameters whiting are not fully-selected at their maximum age, thus there is no data available with which to calculate the catch curve.

Table 7.1 Combinations of Tier 3 options, current relative biomass levels and catch options investigated for both flathead-like and school whiting-like species using simulation tests.

F estimation Method	Catch Averaging Period	Catch Control Rule	Current relative biomass	Future catch	Results	
					flathead	whiting
Catch curves	4 years	original	low	=TAC	Figure 7.2	-
Catch curves with selectivity	matched to F_{CUR} period	new	low	=TAC	Figure 7.3	Figure 7.6
Catch curves with selectivity	matched to F_{CUR} period	new	near target	=TAC	Figure 7.4	Figure 7.7
Catch curves with selectivity	matched to F_{CUR} period	new	high	=TAC	Figure 7.5	Figure 7.8
Known non-equilibrium *F*	last year	new	low	=TAC	Figure 7.9	Figure 7.10
Catch curves with selectivity	matched to F_{CUR} period	new	low	catch=0.5 TAC for 10 years	Figure 7.11	Figure 7.12
Catch curves with selectivity	matched to F_{CUR} period	new	low	catch=0.5 TAC every 4th year	Figure 7.13	Figure 7.14
Catch curves	matched to F_{CUR} period	new	low	=TAC	Figure 7.15	-
Catch curves with selectivity	matched to F_{CUR} period	original	low	=TAC	Figure 7.15	Figure 7.16
Catch curves with selectivity	most recent 4 years	new	low	=TAC	Figure 7.15	Figure 7.16

Table 7.2 Input parameters used for flathead-like species

Parameter	value		sensitivity tests
First historical year	1915		
Last historical year	2005		
number of future years	20		
maximum age	20		
growth parameters	female	male	
$L\infty$	56.03	45.7	
k	0.156	0.18	
t_0	-2.783	-3.41	
natural mortality, M	0.22		(0.15, 0.25)
steepness, h	0.72		(0.6, 0.9)
length-weight parameters			
a	0.0000058		
b	3.31		
length selectivity parameters			
S_{25}	26.5		
S_{50}	31.0		
knife-edge length at maturity	36.0		

Table 7.3 Input parameters used for school whiting-like species

Parameter	value	sensitivity tests
First historical year	1947	
Last historical year	2006	
number of future years	20	
maximum age	6	
growth parameters		
$L\infty$	26.0	
k	0.25	
t_0	-1.15	
natural mortality, M	0.6	(0.5, 0.7)
steepness, h	0.75	(0.65, 0.75)
length-weight parameters		
a	0.000013	
b	2.93	
length selectivity parameters		
S_{25}	16.5	
S_{50}	18.0	
knife-edge length at maturity	16.0	

7.3.2 Sensitivity tests

In order to test the revised Tier 3 procedure for robustness to mismatches between the biological parameters used in the assessment procedure and those used in the operating model, a series of sensitivity tests are run for both the flathead-like and whiting-like species. The values of natural mortality and steepness used in the assessment procedure are varied as shown in Table 7.2 and Table 7.3.

7.3.3 Performance measures

The results of each scenario are summarised by plots of the trajectory of relative biomass and catch over time. Table 7.4 describes in detail what these figures show.

The performance of scenarios is also evaluated using six performance measures relating to stock level, catch, and variability in catch. Specifically, the performance measures are:

1. Average catch over the 20 year projection period
2. Average catch over the first five years of the projection period
3. Depletion in final year : final biomass/B_0
4. Lowest depletion : lowest biomass/B_0 in the 20 year projection period
5. Catch variability : average percentage change in catch from year to year
6. Probability of the biomass in the projection period being below the limit ($0.2B_0$)

For selected scenarios, these performance measures are summarised in box plots.

7.4 Results

7.4.1 Tier 3 procedure

Table 7.4 provides a key to the results pages.

Application of the original Tier 3 procedure to a depleted flathead-like stock produces unsatisfactory results (Figure 7.2). The stock does not begin to recover from its initial depleted state until catches have become very low. At the end of the simulation period an equilibrium has not been reached.

Changing all three aspects of the Tier 3 procedure to the revised methods leads to good results for flathead. For the depleted stock (Figure 7.3) the relative stock size reaches the target after 10 years, and maintains this level. After an initial drop, catches increase and become stable. A stock already at the target level **(**Figure 7.4) is maintained close to this level, although there is some evidence of minor long-term oscillation. For a stock above the target level (Figure 7.5), the revised Tier 3 procedure initially sets catch too high, causing the stock to fall below the target, but this is eventually corrected. For flathead the slow response is because the reference catch is averaged over 18 years.

The original Tier 3 procedure cannot be applied to whiting, as they are not fully-selected by their maximum age, thus providing no data for use in the catch curve estimation. The revised Tier 3 procedure appears to work reasonably well for the whiting-like species, although there is more oscillation about the target stock level, probably due to the high recruitment variability and short lifetime of such a species. For a depleted stock (Figure 7.6), the stock reaches the target level after ten years, and stays near this level. The catch remains fairly steady. The stock already at the target level (Figure 7.7) initially drops (due mainly to low recruitments in the final historic years), but quickly reverts to the target. The stock above the target level (Figure 7.8) shows a response similar to flathead, initially setting catches too high, but the stock recovers more quickly to the target level.

Assuming perfect knowledge of recent non-equilibrium F values improves the Tier 3 behaviour for both species, with equilibrium target levels reached quickly, and then maintained, and with minimal variation in catches (Figure 7.9 and Figure 7.10). This assessment method indicates the improvements that may be gained by using an assessment method that can estimate non-equilibrium F values. The performance of such assessment methods within Tier 3 remains to be tested.

The ability of the revised Tier 3 procedure to deal with the possibility of the catch not being equal to the TAC has also been examined, using the depleted stock scenarios for both flathead-like and whiting-like species. If the catch is half the TAC for the first 10 years of the projection the stock increases to above the target level, but then decreases to close to the target as catches then equal the TAC for the next 10 years (Figure 7.11 and Figure 7.12). If the catch is half the TAC every four years, and equal to the TAC in the other years, this has little effect on the ability of the procedure to achieve the biomass target, for both the flathead-like and whiting-like species (Figure 7.13 and Figure 7.14).

We examined the effect of changing, one at a time, each of the three aspects of the revised Tier 3 procedure to that used in the original procedure. For the flathead-like species with a depleted stock, the performance measures for each of these scenarios as well as the original and revised procedures are summarised in Figure 7.15. The original Tier 3 catch control rule does not work at all well for the flathead-like species – catches stay high and biomass continues to decline, leaving the stock further depleted. When standard catch curves are used to estimate F_{CUR}, the stock does not stabilise as close to the target level, and average catch over 20 years is lower than for the revised procedure, as well as being more variable. When there is a mismatch in the period used to calculate C_{CUR} and F_{CUR} the procedure does not work well for the flathead-like species. The biomass does not stabilise at the target level and average catches are lower than for the revised procedure.

For the whiting-like species, recall that the original catch curve method is not able to be used at all because whiting are not fully-selected at their maximum age. The performance measures for revised procedure, and the procedures with the other two aspects unchanged from the original are shown in Figure 7.16. The original catch control rule works moderately well, with the stock stabilising above the target level, but with average catches considerably lower than the revised procedure. When there is a mismatch in the period used to calculate C_{CUR} and F_{CUR} the results are only marginally worse than those for the revised procedure. This is because there is not a big mismatch in the periods as whiting is such a short-lived species.

Results show that equilibrium assessment methods such as catch curves and catch curves with selectivity can perform reasonably well when used in combination with an appropriate catch averaging period, and the new catch control rule. All three aspects of the revised Tier 3 approach are important.

7.4.2 Sensitivity tests

The results of the revised Tier 3 procedure when either the natural mortality or steepness values used in the assessment procedure are varied from the ‘true’ value are shown for the flathead-like species in Figure 7.17, and for the whiting-like species in Figure 7.19. In all cases, the scenarios with low current relative biomass were used.

To enable comparisons to be made across scenarios more easily, the first five performance measures for each scenario and each species are summarised in box plots (Figure 7.18 and Figure 7.20).

The results for both the flathead-like and whiting-like species are very similar. The performance of the Tier 3 procedure is fairly insensitive to different values of the stock-recruit steepness parameter, *h*. The scenarios with a value of *h* higher or lower than that used in the operating model both recover the stock to fairly close to the target level at the end of the 20 year projection period. Catches are slightly lower than those of the base scenario for the lower value of *h*, and slightly higher for the higher value of *h*.

Using the wrong value of natural mortality, *M,* in the assessment rule however, leads to poor outcomes. For an *M* lower than the true *M*, the assessment procedure estimates fishing mortality to be much higher than the true value, so catches are set very low, leading to the biomass far exceeding the target level. For an *M* higher than the true *M*, fishing mortality is underestimated, so catches are set too high, and the stock biomass falls to well below the target level.

7.5 References

Caswell H. 2001. Matrix population models: construction, analysis, and interpretation, 2nd edn. Sinauer Associates, Sunderland, MA

Klaer, N. 2007. Yield, and total mortality values and Tier 3 estimates for selected shelf and slope species in the SESSF 2007. Report to ShelfRAG, Canberra, September 2007.

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Pope, J.G. 1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Bull. I-ICNAF, No. 9:65-74.

Table 7.4 Explanation of the results pages.

Species	The type of species investigated. Note that these simulations do not use the real species' stock levels.
F_{CUR} estimation	The method used to estimate current fishing mortality (F_{CUR})
Catch averaging period	The number of years over which to average the recent catch value (C_{CUR})
Catch control rule	The version of the catch control rule used
current relative biomass	SB_{year}/SB_0 at the end of the last year of real catches
future catch	How the catch in the future relates to the calculated TAC

relative biomass The black line shows an artificial historic relative spawning biomass (SB_{year}/SB_0) series. The series has been chosen to result in a current stock level as specified in the table above. The red line shows the relative biomass in future years, after removal of the catches as calculated by the version of the Tier 3 assessment procedure specified above. The solid red line is the median of the relative biomass calculated from 100 simulations of the assessment procedure. The dotted red lines are the 2.5 and 97.5 percentiles of the simulated relative biomass values. The grey line shows the target relative biomass level (0.48).	**catch** The black line shows the actual historic catch of the species up to the year of the most recent stock assessment. The red line shows the catch in future years, as calculated by the version of the Tier 3 assessment procedure specified above. The solid red line is the median of catch from 100 simulations of the assessment procedure .The dotted red lines are the 2.5 and 97.5 percentiles of the simulated catch values.
future relative biomass This graph is the same as the one above, but without the historic relative biomass series.	**RBC** This graph shows the Recommended Biological Catch (RBC) calculated by the Tier 3 assessment procedure specified above. The solid line is the median of the RBC from 100 simulations, and the dotted lines are the 2.5 and 97.5 percentiles.
TAC This graph shows the Total Allowable Catch (TAC) calculated by the Tier 3 assessment procedure specified above. The solid line is the median of the TAC from 100 simulations, and the dotted lines are the 2.5 and 97.5 percentiles. The TAC can differ from the RBC by the subtraction of expected discards, and by the constraint that the TAC cannot change by more then 50% from year to year.	**future catch** This graph is the same as the one on the top right, but without the historic catch series. The catch can differ from the TAC if the TAC is greater than the remaining vulnerable biomass, or if it has been set to be different, as specified in the table above.

Species	flathead-like
F_{CUR} **estimation**	catch curve
Catch averaging period	4
Catch control rule	original
current relative biomass	low (0.32)
future catch	=TAC

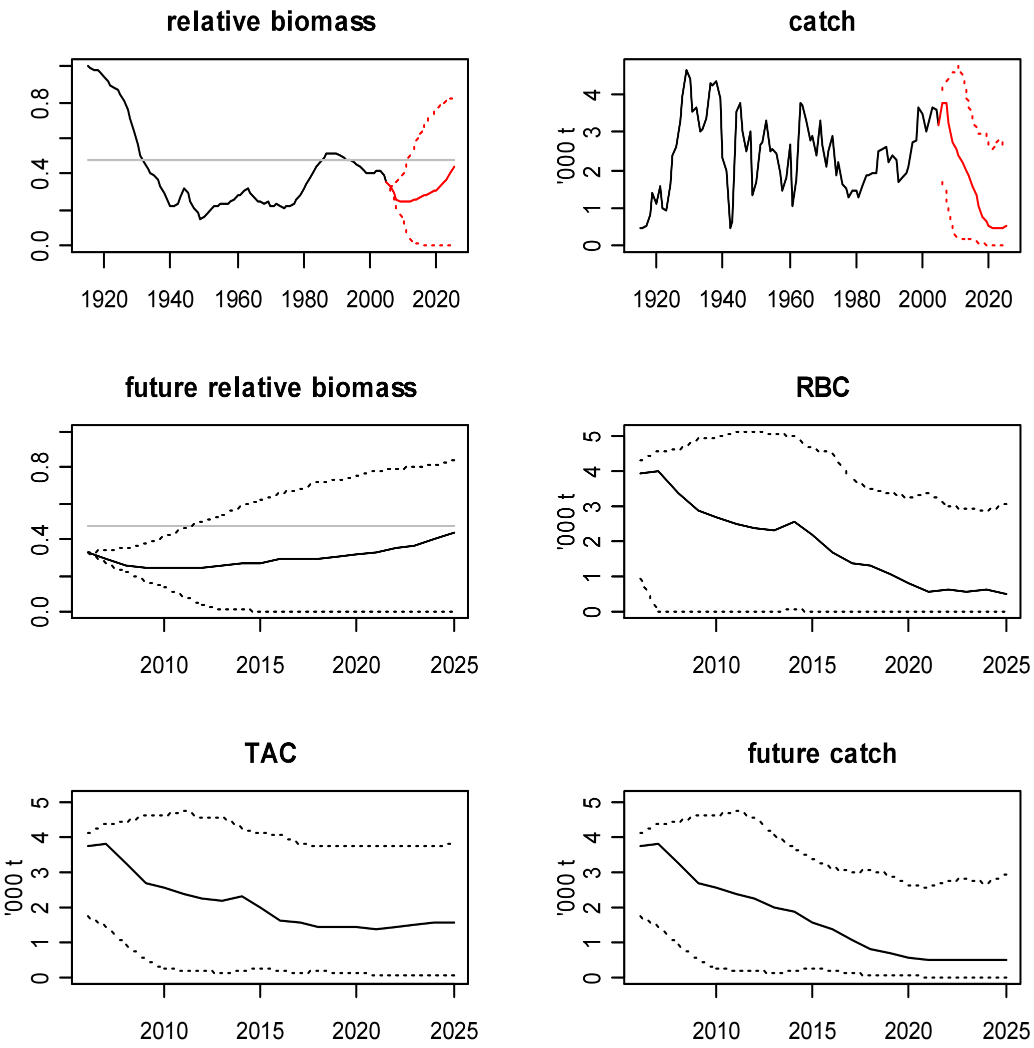

Figure 7.2 The original Tier 3 approach

Species	flathead-like
$\boldsymbol{F}_{\mathbf{CUR}}$ **estimation**	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (18 years)
Catch control rule	new
current relative biomass	low (0.32)
future catch	=TAC

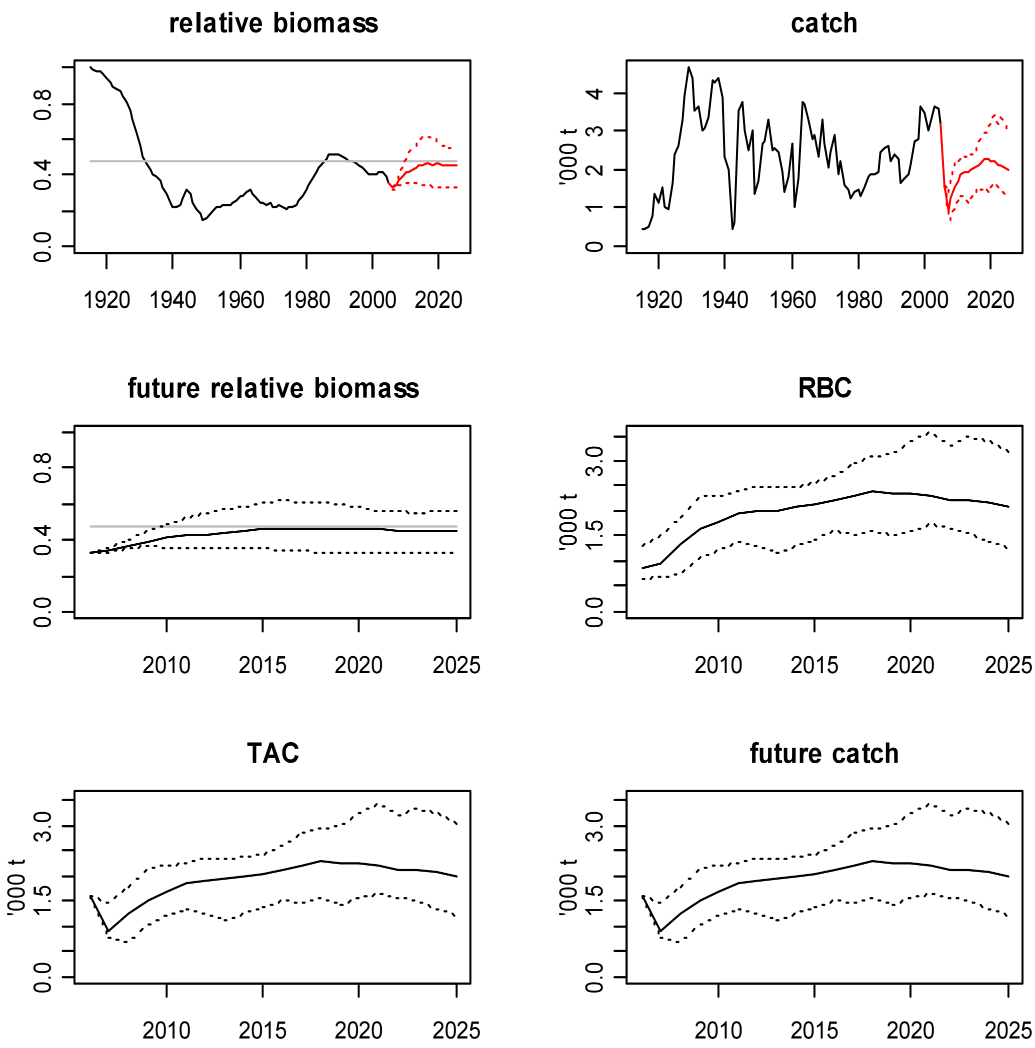

Figure 7.3 The revised Tier 3 approach – low current relative biomass

Species	flathead-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (18 years)
Catch control rule	new
current relative biomass	target (0.48)
future catch	=TAC

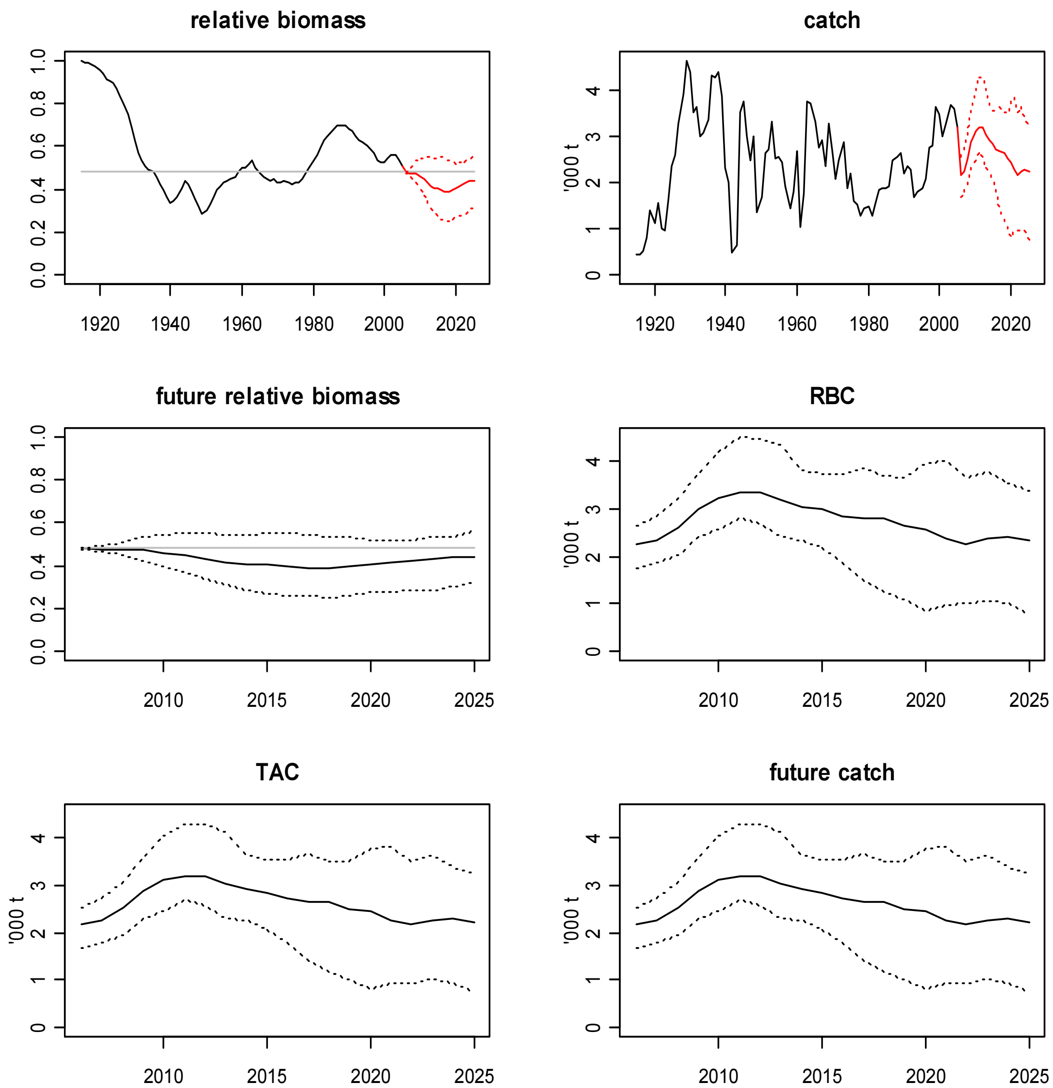

Figure 7.4 The revised Tier 3 approach – target current relative biomass

Species	flathead-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (18 years)
Catch control rule	new
current relative biomass	high (0.6)
future catch	=TAC

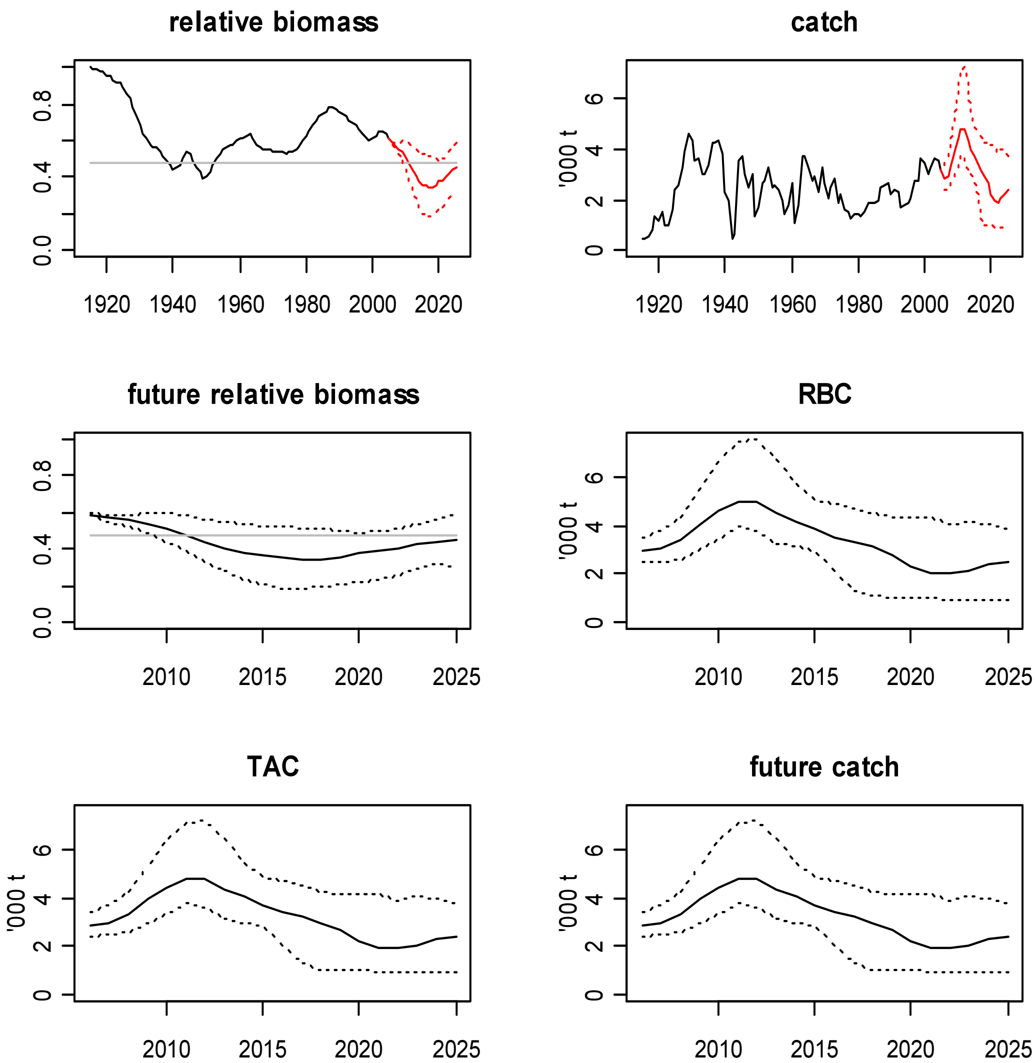

Figure 7.5 The revised Tier 3 approach – high current relative biomass

Species	whiting-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (3 years)
Catch control rule	new
current relative biomass	low (0.36)
future catch	=TAC

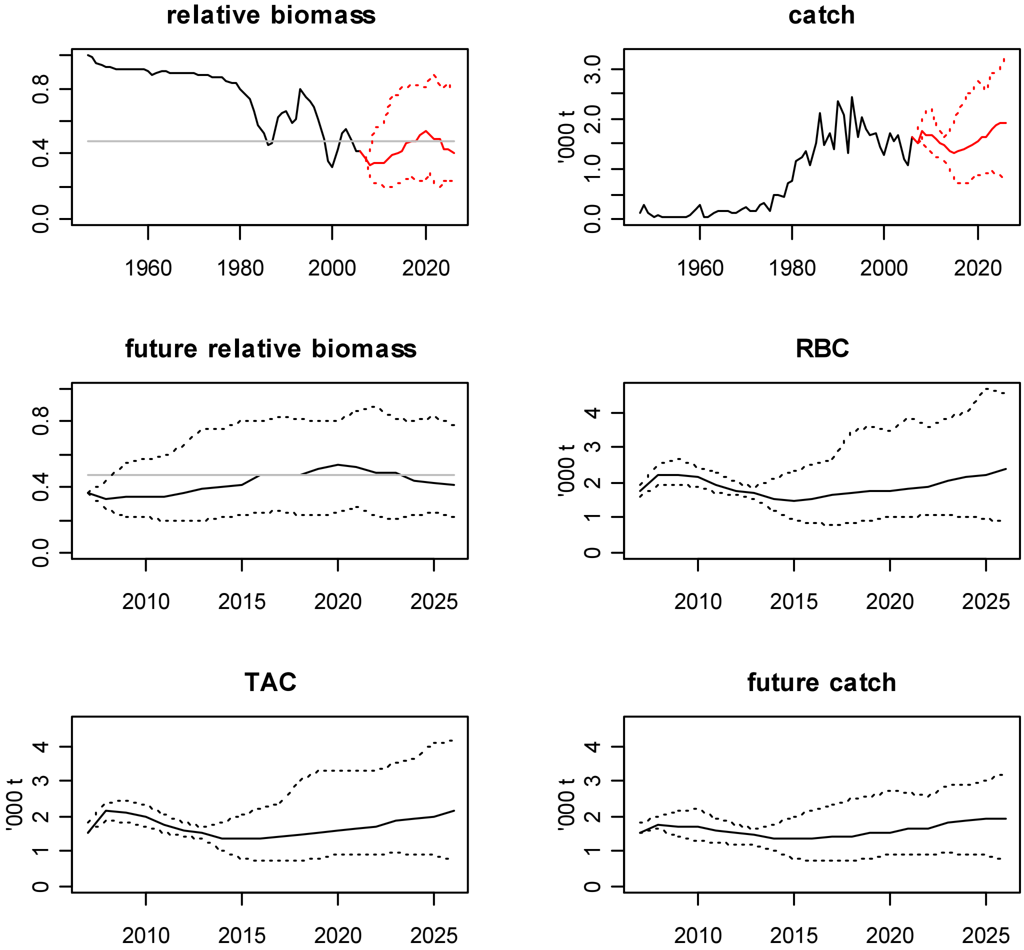

Figure 7.6 The revised Tier 3 approach – low current relative biomass

Species	whiting-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (3 years)
Catch control rule	new
current relative biomass	target (0.48)
future catch	=TAC

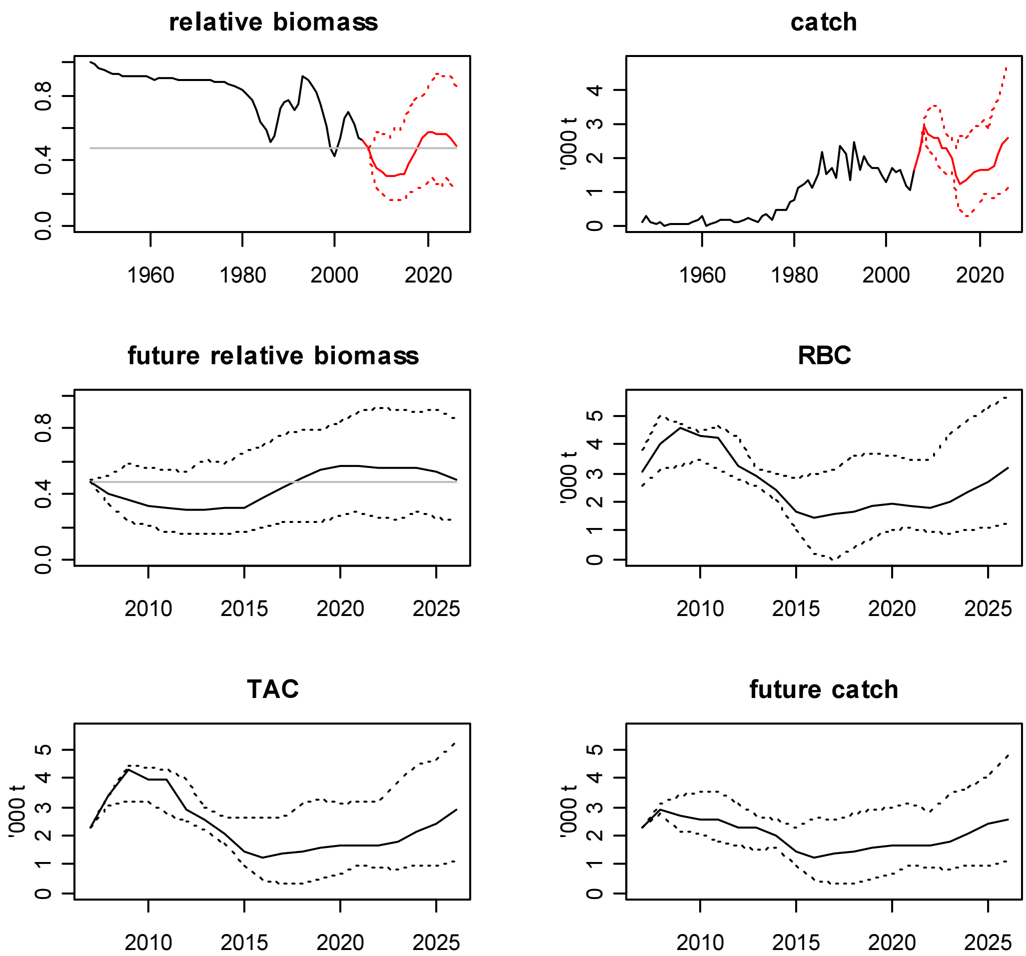

Figure 7.7 The revised Tier 3 approach – target current relative biomass

Species	whiting-like
***F_{CUR}* estimation**	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (3 years)
Catch control rule	new
current relative biomass	high (0.6)
future catch	=TAC

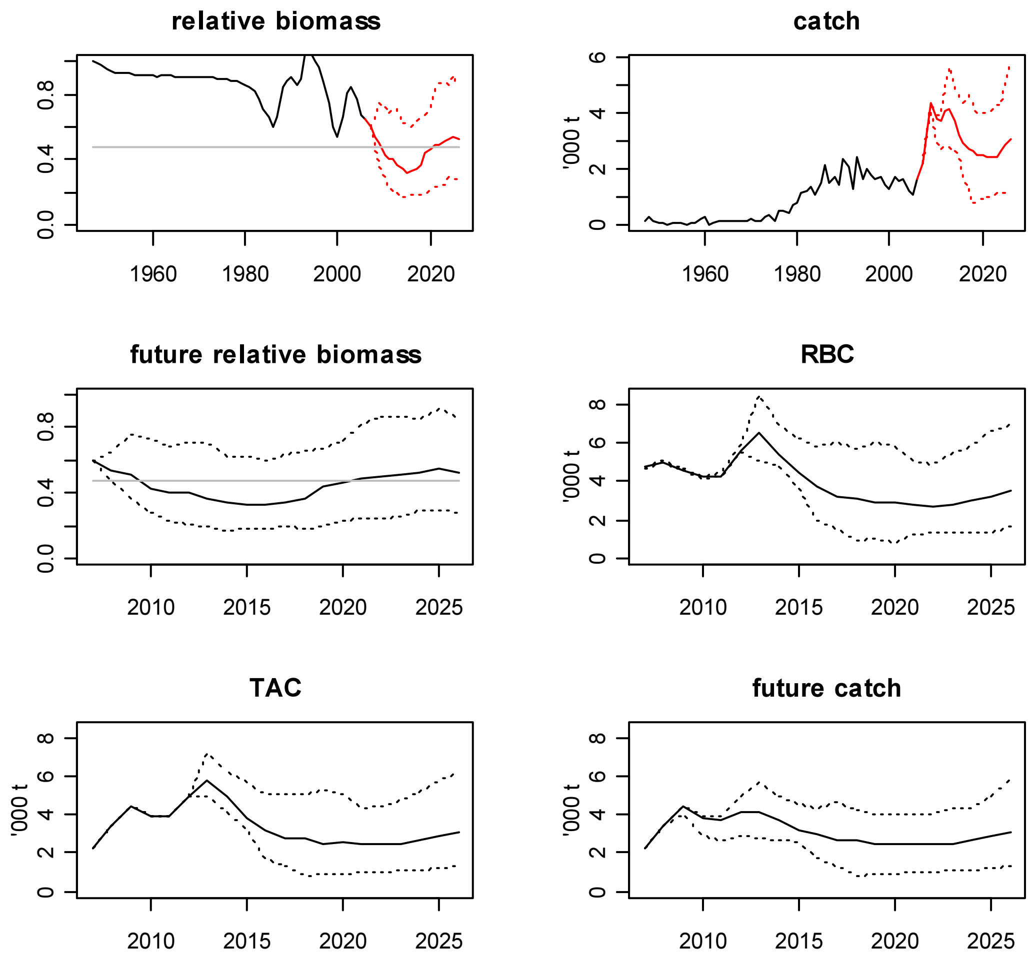

Figure 7.8 The revised Tier 3 approach –high current relative biomass

Species	flathead-like
F_{CUR} estimation	‘true’
Catch averaging period	last year
Catch control rule	new
current relative biomass	low (0.32)
future catch	= TAC

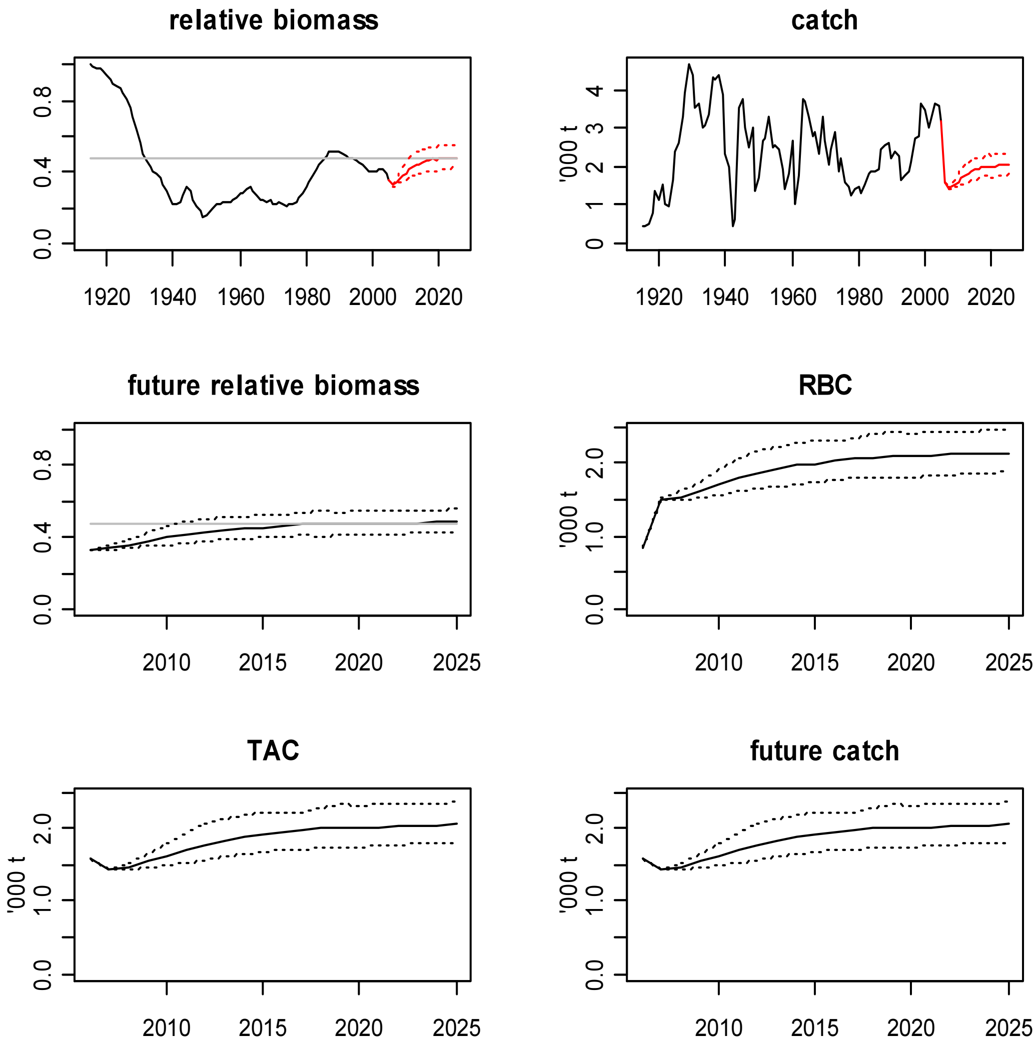

Figure 7.9 The revised Tier 3 approach, using the ‘true’ F_{CUR}

Species	whiting-like
F_{CUR} estimation	'true'
Catch averaging period	last year
Catch control rule	new
current relative biomass	low (0.36)
future catch	= TAC

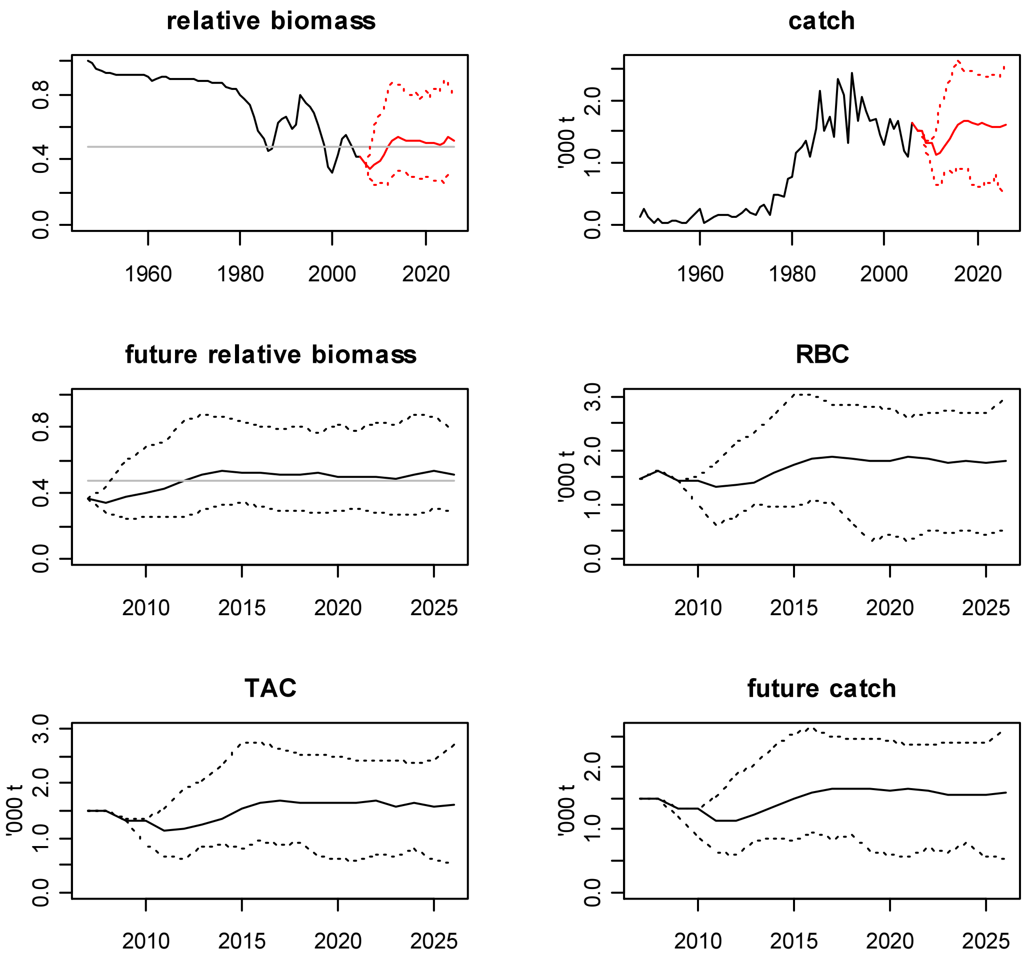

Figure 7.10 The revised Tier 3 approach, using the 'true' F_{CUR}

Species	flathead-like
F_{CUR} **estimation**	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (18 years)
Catch control rule	new
current relative biomass	low (0.32)
future catch	=0.5 TAC 10 years, then = TAC 10 years

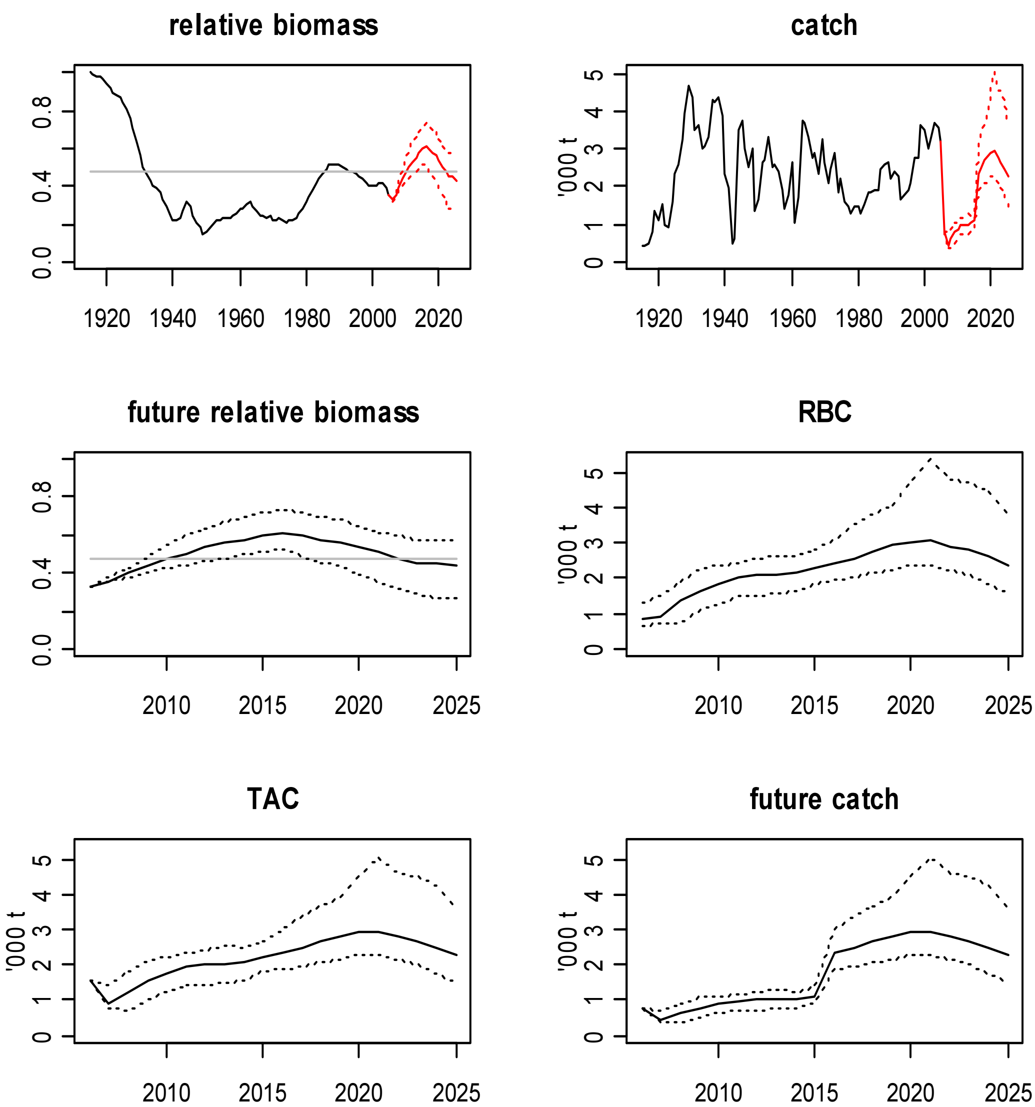

Figure 7.11 The revised Tier 3 approach, with catches <TAC for 10 years

Species	whiting-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (3 years)
Catch control rule	new
current relative biomass	low (0.36)
future catch	= 0.5 TAC 10 years, then =TAC 10 years

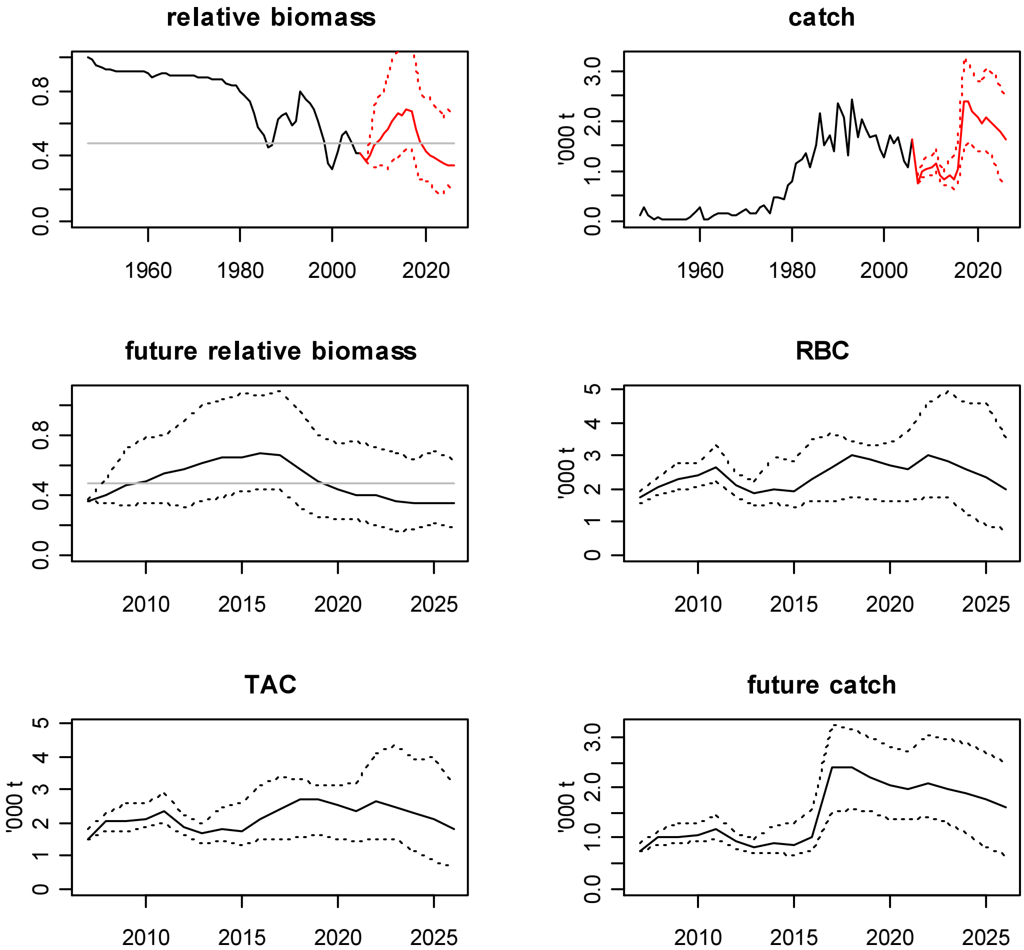

Figure 7.12 The revised Tier 3 approach, with catches <TAC for 10 years

Species	flathead-like
$\boldsymbol{F_{CUR}}$ **estimation**	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (18 years)
Catch control rule	new
current relative biomass	low (0.32)
future catch	0.5 TAC every 4 years

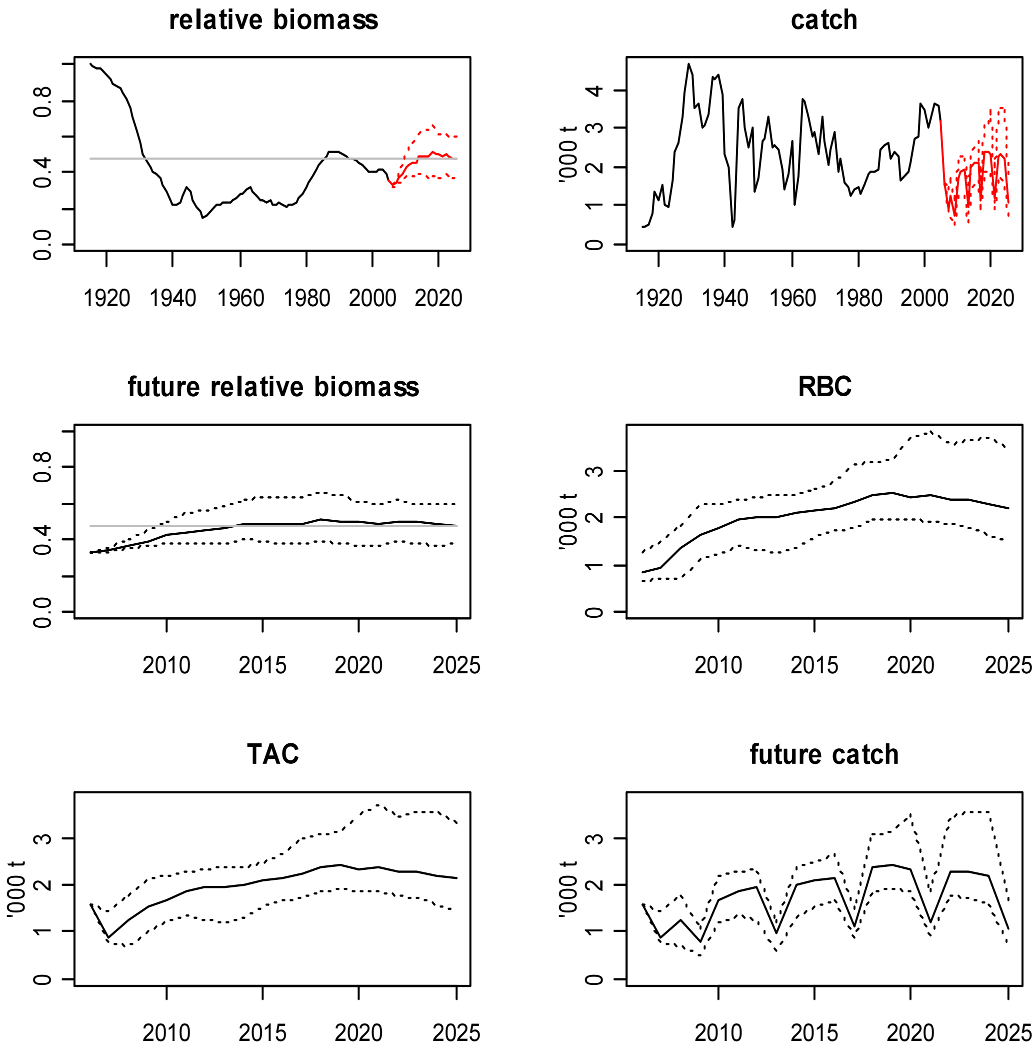

Figure 7.13 The revised Tier 3 approach, with catches <TAC every 4 years

Species	whiting-like
F_{CUR} estimation	catch curve with selectivity
Catch averaging period	matched to F_{CUR} period (3 years)
Catch control rule	new
current relative biomass	low (0.36)
future catch	catch=0.5 TAC every 4 years

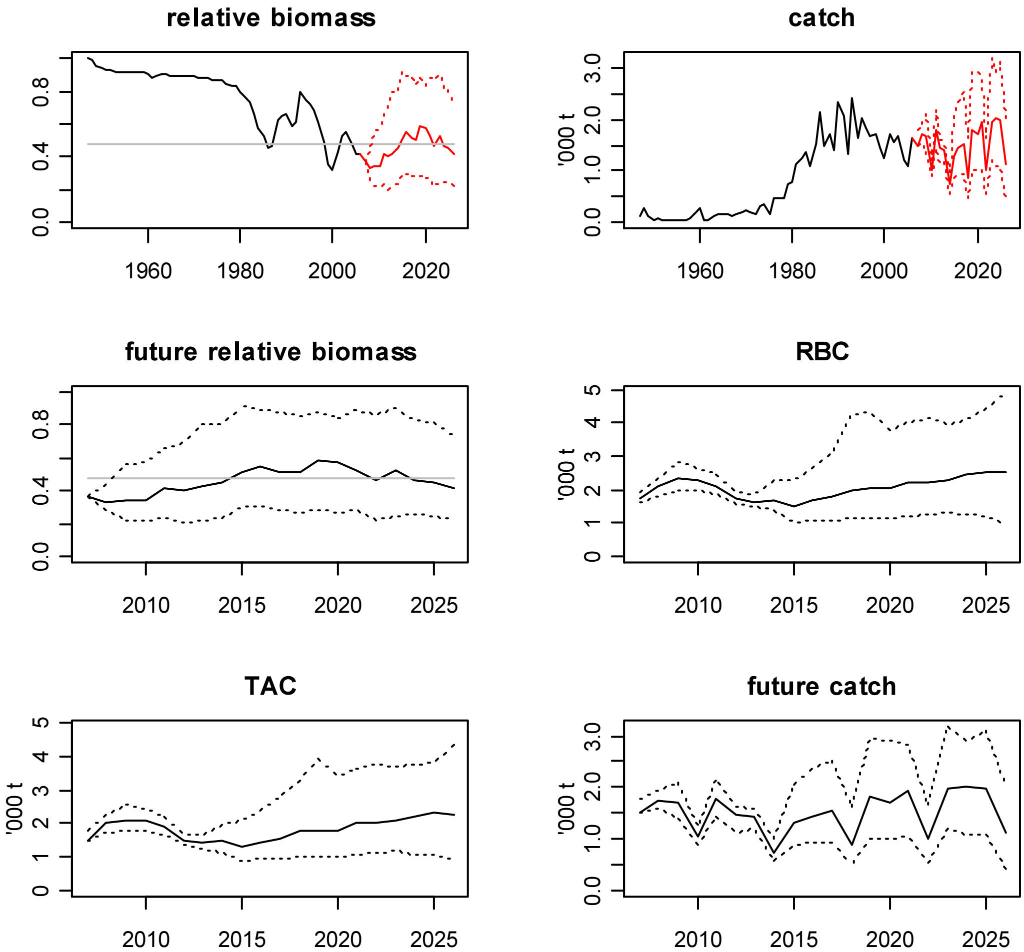

Figure 7.14 The revised Tier 3 approach, with catches <TAC every 4 years

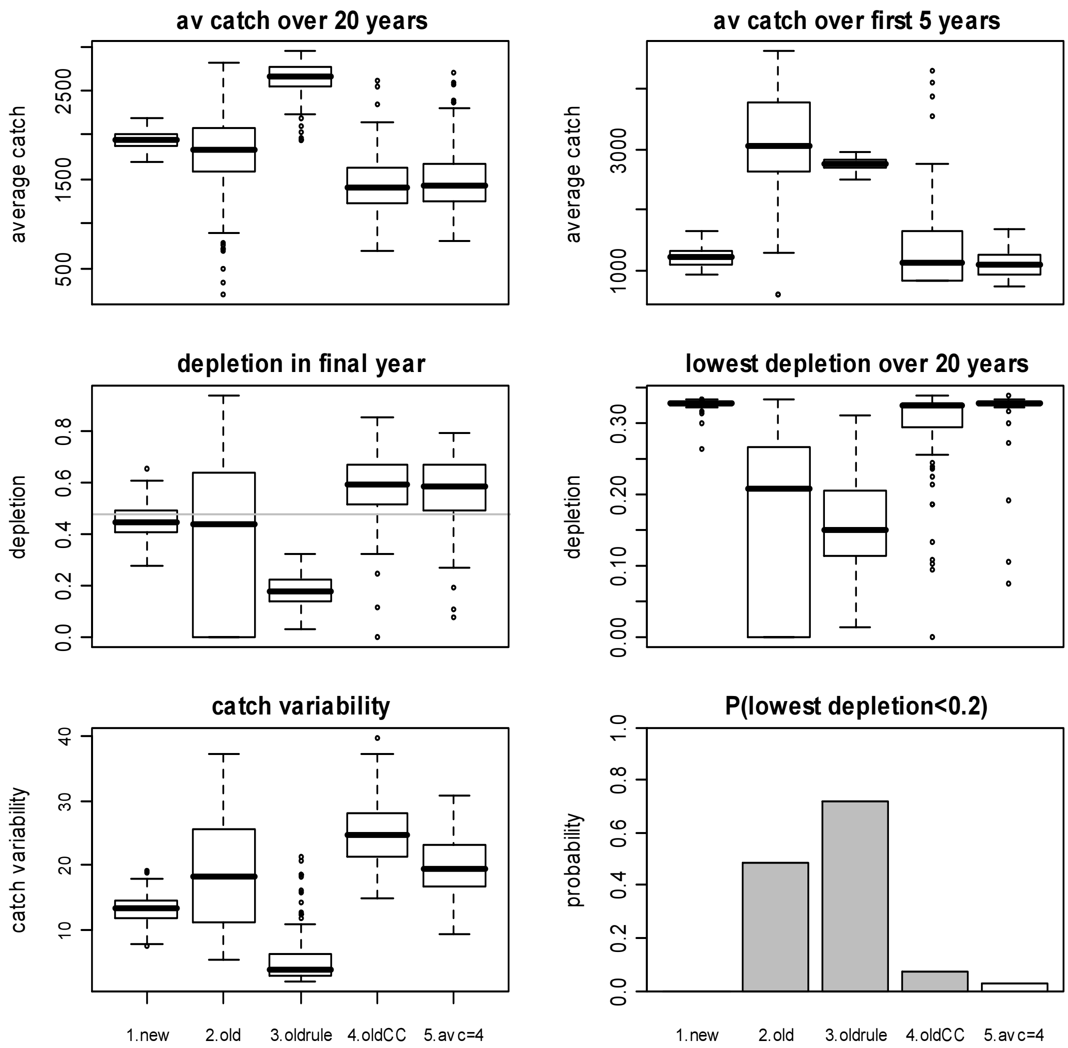

Figure 7.15 Box plots summarising the performance measures for five versions of the low stock size flathead revised Tier 3 assessment, showing the revised and original procedures, as well as the effect of changing each aspect of the Tier 3 procedure. 1.new: the revised procedure; 2.old: the original procedure; 3.oldrule: the revised procedure, but with the catch control rule replaced by the original rule; 4.oldCC: the revised procedure, but with the *F* estimation method replaced by the original standard catch curve method; 5.avc=4: the revised procedure, but with the reference catch averaging period not matched to the F estimation period.

For each scenario, the dark horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively (i.e. the middle 50 % of the data). The vertical dashed lines show either the maximum and minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

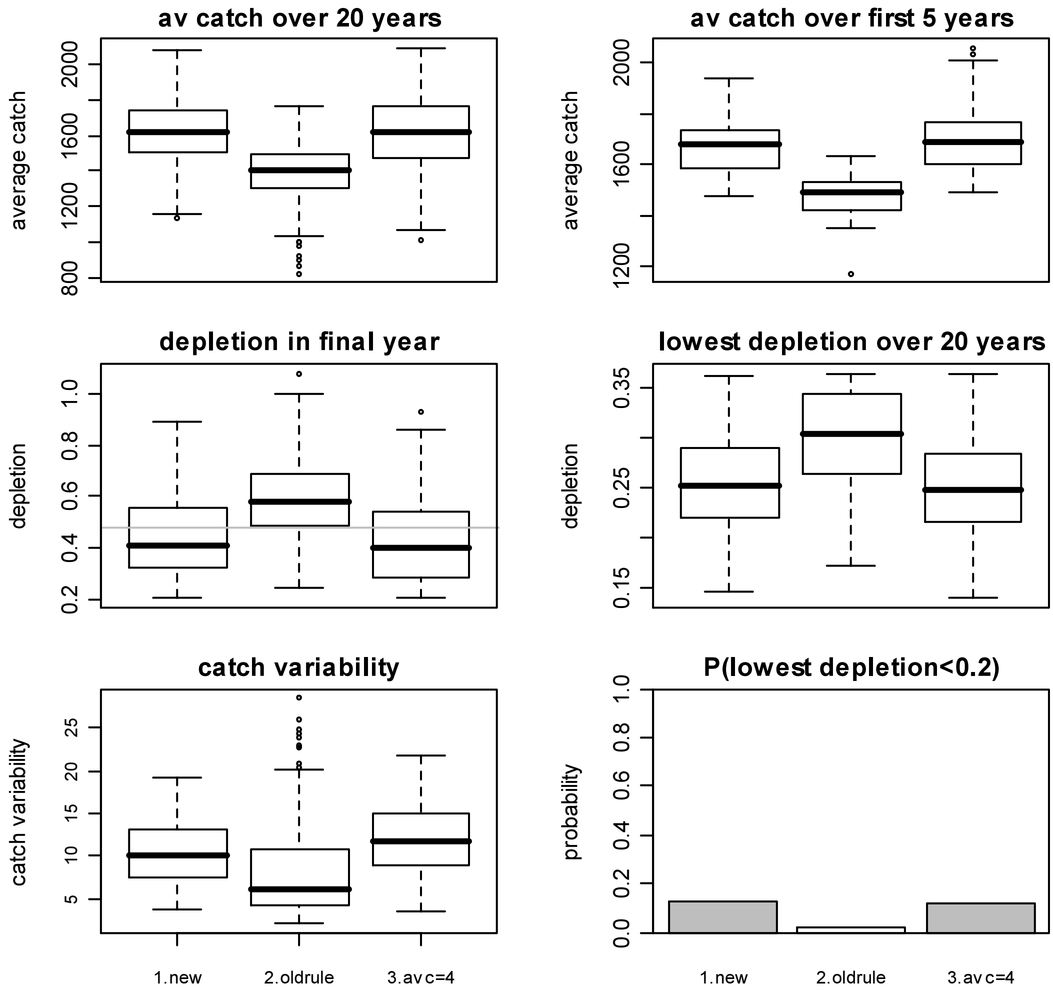

Figure 7.16 Box plots summarising the performance measures for three versions of the low stock size whiting revised Tier 3 assessment, showing the revised procedure, as well as the effect of changing two aspects of the Tier 3 procedure. 1.new: the revised procedure; 2.oldrule: the revised procedure, but with the catch control rule replaced by the original rule; 3.avc=4: the revised procedure, but with the reference catch averaging period not matched to the *F* estimation period.

For each scenario, the dark horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively (i.e. the middle 50 % of the data). The vertical dashed lines show either the maximum and minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

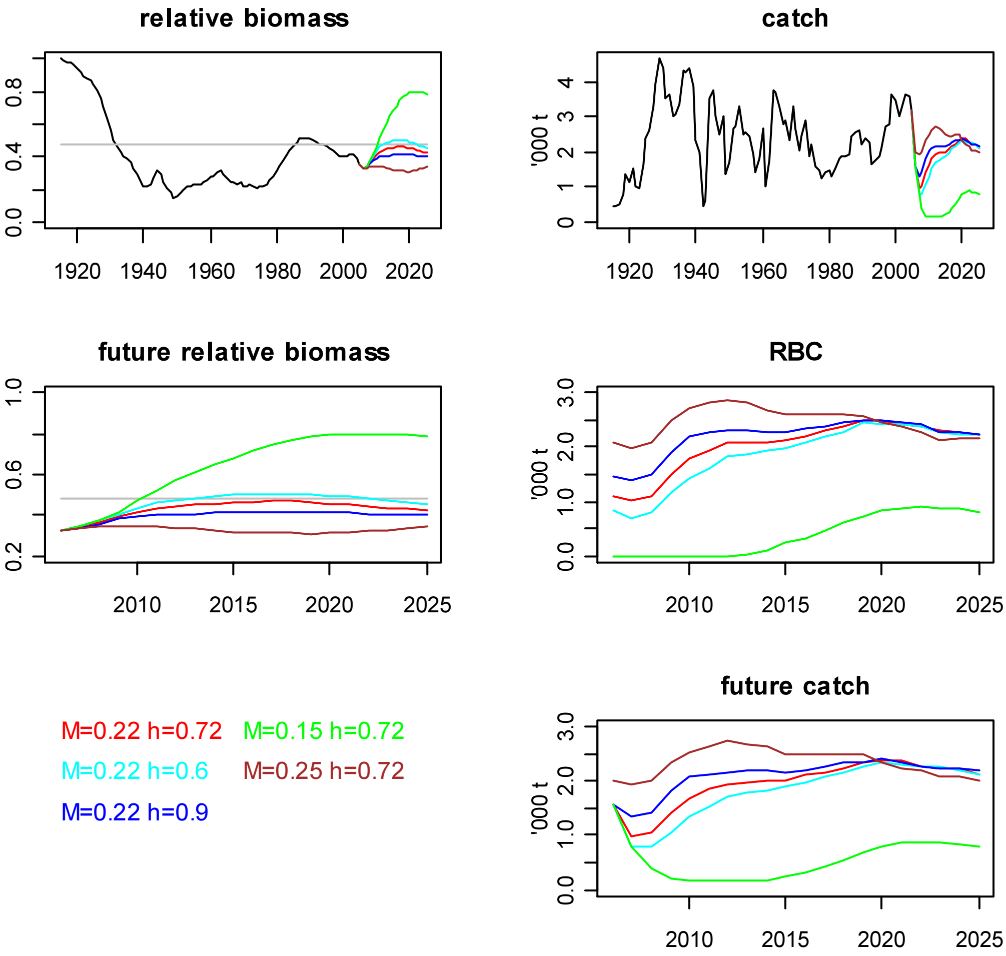

Figure 7.17 The trajectories for five versions of the flathead revised Tier 3 assessment, using different values of *M* and *h* in the assessment procedure. The red line is the result using the ‘true’ values of *M* and *h*.

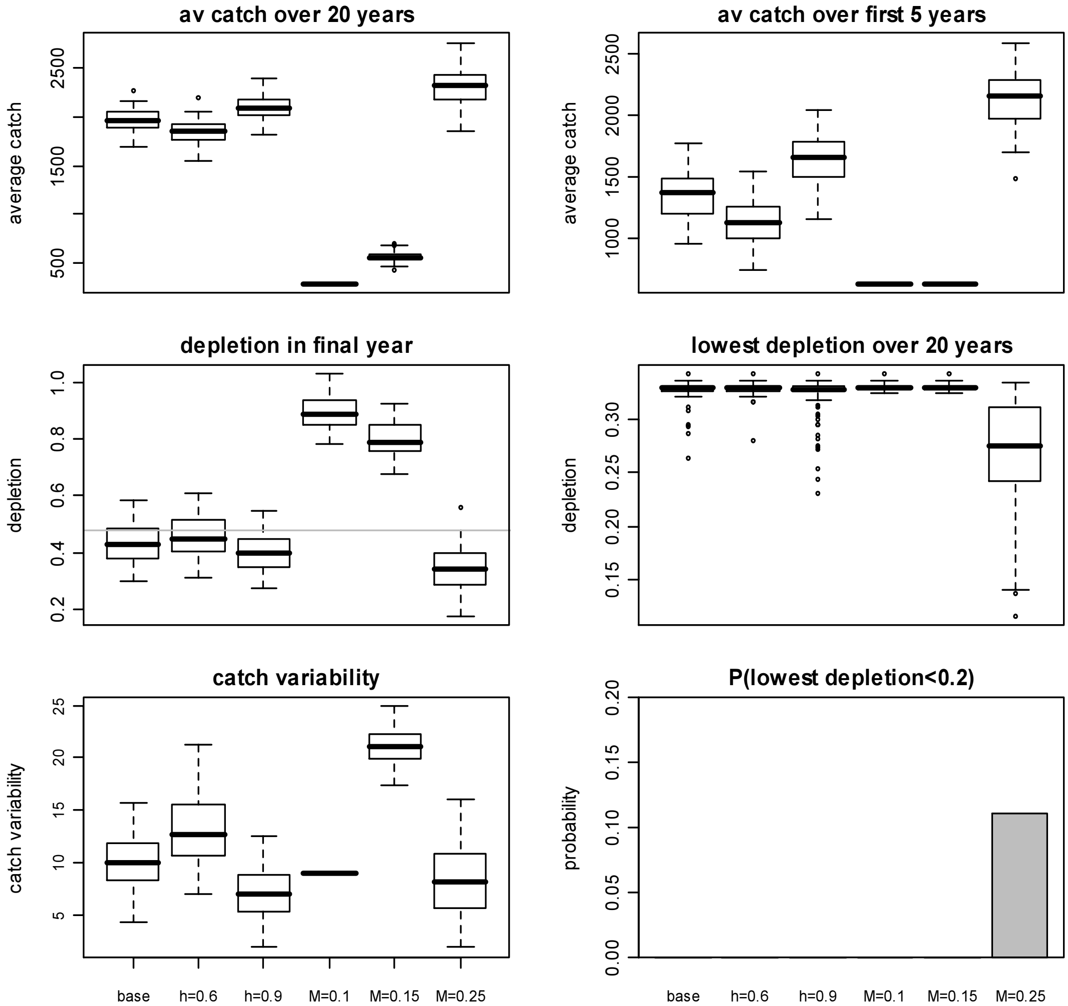

Figure 7.18 Box plots summarising the performance measures for five versions of the flathead revised Tier 3 assessment, using different values of *M* and *h* in the assessment procedure.

For each scenario, the dark horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively (i.e. the middle 50 % of the data). The vertical dashed lines show either the maximum and minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

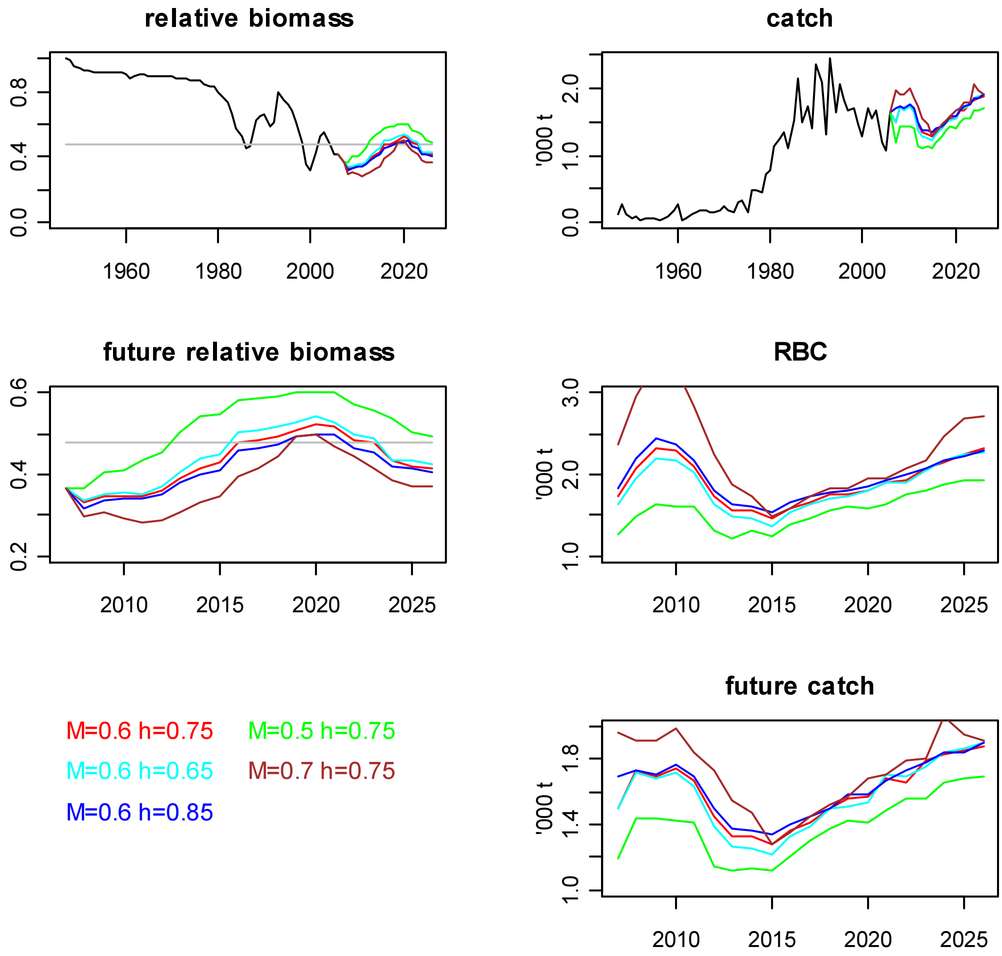

Figure 7.19 The trajectories for five versions of the whiting revised Tier 3 assessment, using different values of *M* and *h* in the assessment procedure. The red line is the result using the 'true' values of *M* and *h*.

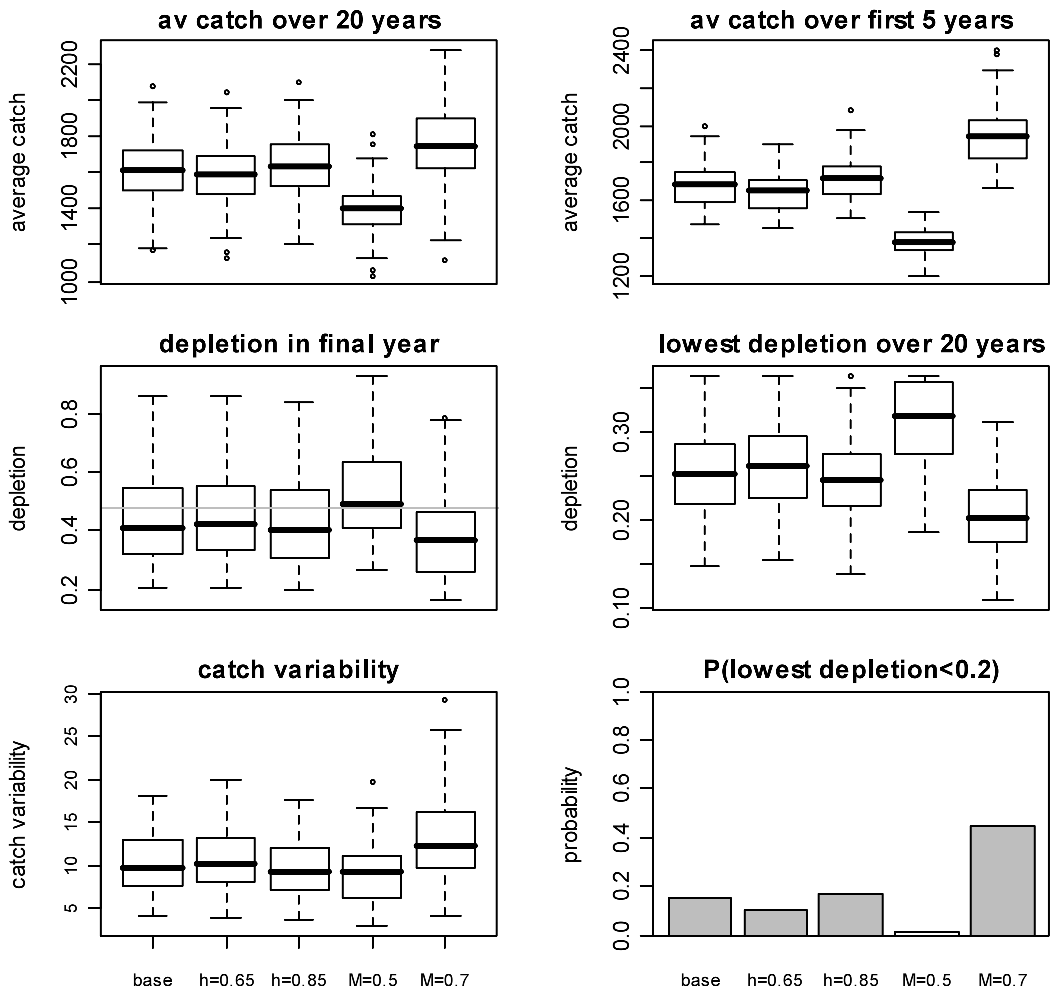

Figure 7.20 Box plots summarising the performance measures for five versions of the whiting revised Tier 3 assessment, using different values of *M* and *h* in the assessment procedure.

The horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively (i.e. the middle 50 % of the data). The vertical dashed lines show either the maximum and minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

8. Performance evaluation of age structure-based harvest strategies for blue-eye trevalla (*Hyperoglyphe antarctica*): impacts of spatial uncertainty

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8.1 Summary

Harvest control rules (HCRs) used to provide scientific advice to management calculate future recommended catch levels by comparing estimates of present stock status or current levels of fishing mortality to target and limit reference points. Under a precautionary approach to management, as uncertainty regarding stock status increases, application of harvest control rules should result in the recommendation of lower catches, thus achieving larger stock sizes. Implementation of a Tier framework of harvest control rules used to recommend catches in south-eastern Australia is outlined, with the choice of Tier rule reflecting the uncertainty in the available information on stock status.

A management strategy evaluation (MSE) approach is used to evaluate the performance of the 'data-poor' Tier 3 HCR, which uses information from the age structure of the catch only to calculate future catches. The MSE is conducted given appropriate model parameterization for blue eye trevalla (*Hyperoglyphe antarctica*), a long-lived, late maturing scalefish species that is exploited by multiple gear types, and exhibits spatial and seasonal variability in availability to the fishery, possibly further complicated by spatial structure in the population dynamics. Several versions of the Tier 3 HCRs are tested, which vary in both the types of reference points used to predicate management action, and in the manner for which spatial variability in the fishery is accounted for when setting catches for the entire resource.

Results suggest that implementation of age-structure based HCRs such as those examined can be used to effectively manage a species such as blue eye, given appropriate choice of reference points. Spatial disaggregation of data leads to uncertain estimates of current mortality, however appropriate weighting of spatial estimates of stock status leads to improved conservation of the resource over 'pooled data' approaches when spatial structuring in the population is present. Care and common sense needs to be taken when applying such rules, as simulated outcomes are sensitive to many of the uncertainties inherent to an information poor, spatially heterogeneous resource, meaning that automated 'blind faith' management of such species using HCRs such as these is perhaps unwise. Additional considerations besides the HCR should be made to achieve a desired precautionary result when compared to more data-rich scenarios.

8.2 Introduction

Harvest strategies (often termed Management Procedures) are well recognized as effective tools for conservation of natural resources and have been widely applied in fisheries management, principally in output control, data-rich fisheries (*e.g.* Butterworth *et al*. 1997, Butterworth and Punt 1999, Cooke 1999, Kell *et al*. 1999, 2005). Harvest strategies consist of the following components: data collection schemes, assessment methods, and harvest control rules (HCRs). The latter translate stock indicators from assessment results into specifications for management actions (*e.g.* Restrepo and Powers 1999). A successful HCR should provide appropriate response to deviations from management targets, be robust to key uncertainties, and emphasize precautionary action given uncertainty. The latter point is particularly important for so-called 'data-poor' situations, when the reliability of stock indicators is likely questionable. Simulation methods using a management strategy evaluation (MSE) approach are well-developed, and offer powerful tools for comparing among HCRs (*e.g.* De Oliveira *et al*. 2008, Butterworth and Punt 1999, Smith *et al*. 1999).

The blue eye trevalla (*Hyperoglyphe antarctica*) is a high-valued species in Australia's Southern and Eastern Shark and Scalefish Fishery (SESSF). The fishery for this long-lived, late maturing species is characterized by a large number of gear types operating in a range of areas, with uncertainty in stock structure, spatial and seasonal variability in availability of different age classes, and low levels of sampling effort across the fishery (Smith and Wayte 2002, Fay 2006). Scientific advice for management in the SESSF takes the form of a Recommended Biological Catch (RBC) for each quota species (including blue eye trevalla) for the entire fishery to inform the setting of the Total Allowable Catch (TAC) (Smith *et al*. 2008). At present, the TAC for blue eye pertains to the entire fishery because there are no measures in place to allocate the TAC spatially.

In 2005, the SESSF adopted a formal harvest strategy framework (HSF) as a basis for setting RBCs (Smith and Smith 2005, Smith *et al*. 2008). This framework is based on a Tier system of HCRs, with the decision as to which Tier a particular stock is placed in being dependent on the type of information available on which to base a stock status determination. The Tier framework is intended to follow the precautionary approach, in that control rules should recommend lower RBCs, and result in maintaining the stock at higher levels of spawning biomass on average as information quality declines and progression through the Tiers proceeds. The SESSF harvest strategies specify a biomass level B_{LIM} (currently 20% of unfished spawning biomass), below which targeted fishing should cease, and a target biomass B_{TARG}. The HCRs operate by specifying a maximum fishing mortality rate that defines overfishing (F_{LIM}), and a target fishing mortality rate that defines optimum utilization (F_{TARG}), with supposed decreases in this target as uncertainty about stock status increases.

The Tier 3 HCR has been applied to blue eye trevalla. This HCR is designed for stocks for which there exists no estimate of current biomass, but where an estimate of the current fishing mortality rate, F_{CUR}, is available, most frequently from the results of catch curve analysis applied to age composition data. The Tier 1 HCR is for the most information-rich case, and involves calculating RBCs from the results of fitting an integrated stock assessment model (*e.g.* Stock Synthesis, Methot 2007) to the available data. As the HSF was not tested before being implemented, it is not clear how the Tier framework of HCRs performs, and indeed whether scientific advice for management is more precautionary for species managed using the Tier 3 HCR, than it would be under Tier 1. Concern about the performance of the Tier 3 HCR has been noted following implementation (Klaer *et al*., this volume Section 7). There is also concern that the nature of the calculation of RBCs for Tier 3 (applying an appropriate multiplier to recent average catch levels) could produce a ratchet effect of continually increasing or decreasing catches, even though information suggests that the target level has been reached. Specifically, it is clear that the original target fishing mortality rate for Tier 3 ($F_{\mathrm{TARG}}=M$) was inappropriate for many species. A revised harvest control rule (Klaer *et al.*, this volume Section 7), which shows consistency with the more data-rich Tier rules in terms of reference points, was applied in 2008. Finally, it is not clear how best to cope with possibly conflicting information from multiple areas and gear types.

This paper uses management strategy evaluation (MSE) to assess the performance of the Tier 3 HCRs for blue eye trevalla given key uncertainties. Implementation of MSE typically involves assessing the consequences of a range of management options, and transparently deals with trade-offs in performance criteria given a specified set of management objectives. The performance of HCRs is assessed based on how well they meet management targets and objectives. The performance of several versions of the Tier 3 HCR that use different specifications for the various reference points and/or utilize different estimation methods are compared. These alternatives facilitate correspondence with the Tier 1 and Tier 2 HCRs, and include calculation of biomass estimates and assumptions regarding the stock-recruitment relationship, negating the need for the RBC to rely directly on previous year's catch level. HCR performance is considered both when there is no spatial structuring of the population or fishery, and when there exist two regions in which the fishery operates, with uncertainty related to differing exploitation patterns, and selectivity by region, and also given different assumptions regarding the spatial structure and degree of mixing of the fished stock between regions.

Emphasis is placed on presenting key results and demonstrating HCR behaviour given different approaches regarding how to improve the performance and precautionary nature of the tier framework. Comparisons with data-rich scenarios are presented for some cases. While the MSE procedure is restricted to a case study of a single species and fishery, the nature of the studied resource is relevant to other fished populations within the SESSF, and the discussion outlines general points that may be taken into account when applying these methods for other systems, particularly when faced with issues related to spatial uncertainty, either with respect to the resource or the fishery.

8.3 Methods

8.3.1 Simulation protocol

Performance of the HSF for blue eye is evaluated using a simulation modelling framework that incorporates feedback between the various harvest control rules and the population dynamics. Attention in this section is focused on describing the harvest control rules and the various modifications made to their implementation, rather than describing the technical details of the operating model, which are detailed in full in Section 11. The general approach consists of tuning a spatial length- and age-structured operating model to represent a set of hypotheses for the dynamics of the blue eye trevalla population and fishery. Note that this approach is different from those presented in other sections because the values for the parameters of the operating model are not based on the results of a stock assessment, as no model for the population dynamics exists for blue eye in the SESSF.

The operating model is then projected over a historical period given the known catch history for blue eye, and age composition data are generated given the known 'true' population. The chosen HCR is then used to determine the RBC for the following year(s), given an estimation method (catch curve analysis) and the selected parameters governing the HCR. The RBC is then allocated to fleet and region within the operating model, the population size updated given this new catch, and additional data generated. The assessment / population update cycle is repeated for the projection period of 20 years, with annual assessment and updating of the RBC. A *scenario* is defined as the combination of a set of parameters for the operating model, a data collection scheme, and a specific version of the Tier 3 HCR. One hundred simulations were conducted for each scenario, each differing due to process error in the population dynamics, observation error when generating the age data, and error associated with implementation of the estimation method and application of the HCR. At the end of the projection period, as series of summary statistics are calculated and these are compared among simulations to derive a set of performance measures, which are used to compare results among scenarios.

8.3.2 Operating model

The operating model consists of an age-structured population dynamics model that can be parameterised to include spatial regions (with movement of fish among regions), and multiple fleets, to capture key dynamics for blue eye trevalla. Full technical specifications for the operating model are detailed in Section 11. Analyses detailed in this paper consider two versions of the operating model: (a) a single population occupying a single region and exploited by a single fishing fleet, and (b) a population occupying two regions with movement between regions, and exploited by one or two fishing fleets (with different selectivity patterns). Several parameterizations of each version of the operating model are considered to investigate the implications of key uncertainties. The parameterization of the operating models, along with the values for blue eye biological parameters considered for the various scenarios, are given in Table 8.1, Table 8.2 and Figure 8.1.

Scenarios using the two-region version of the model are designed to mimic general assumptions regarding the nature of the blue eye trevalla fishery, rather than the actual spatial structure. Two 'continental slope' regions with differing exploitation histories are assumed, with levels of stock mixing between the two regions ranging from full mixing, in that the impacts of spatial variability are minimal, to almost no mixing, indicating a high degree of spatial structuring in the blue eye population. Spatial differences in population responses to exploitation are more likely to be observed under the latter scenario. The regional catch histories used to drive the population dynamics models (Figure 8.1f) are taken from the landings data from the relevant zones of the SESSF, with the geographic split in these data being catches taken east and west of Tasmania.

8.3.3 Harvest strategies

The harvest strategies consist of a data collection scheme, a method to estimate the current fishing mortality rate F_{CUR}, and a HCR. Scenarios are limited to instances where the harvest strategy is applied every year of the projection period, consistent with the current practice of annual setting of TACs within the SESSF. The two forms for the Tier 3 HCR shown in Figure 8.2 are tested, with three methods for estimating F_{CUR}. Variations of the HCRs that utilise different reference points and have differing data requirements are implemented as outlined below.

8.3.3.1 Data and estimation methods

Data available for the Tier 3 analyses were limited to fishery-dependent age-composition data (*i.e.* no index of abundance or fishery independent data), with an annual multinomial sample size of 100 allocated by fleet and region in the same proportions as the annual catch. Four years of age data are assumed to be available to the estimators. Two catch curve estimation methods were employed: (a) the Chapman and Robson (1960) catch curve estimator (CR), and (b) a multi-year equilibrium *F* age-structure based-estimator (MYEF). The estimators aim to estimate total mortality, *Z*, with estimation of *F* then achieved given an assumed value for the rate of natural mortality, *M* (denoted 'assumed *M*' in Tables 8.1 and 8.2). For the CR method, catch curves were applied to the annual age-composition data, with F_{CUR} calculated as an inverse-variance weighted average of the annual estimates. In contrast, MYEF integrates over all years during the estimation, therefore averaging over years is not required to obtain an estimate of F_{CUR} in this instance.

a) Chapman and Robson catch curve estimator (CR)

The CR estimator assumes that the population is in equilibrium, and that recruitment is constant over time. The estimate of *Z*, from a sample of the age composition for a given year is calculated by:

$$Z_y = \ln\left(\frac{1+\bar{a}_y - 1/n_y}{\bar{a}_y}\right) \tag{1}$$

where $\bar{a}_y$ is the mean age (above the recruitment age) of the sample and n_y is the sample size for year *y*. A single estimate of *Z* is required to calculate the RBC, and so weighted averages of estimates of Z_y from the most recent four years of age data were calculated, with weighting inverse to the variance estimate for each year:

$$Var(Z_y) \approx \frac{\left(1-e^{-Z_y}\right)^2}{n_y e^{-Z_y}} \tag{2}$$

Catch curve estimators are known to be sensitive to the age-range of the data used (Chapman and Robson 1960, Dunn *et al*. 2002). For the analyses presented here, the recruitment age was assumed to be that for which the numbers at age were greatest, with the maximum age being determined from the sample. CR assumes uniform selectivity for ages above the recruitment age, likely biasing estimates of vulnerable biomass.

(b) Multi-year equilibrium F age-structure based-estimator (MYEF)

Estimation of F_{CUR} using MYEF involves fitting an equilibrium-based age structured production model to the available age-composition data, with the population model being of the form:

$$N_a = \begin{cases} 1 & \text{if } a = 0 \\ N_{a-1} e^{-(s_{a-1}F+M)} & \text{if } 0 < a < 100 \\ \dfrac{N_{a-1} e^{-(s_{a-1}F+M)}}{\left(1 - e^{-(s_a F+M)}\right)} & \text{if } a = 100 \end{cases} \tag{3}$$

where the N_a s are the numbers at age, *s* is the (estimated) selectivity at age (assumed to be asymptotic and to follow a logistic curve), *F* is the estimated rate of fishing mortality, and *M* is the assumed rate of natural mortality. The values for *F* and *s* are determined by minimizing the negative log-likelihood function:

$$-\ln L = \sum_y n_y \sum_a O_{y,a} \ln\left(\frac{\tilde{N}_a}{O_{y,a}}\right) \tag{4}$$

where $O_{y,a}$ is the observed proportions by age in year *y*, n_y is the sample size in year *y*, and $\tilde{N}_a$ are the predicted proportions of catch at age:

$$\begin{aligned} \tilde{N}_a &= \bar{N}_a / \sum_{a'} \bar{N}_{a'} \\ \bar{N}_a &= \frac{N_a s_a F}{(s_a F + M)} \left(1 - \exp^{-(s_a F + M)}\right) \end{aligned} \tag{5}$$

Minimisation of (4) was achieved using AD Model Builder (Otter Consulting, Inc.), which also enables calculation of the variance of the *F* estimate. Differences between MYEF and CR are that account is taken of selectivity, data from all ages are used, and that the likelihood used is multinomial. As *F* is calculated under an equilibrium approach using all the available data under MYEF, no averaging of annual mortality estimates is necessary to calculate the RBC, as is needed with the CR estimator.

The scenarios outlined in Table 8.1 and Table 8.2 include uncertainties when applying the estimation models. Importantly, the impact of assuming the incorrect value for *M* when conducting the estimation is examined.

8.3.3.2 Harvest Control Rules

Each of the scenarios outlined in Table 8.1 and Table 8.2 were projected using three versions of the Tier 3 HCRs shown in Figure 8.2, which differed either by adopting the 'old' or 'new' rule, and in the choice for the target and limit reference points:

1. The shape of the HCR follows the 'old' rule (Figure 8.2, top-right panel), with $F_{\text{TARG}} = M$,

2. The shape of the HCR follows the 'new' rule (Figure 8.2, bottom-left panel), with $F_{\mathrm{TARG}} = 0.5M$ and $F_{\mathrm{LIM}} = M$,

3. As for 2), but with the reference points adopting a Tier 1-like approach with $F_{\mathrm{TARG}} = F_{40}$, and $F_{\mathrm{LIM}} = F_{20.}$

The values for *M* used in the HCRs (and that used to calculate *F*) are the 'assumed *M*' values as detailed in Table 8.1 and Table 8.2.

Empirical investigation suggests that the assumption of $F_{MSY} \approx M$ is too high for blue eye (Figure 8.3). Walters and Martell (2004) suggest $F_{MSY} = cM$, with values for *c* including 0.8 in general, but 0.6 or less for commonly fished species (Walters and Martell, 2004). For U.S. west coast species, the average is *c* = 0.62 (MacCall, 2007), and so 0.5*M* was chosen for the analyses here to adopt a conservative estimate. F_{40} and F_{20} are defined as the fishing mortality rates which will result in (under equilibrium age structure) spawning biomasses of 40% and 20% of unfished spawning biomass. Calculation of these values therefore depends on the values for the parameters of the stock-recruitment relationship (assumed to follow a Beverton-Holt relationship), and requires estimates of the steepness parameter *h* (Mace and Doonan 1988) and information on growth and fecundity in addition to an estimate of *M*. In contrast, versions 1) and 2) of the Tier 3 HCR only relies on an estimate of *M* to calculate the RBC given F_{CUR}.

Calculation of the RBC under version 1) is achieved by applying the appropriate multiplier from Figure 8.2b to C_{CUR}, defined as the average catch over the four years prior to the year for which an RBC is needed. Under versions 2) and 3), the RBC is calculated by first obtaining F_{RBC} given Figure 8.2c, and applying the following formula:

$$RBC = \frac{C_{CUR}(1 - e^{-F_{RBC}})}{(1 - e^{-F_{CUR}})} \tag{6}$$

Note that equation (6) allows for greater increases in catch than does the old Tier 3 HCR (maximum increase of 20% above the recent average, Figure 8.2b), if F_{CUR} is estimated to be below the target level. An additional restriction was placed on the HCRs in that the maximum allowable change in the catch (RBC) from one year to the next was 50%.

Comparison of Tier 3 performance with that expected under Tier 1 is achieved by calculating the projected spawning stock biomass trajectories for a set of the scenarios in Table 8.1 under the Tier 1 HCR. This involved generating additional data (CPUE and length composition), and applying Stock Synthesis 2 (Methot 2007) to this data set each year of the projection period. Results for Tier 1 HCR are simply shown for comparison purposes because the focus of this paper is the Tier 3 HCRs.

8.3.3.3 Adjustments for fleet/spatial structure

The addition of uncertainty in spatial structure through the scenarios in Table 8.2 presents additional challenges when implementing the Tier 3 HCRs, because of the need for decisions regarding what combinations of fleet and region are to provide the parameters used when calculating the RBC, and how to choose among potentially differing estimates of the fishing mortality rate. Currently, application of the Tier 3 HCR does not account for regional complexity, with analyses being conducted on aggregated data from all regions for the gear type that takes the majority of the current catch. The scenarios in Table 8.2 were crossed with the following estimation combinations to investigate how performance given spatial structure changes with assumptions as to how the data are used:

1. spatial complexity is ignored, and a single analysis (CR, MYEF) is conducted using the pooled data from both regions (added together as samples are allocated by region with respect to catch),
2. the data from the two regions are analysed separately to obtain two estimates of current fishing mortality / stock status; these estimates are then weighted by the inverse of the variance estimates to obtain the RBC.
3. Separate analyses as in 2*,* but the maximum estimated F is used to calculate the RBC.

The variance estimates of F_{CUR} are (primarily) driven by sample size, and so option 2 effectively weights the regional estimates by the current catch allocation. Option 3. is potentially the more conservative option as it bases the RBC on the parameters for the region with the highest estimated mortality rate. However, this option can be expected to be more prone to inaccurate estimates of F that might result from a low regional sample size.

8.3.4 Performance measures

Performance of the various HCRs is evaluated using a set of summary statistics:

1. The median (over simulations) spawning stock status at the end of the projection period (final spawning biomass as a fraction of unfished spawning biomass, B_0).

2. The inter-quartile range of the spawning stock status (relative to B_0) at the end of the projection period.

3. The probability of the spawning biomass being below the Tier 1 limit reference point (B_{20}) at the end of the projection period.

4. The probability of the spawning biomass going below the Tier 1 limit reference point (B_{20}) at some point during the projection period.

5. The median of the average annual catch during the projection period.

6. The median coefficient of variation of the annual catches during the projection period.

Performance measures 1-4 relate to the effect of implementing the HCR on spawning biomass, while measures 5-6 provide information regarding the catch performance of the HCR.

8.4 Results

The results of the simulations are displayed in the form of biplots (*e.g.* Figure 8.4), with each point representing a scenario, and the location of points corresponding to the values obtained for the relevant performance measures. Plotting characters refer to the scenario numbers as per Table 8.1 and Table 8.2. Boxplots of the performance metrics across scenarios are also used to compare among the different HCRs and methods of obtaining *F* estimates. Simple linear models are also used to evaluate the contribution of the different scenario specifications to the values obtained for the performance metrics. The scenario characteristics as defined in Table 8.1 and 8.2, the catch curve estimation type, the choice of HCR, and (for the spatial analyses) the method for obtaining a single *F* estimate, were included as factors in the linear predictors of these models, fitted separately for the six performance metrics. Interaction terms involving some of the variables were also considered.

8.4.1 Non-spatial analyses

The general performance of the old Tier 3 HCR (estimation using CR $F_{\mathrm{TARG}}=M$) is compared with that of the new Tier 3 HCR (using MYEF with $F_{\mathrm{TARG}}=F_{40}$) in Figure 8.4. Many of the scenarios are well below the Tier 1 target and limit biomass reference points (40 and 20% of unfished spawning biomass) at the end of the projection period for the old Tier 3 HCR (red points), with high probabilities of going below B_{20} during the projection period. While the performance of the new HCR varies considerably among scenarios (Figure 8.4, blue points), the projections under this HCR lead to lower catches, and are generally more optimistic regarding stock status (Figure 8.4). Comparison of performance for three scenarios suggests that, for these scenarios at least, the Tier 3 HCRs are not precautionary compared to the Tier 1 HCR, because the Tier 1 HCR leads to higher relative biomass and, for two of the three scenarios, to lower, less variable annual catches (Figure 8.5). An accounting for the differences in performance among scenarios for the non-spatial analyses reveals that the changes in performance with respect to the final stock status, the risk of going below the limit reference point, and the magnitude in catch levels are driven mainly by the shift of estimation method from CR to MYEF, rather than the different HCR (Table 8.3). However, adopting $F_{\mathrm{TARG}}=F_{40}$ and $F_{\mathrm{LIM}}=F_{20}$ did result in an increase in the median of the final relative spawning biomass. The difference between the two estimation methods can be seen clearly in Figure 8.6, which shows the distribution of the values for the performance measures across the different scenarios when applying the new Tier 3 HCR with $F_{\mathrm{TARG}}=F_{40}$ and $F_{\mathrm{LIM}}=F_{20}$.

The difference in performance observed under MYEF appears to be somewhat determined by the choice of reference points however, with application of the new Tier 3 HCR using a $F_{\mathrm{TARG}}=0.5M$ and $F_{\mathrm{LIM}}=M$ resulting in pretty much the same performance irrespective of whether estimation of *F* is conducted using CR or MYEF (Table 8.3, ‘MYEF*(new HCR, Ftarg=0.5M, Flim=M) interaction’). The HCR based on the spawner-recruit reference points ($F_{\mathrm{TARG}}= F_{40}$ and $F_{\mathrm{LIM}}= F_{20}$) leads to higher values for relative spawning biomass, lower probabilities of dropping below the limit, and lower, less variable annual catches than the $F_{\mathrm{TARG}}= 0.5M$ version of the Tier 3 HCR (Figure 8.7).

Variability in the values obtained for the performance measures was not solely restricted to the choice of estimation method and HCR type. Scenarios with low steepness (h=0.2) resulted in lower final biomass, increased probability of dropping below B_{20}, and increased variability in the annual catches (Table 8.3). Likewise, more productive stocks (h=1.0) resulted in higher final biomass levels and a lower probability of being below the limit reference point at the end of the projection period. Scenarios in which the initial (prior to implementation of the HCR) relative stock size was low resulted in lower levels of catch (albeit more variable, also, higher initial stock size gave higher catches), but an increase in the final relative stock size and decrease in the probability of being below the limit at the end of the projection. In terms of magnitude, the factor with the largest impact on the biomass related performance measures was whether the assumed value for M was correct or not. Assumed values for M less than the true value resulted in more optimistic outcomes in terms of stock status, with higher final biomasses, and lower probabilities of dropping below the limit reference point (Table 8.3, 'assumed M < true M'). Average catches were also lower. Conversely, assuming a value for M greater than the true value results in an under-estimation of F, and consequently, outcomes with lower final relative biomass and higher risk of dropping below the limit (Table 8.3, 'assumed M > true M').

8.4.2 Spatial analyses

The results for the 'spatial' two-region scenarios for the F_{TARG}=F_{40} version of the new Tier 3 HCR are shown in Figures 8.8 and 8.9, with plots for the three different decision rules as to how to deal with the spatial data. Spatial disaggregation of the data appears to result in wider intervals for the spawning biomass trajectories. For scenarios when the stock is initially at low levels, a decrease in the connectivity of the regions results in tighter intervals of spawning biomass (and lower probabilities of going below B_{20}), presumably because the decrease in movement between regions increases the signal in the data, as the initially exploited region must be driven to very low levels before implementation of the harvest strategies. The initial status of the stock appears to be as important in determining the values for the performance measures than the connectivity among the regions (scenarios 1, 2, and 5 appear together in Figure 8.8, as do scenarios 3 and 6, and 4 and 7). This is also evident from the similarity of the magnitude of the coefficients for these factors obtained from fitting linear models to the performance measures (Table 8.4).

Scenarios with spatial structure in the population dynamics (intermediate or limited mixing) resulted in lower final relative spawning biomasses, increased risk of going below the B_{20} limit, and higher catches (Table 8.4, 'intermediate mixing' and 'limited mixing' than the two-region model with no spatial structure (full mixing). Interestingly, the magnitude of the coefficients for the intermediate and limited mixing scenarios given a particular performance measure were almost the same, such that there was no additional change in performance moving from the intermediate level (in which the average mixing rate is 20%) to the limited level (5%). The age structure of fish mixing between regions appeared less important in driving performance, although the scenario where movement is limited to adults only resulted in a lower probability of dropping below the limit during projection, and less variable catches (Table 8.4, 'adults move only'). Whether selectivity was dome-shaped, or modelled differently by region was a major determinant of performance, with the amount of dome-shaped selectivity (in 1 region or 2) leading to higher final relative spawning biomasses and lower probabilities of going below the B_{20} limit (Table 8.4, 'Different selectivities by region' and 'Selectivity dome-shaped in both regions'). Lower catches resulted from selectivity being dome-shaped in both regions (Table 8.4, 'Selectivity dome-shaped in both regions').

Analysing the data by region and then choosing the maximum estimated F to set the RBC (Table 8.4, 'choose highest regional F') unsurprisingly led to the most optimistic results regarding spawning stock biomass (Figure 8.8c and Figure 8.9a), and the probability of going below the limit (Figure 8.9c and 8.9d). However, this choice also results in tighter intervals for the biomass (Figure 8.9b). The relative performance of the different scenarios is very similar when data from both regions are analysed together and when the regional estimates are weighted by their variance (Figures 8.8a and 8.8b, Figure 8.9). An exception is when movement between regions is limited to pre-recruits (Figure 8.8, scenario 8). In this instance, aggregating the data and conducting a single analysis appears to be a much more conservative way to determine RBCs, because the relative biomass is well below B_{20} when regional estimates of F are weighted by the inverses of their variances. Interestingly, there was little evidence for changes in performance as a result of interactions between the parameter values for the different spatial scenarios and the manner in which the annual F estimates were obtained. Also, the effect of the values for the spatial parameters and method for obtaining annual F was similar despite the reference points used in the HCR (Table 8.4).

Although the results suggest that reasonable performance can be achieved using Tier 3 given an appropriate choice of reference points and decision rule for dealing with space, Figure 8.10 suggests that performance of these HCRs is not really satisfactory, because higher relative spawning biomass may be a result of closing the fishery for a number of years following a series of successive increases (or decreases) in the RBC. The trajectories in Figure 8.10 suggest, as inferred above, that for a species like blue eye, the catch curve is fairly unresponsive in detecting changes in F. This can be expected for a long-lived species, where there would presumably be a lot of inertia in the age structure. As such, the estimates of F obtained may not be reflecting the current fishing mortality rate.

8.5 Discussion

Management based on rapid stock assessment is attractive for fisheries where there are limited data, and methods for this, such as catch curve analysis, are well-established (albeit also with well-established shortcomings related to unrealistic assumptions). The MSE testing of the Tier 3 HCRs presented here suggests that it is indeed possible to formulate HCRs based on the results of catch curves that address management objectives, despite some of these shortcomings. However, it is also clear that implementing the Tier 3 HCRs can result in undesirable behaviour, and that outcomes are sensitive to many of the known shortcomings of the estimation methods.

Assessing performance of the HCRs through their ability to conserve stock biomass may not be an appropriate choice – the spawning biomass trajectories in Figure 8.10 suggest that satisfactory outcomes for a scenario (for example, a low probability of being overfished) can be achieved with undesirable system properties (such as complete closure of the fishery following a ratcheting increase in catch). Klaer *et al*. (this volume, Section 7) and Smith *et al.* (2008) address issues related to the unresponsiveness and ratcheting behaviour of the Tier 3 HCR, the former of which is likely to be more pronounced for longer-lived species as the catch curve does not relate to current conditions. Unresponsiveness in the Tier 3 HCR is also a consequence of restrictions on the magnitude of permitted changes in management actions (the RBC is only allowed to change by 50% in a given year even if the estimate of F changes dramatically). The results suggest that such a behaviour appears to favour stocks that are initially at low levels prior to implementation of the HCRs over stocks that are at or above management targets, as lower values for the initial depletion led to higher final relative spawning biomasses (Tables 8.3 and 8.4).

Differences in the performance of the Tier 3 HCRs appeared to be related to both the values chosen for the reference points and the method used for estimation, with MYEF outperforming CR (Figure 8.6). Tier 3 HCRs that used the spawner-recruit based reference points resulted in the best perceived performance. However, for the spatial analyses performance of the same rule using a target of $0.5M$ was generally only marginally different even though the data requirements were markedly less. As estimates of M already tend to be uncertain (with highly sensitive results to getting the value 'wrong'), including additional uncertainty associated with estimating the compensation of the spawner-recruit curve (steepness) is perhaps unnecessary. However, Figure 8.7 clearly shows that $0.5M$ is not necessarily an appropriate target rate of fishing mortality (when compared with Tier 1 reference points) for all instances (*e.g.* when steepness is low). Note that even 'poorly' performing HCRs require an estimate of M, typically derived from longevity and growth information (*e.g.* Hoenig 1983, Jensen 1996). While such information generally tends to be available, the nature of a 'data-poor' fishery may mean that these estimates are uncertain.

The results clearly demonstrate the need for careful application of common sense when applying methods such as the Tier 3 HCRs. For example, the implications of dome-shaped selectivity are that mortality is over-estimated, leading to specification of lower catches, but it would be somewhat foolish to use this conservation of stock biomass as a reason for implementation in an instance when selectivity is known to be dome-shaped. Having an accurate estimate for M appears to be very important for HCR performance, with scenarios where the chosen value for M is higher than the true value resulting in high probabilities of dropping below the limit reference point. Similarly, scenarios for which the assumed value for M is lower than the true value are among the most conservative in terms of biomass relative to the unfished state at the end of the projection. These results are unsurprising, as the estimate of F is clearly negatively correlated with M. The impact of selectivity being dome-shaped is similar to that of under-estimating M, in that F is over-estimated (because the estimators assume selectivity to be asymptotic), resulting in lower RBCs and higher spawning stock biomasses.

While the analyses here focused on the use of age data, it should be noted that the same estimation methods and HCRs can be applied given length frequency data, and estimates of growth, with expected further additional uncertainty in the simulation outcomes. Although the analyses tested the impact of collecting data from multiple regions, and in an instance where the regional allocation of catches was changing, the data were generated in proportion to the catch, with no over-dispersion or bias in the sample other than the stochasticity imposed on the data through sample size and multinomial sampling. The low sampling effort present in the actual blue eye data set, coupled with seasonal differences in availability means that the age and length data are not representative of the fishery. While the analyses investigating the impacts of region-specific selectivity go some way to addressing these questions, it is likely that incorporation of bias and non-representative sampling into the MSE framework will further degrade HCR performance.

Most fisheries and also fished populations exhibit spatial structure, creating spatial heterogeneity in realized exploitation rates and biomass trends, depending on the level of mixing in the stock. However, most management options lack the ability (or rather, the infrastructure) to specify the TAC at the level of this spatial structuring. HCRs that show robustness to spatial differences are therefore desirable. Disaggregating the data by fleet and region, analyzing these data separately, and then choosing the maximum estimate of F as the value to determine the RBC appears to produce the most conservative results irrespective of the true nature of stock connectivity and fishery behaviour. However, application of this version of the HCR does lead to perhaps unnecessary lower catches when the connectivity of the stock between regions is high. This method would be inappropriate if the maximum F estimate came from a sector of the fishery which was a minor component of the catch, as it would be more likely that such an F estimate would be both uncertain and not representative of the overall exploitation rate. Weighting fleet and regional estimates of F by their variance accommodates this if the data are collected proportionally with the catch. If not, then additional rules to determine how to proceed will be needed. Spatial disaggregation of data that already has low sample size will result in more variable estimates of mortality than might be expected given population dynamics, particularly when constructing annual catch curves.

The use of an MSE approach enables the testing of the control rules used to set catches, by evaluating performance given the known true state of the system. Such a framework can be used to identify strategies that perform poorly in the fairly well-ordered structure of the simulation. Perhaps more importantly, the relative performance of different strategies can be compared. The adoption of a precautionary approach to management of exploited marine resources is increasingly common, and it is clear that testing of these approaches is necessary in order to understand whether these rules can be expected to act as intended. The analyses described focus on parameterizations of the operating model which mimic blue eye trevalla, but the system can be extended to examine the performance of the Tier framework given different life histories. Indeed, a natural avenue for further extension of these analyses would be to examine whether the relative performance of the various Tier 3 control rules is dependent on the life-history of the species of interest, and whether the various HCRs need to be modified with life history.

While improved performance and conservation of stock biomass is achieved under the Tier 3 HCR, the variability around the stock biomass, and in catches under this HCR are greater than that expected for a more data-rich scenario (e.g. integrated assessment using Stock Synthesis). This is to be expected; data-poor methods should in principle estimate quantities of interest with greater uncertainty than those for which more data available.

While the Tier 3 HCR based on reference points such as F_{40} and F_{20} is more equivalent to the Tier 1 HCR, care should be taken regarding the ability to estimate F sufficiently well enough to be able to apply this rule successfully. Application of these reference points under the Tier 3 HCR requires an estimate of the value for steepness, which cannot be obtained during the analysis and needs to be assumed. However, this is not much different than data-rich scenarios in the SESSF, as estimation of steepness in stock assessments for this fishery is uncommon.

The desired F to be estimated is the current rate of fishing mortality, whereas the annual catch curve integrates over the fishing mortality rates experienced by the stock for the length of the age structure, which may either not correspond well with recent trends in F, or, if data are noisy, may impede estimation of F. Poor ability to estimate F may mean a lack of ability to truly discriminate between the reference points involved in the HCR. This may be particularly important for long-lived, late-maturing species where F_{40} and F_{20} are similar. Successful implementation of a harvest control rule relies on being able to readily distinguish between values for stock indicators that result in changes in management action. Approximate confidence intervals for the current rate of fishing mortality on blue eye trevalla based on application of the MYEF estimator to data from the auto longline fishery are wider than the range of Fs over which changes in management actions are indicated given the HCR (Fay 2008). Indeed, initial MSE testing of methods for estimating F based on age structure suggested that estimation ability was such that the choice of whether to increase or decrease catch based on current F relative to the target was only made correctly a little over half of the time.

Precaution with respect to Tier 1 is not explicitly built into the Tier 3 HCR at present, particularly as the quantities for F_{TARG} and F_{LIM} are the same as for Tier 1 (even though their estimates may be different). Conservation of stock biomass under the Tier 3 HCR arises from the behaviour of the rules. Additional measures to modify the Tier 3 HCR such that there is equivalency of risk with the Tier 1 HCR could involve the choice of alternative reference points (*e.g.* $F_{TARG} = F_{50}$), the application of a discount to the RBC for being at a less data-rich tier level (Smith *et al*. 2008), or perhaps application of current HCRs with a more conservative value for F_{CUR}, based on some percentile of the confidence interval of the estimate. Further simulation testing to address the efficacy of such approaches is clearly warranted, and is a suitable candidate for future work.

8.6 References

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Table 8.1: Parameterisation of the operating model for scenarios under the 1 region / 1 fleet model. h is the steepness parameter of the spawner-recruit relationship, Bcurr/B0 is the spawning biomass relative to unfished prior to implementation of the HCRs, and n_A is the annual sample size for the age composition data.

#	Scenario	Type of selectivity curve	true M	h	B_{curr}/B_0	n_A	assumed M
1	base-case	asymptotic	0.08	0.75	0.40	100	0.08
2		asymptotic	0.08	0.75	0.20	100	0.08
3		asymptotic	0.08	0.75	0.75	100	0.08
4		asymptotic	0.12	0.75	0.40	100	0.12
5		asymptotic	0.12	0.75	0.20	100	0.12
6		asymptotic	0.12	0.75	0.75	100	0.12
7		asymptotic	0.18	0.75	0.40	100	0.18
8		asymptotic	0.18	0.75	0.20	100	0.18
9		asymptotic	0.18	0.75	0.75	100	0.18
10	low steepness	asymptotic	0.08	0.20	0.40	100	0.08
11		asymptotic	0.08	0.20	0.20	100	0.08
12		asymptotic	0.08	0.20	0.75	100	0.08
13	high steepness	asymptotic	0.08	1.00	0.40	100	0.08
14		asymptotic	0.08	1.00	0.20	100	0.08
15		asymptotic	0.08	1.00	0.75	100	0.08
16	dome-shaped selectivity	dome-shaped	0.08	0.75	0.40	100	0.08
17		dome-shaped	0.08	0.75	0.20	100	0.08
18		dome-shaped	0.08	0.75	0.75	100	0.08
19	estimate M wrong	asymptotic	0.08	0.75	0.40	100	0.05
20		asymptotic	0.08	0.75	0.40	100	0.12
21		asymptotic	0.12	0.75	0.40	100	0.08
22		asymptotic	0.12	0.75	0.40	100	0.18

Table 8.2 Parameterisation of the operating model for the spatial scenarios with 2 regions and movement. ‘Full’ connectivity between regions implies single stock dynamics, ‘intermediate’ has 20% movement rate from one region to the other, while the ‘limited’ scenario only has a 5% movement rate. The movement patterns are as shown in Figure 8.1.

#	Scenario	Type of selectivity curve		true M	h	Bcurr/B0	n_A	assumed M	connectivity	movement pattern
		region 1	region 2							
	"east / west slope"									
1	base-case, full mixing	asymptotic	asymptotic	0.08	0.75	0.40	100	0.08	full	constant
2	intermediate mixing	asymptotic	asymptotic	0.08	0.75	0.40	100	0.08	intermediate	constant
3		asymptotic	asymptotic	0.08	0.75	0.20	100	0.08	intermediate	constant
4		asymptotic	asymptotic	0.08	0.75	0.75	100	0.08	intermediate	constant
5	limited connectivity	asymptotic	asymptotic	0.08	0.75	0.40	100	0.08	limited	constant
6		asymptotic	asymptotic	0.08	0.75	0.20	100	0.08	limited	constant
7		asymptotic	asymptotic	0.08	0.75	0.75	100	0.08	limited	constant
8	movement declines with age	asymptotic	asymptotic	0.08	0.75	0.40	100	0.08	intermediate	pre-recruit
9	movement increases with age	asymptotic	asymptotic	0.08	0.75	0.40	100	0.08	intermediate	adult
10	dome-shaped selectivity	dome-shaped	dome-shaped	0.08	0.75	0.40	100	0.08	intermediate	constant
11	differing selectivities	asymptotic	dome-shaped	0.08	0.75	0.40	100	0.08	intermediate	constant

Table 8.3: Coefficients estimated from the linear models for the non-spatial analyses. Numbers shown represent terms that were assessed to be significant at the alpha = 0.05 level in a full model that included all terms listed.

Linear predictor term	Performance measure					
	$med(B_{final}/B_0)$	$IQR(B_{final}/B_0)$	$P(B_{final}<B_{lim})$	$P(B_{proj}<B_{lim})$	med(avg TAC)	med(CV TAC)
base intercept	0.15	0.32	0.60	0.63	532	
(CR, old HCR, InitDepl=0.4, *h* =0.75, asymptotic Sel)						
MYEF	0.20		-0.40	-0.40	-435	-1.36
new HCR, Ftarg=0.5M, Flim=M	0.09					1.34
new HCR, Ftarg=F40, Flim=F20, adjust for h	0.12					1.43
MYEF*(new HCR, Ftarg=0.5M, Flim=M) interaction	-0.31		0.51	0.49	526	1.67
assumed *M* > true *M*	-0.19	-0.21	0.36	0.25		1.48
assumed *M* < true *M*	0.51		-0.52	-0.61	-430	
InitDepl = 0.75					935	
InitDepl = 0.2	0.12		-0.15	0.21	-306	0.52
dome-shaped selectivity						
h = 1.0	0.13		-0.25			
h = 0.2	-0.19	-0.13	0.31	0.13		0.58

Table 8.4 : Coefficients estimated from the linear models for the spatial analyses using *MYEF*. Numbers shown represent terms that were assessed to be significant (p<0.05) in a full model that included all terms listed. Base intercept values were: new HCR with $F_{TARG}=0.5M$ and $F_{LIM}=M$, obtain a single F estimate with all data, full mixing between regions, movement constant with age, initial depletion = 0.4, and h=0.75.

	Performance measure					
Linear predictor term	med(B_{final}/B_0)	IQR(B_{final}/B_0)	P($B_{final}<B_{lim}$)	P($B_{proj}<B_{lim}$)	med(avg TAC)	med(CV TAC)
base intercept	0.37	0.63	0.38	0.54	331	0.87
new HCR, $F_{TARG}=F_{40}$, $F_{LIM}=F_{20}$, adjust for SRR					30	
wt regional F estimates by variance						
choose highest regional F	0.16		-0.17	-0.17	-108	0.06
InitDepl = 0.75	0.44		-0.50	0.17	-1,043	0.51
InitDepl = 0.2	0.36	0.27	-0.33	-0.20	-835	0.18
Different selectivities by region	0.17	-0.13	-0.15	-0.20	-96	0.12
Selectivity dome-shaped in both regions	0.48	0.18	-0.43	-0.31	-926	0.28
intermediate mixing	-0.36	-0.23	0.34	0.20	840	-0.16
limited mixing	-0.34	-0.27	0.32	0.20	800	-0.14
juveniles move only		-0.17				0.09
adults move only		0.18	0.14	-0.38	180	-0.31

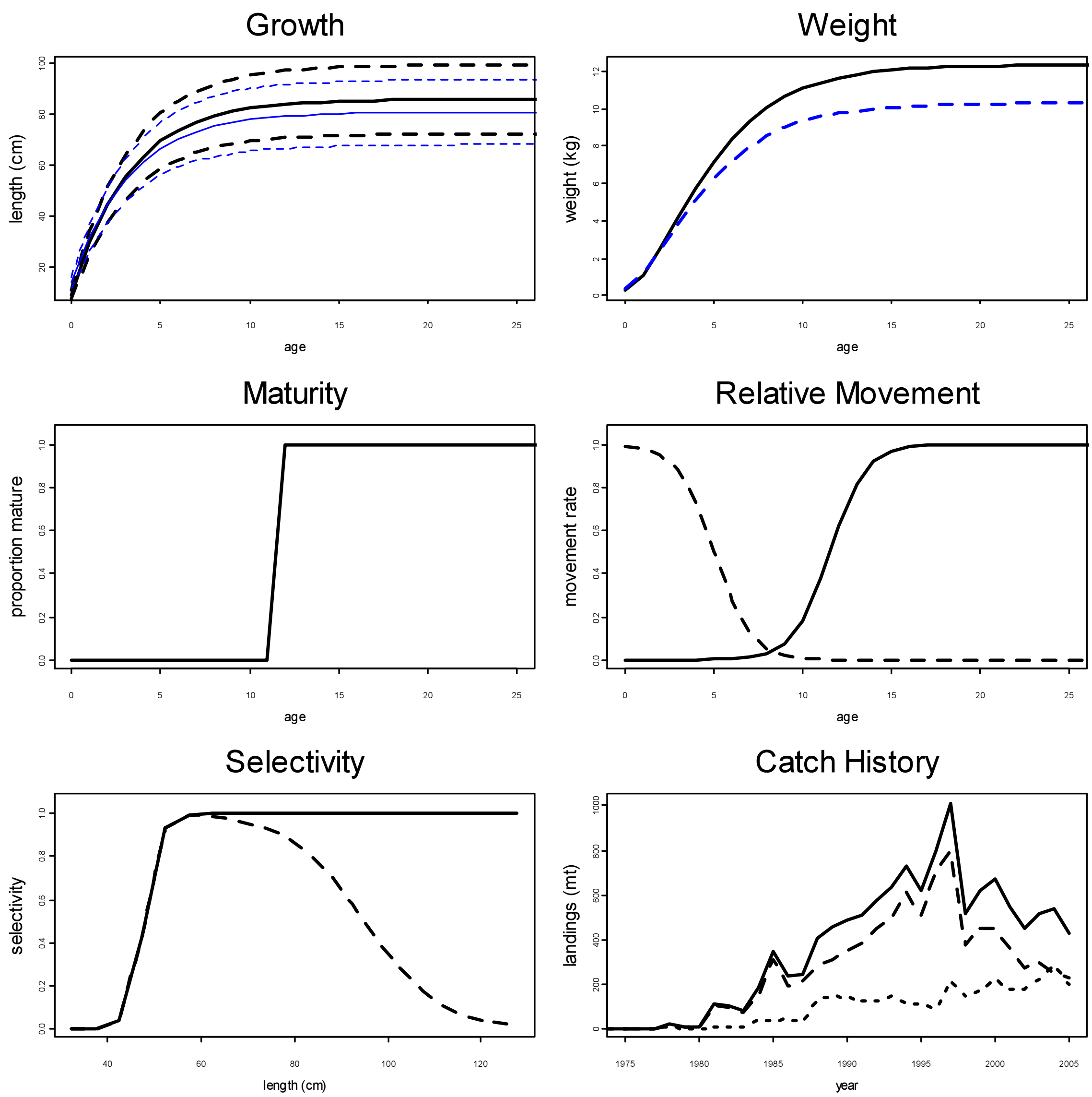

Figure 8.1: Biological and fishery-related parameters. Top row of panels: values for females shown in black lines, males in blue. Solid lines in Growth panel represent mean lengths at age, dashed lines correspond to the 95% intervals for the distribution of length at age. Relative Movement panel shows pattern of relative movement rate for (solid) adult-only movement, and (dashed) pre-recruit movement. Selectivity panel shows both asymptotic (solid line) and dome-shaped (dashed line) patterns with length. Catch history panel indicates both total catches (solid line) and regional catch histories used in the spatial analyses, with dashed line indicating catches from region 1, and dotted line indicating the catch from region 2.

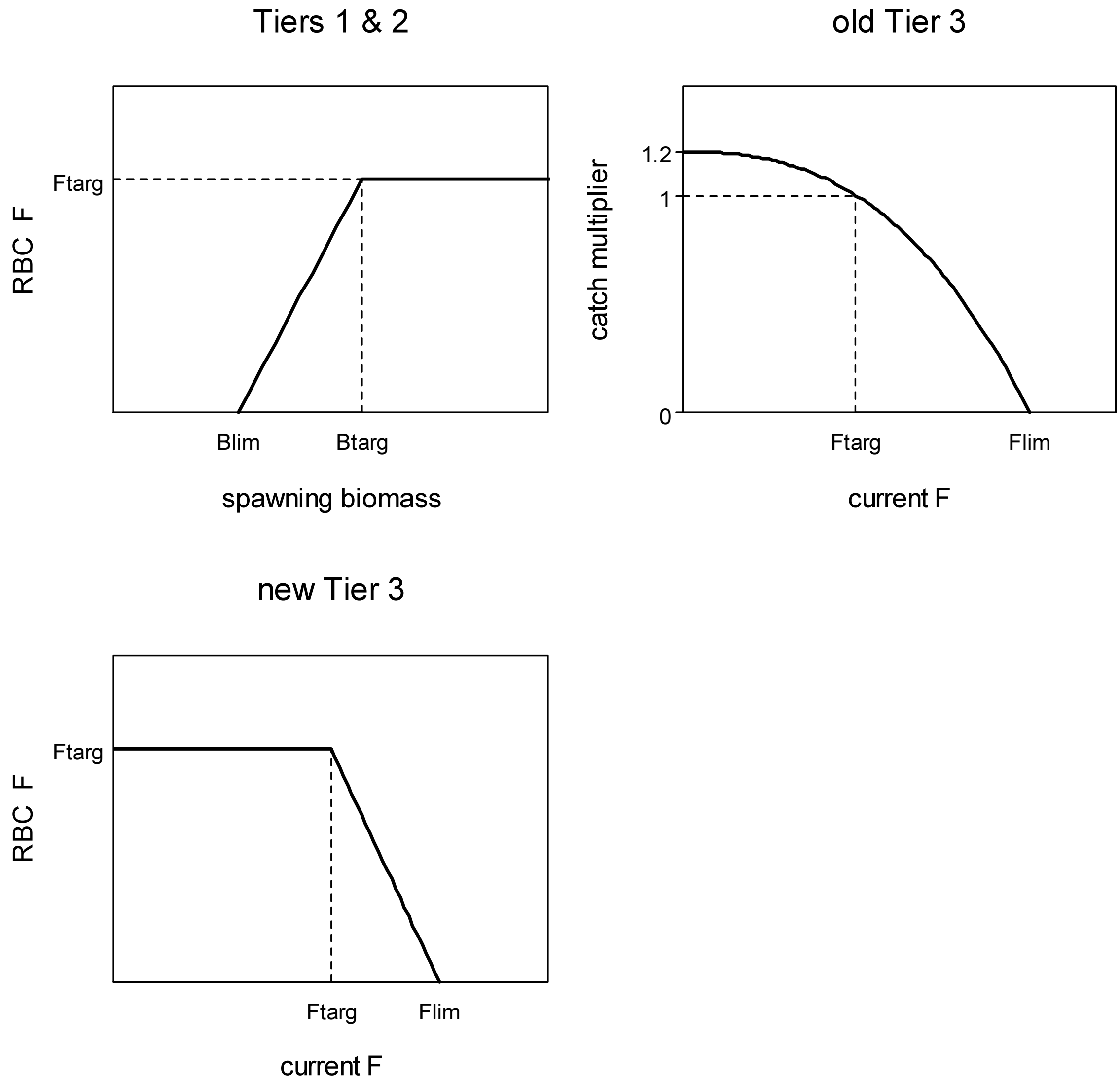

Figure 8.2: Forms for the Harvest Control Rules (HCRs) for Tiers 1 and 2 (top-left panel), old Tier 3 (top-right panel), and new Tier 3 (bottom-left panel). The estimated value for the stock indicator on the *x* axis is used to derive either the RBC rate of fishing mortality (Tier 1 and new Tier 3), or the multiplier to the current catch (old Tier 3).

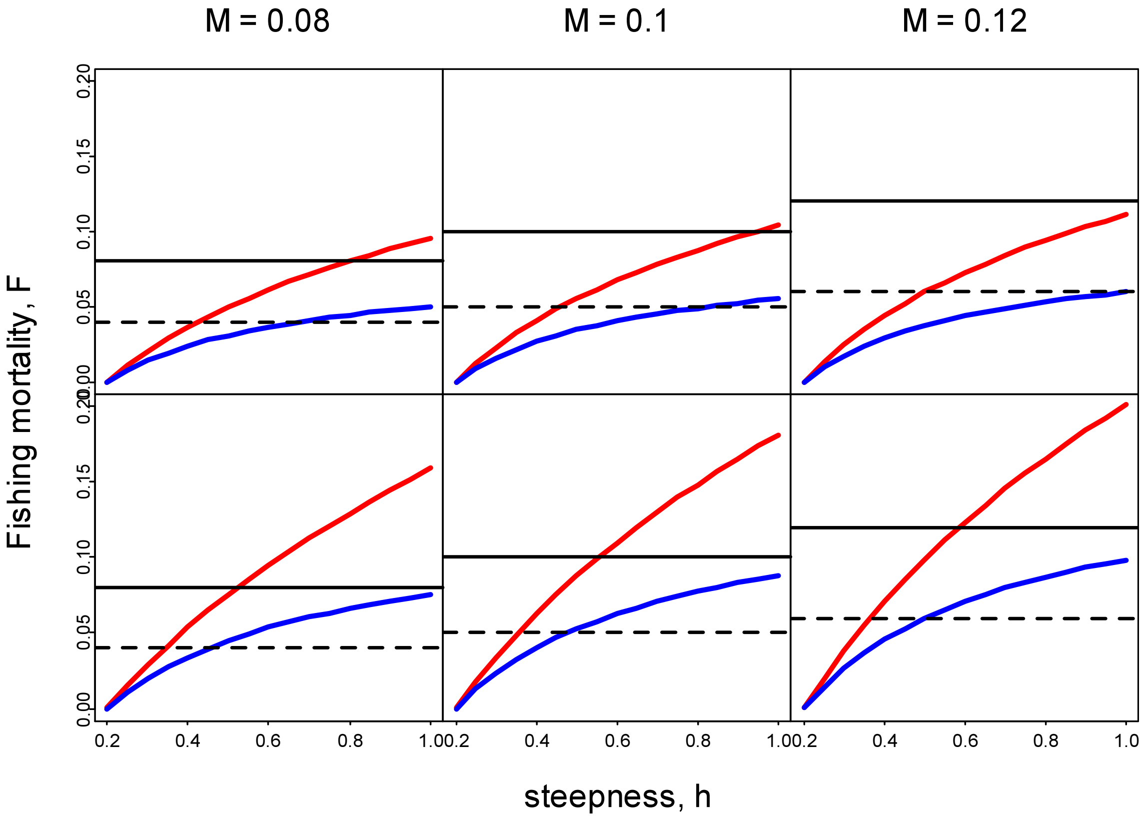

Figure 8.3: Changes in F_{40} (blue) and F_{20} (red) with *M,* and *h* relative to the value for *M* (solid black line) and 0.5*M* (dashed black line). Top row of panels corresponds to an age of maturity of 12 yrs, as used in the analyses presented here. The bottom row of panels shows the change for a maturity age of 6 yrs.

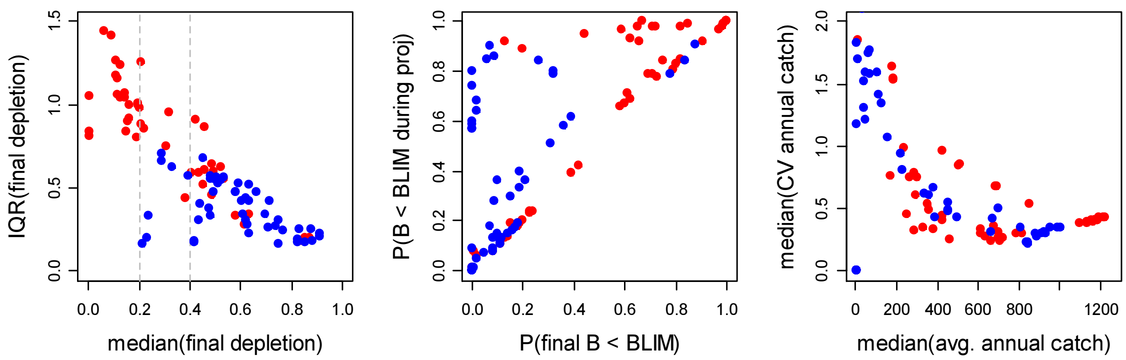

Figure 8.4: Comparing performance of the old Tier 3 HCR (red) with the new Tier 3 HCR (blue), using MYEF and $F_{\text{TARG}} = F_{40}$. Performance measures as detailed in text.

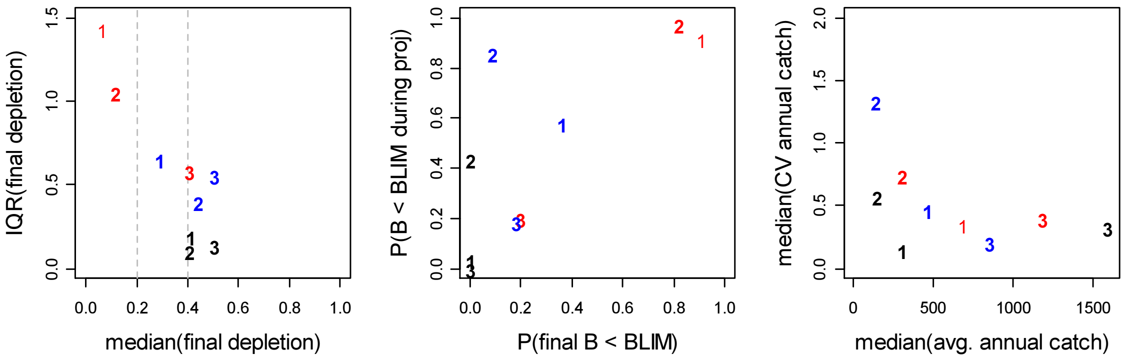

Figure 8.5: Comparing performance of old Tier 3 HCR (red), and new Tier 3 MYEF $F_{\mathrm{TARG}} = F_{40}$ (blue), with the Tier 1 HCR (black). Numbers correspond to scenarios listed in Table 8.1.

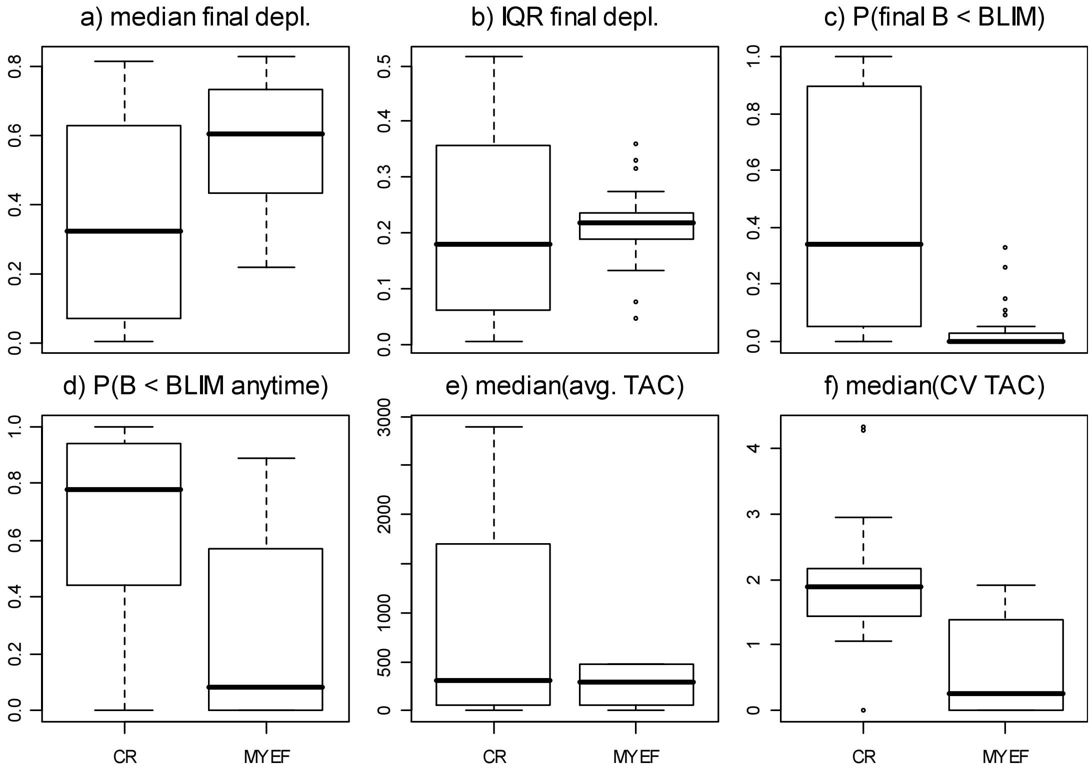

Figure 8.6: Distribution of the values for the performance measures across scenarios by estimation method for the non-spatial analyses when the new Tier 3 HCR is applied with $F_{\mathrm{TARG}}=F_{40}$ and $F_{\mathrm{LIM}}=F_{20}$.

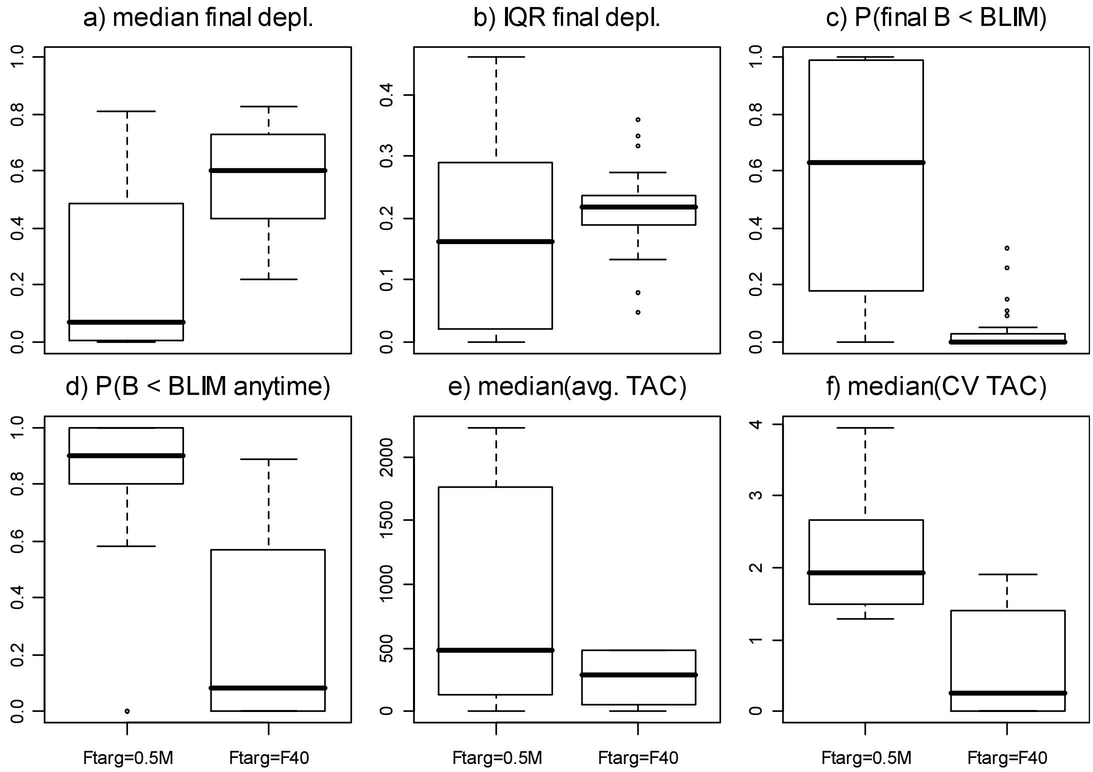

Figure 8.7: Distributions of the performance measures across scenarios given application of the new Tier 3 HCR with MYEF estimation, for two sets of reference points.

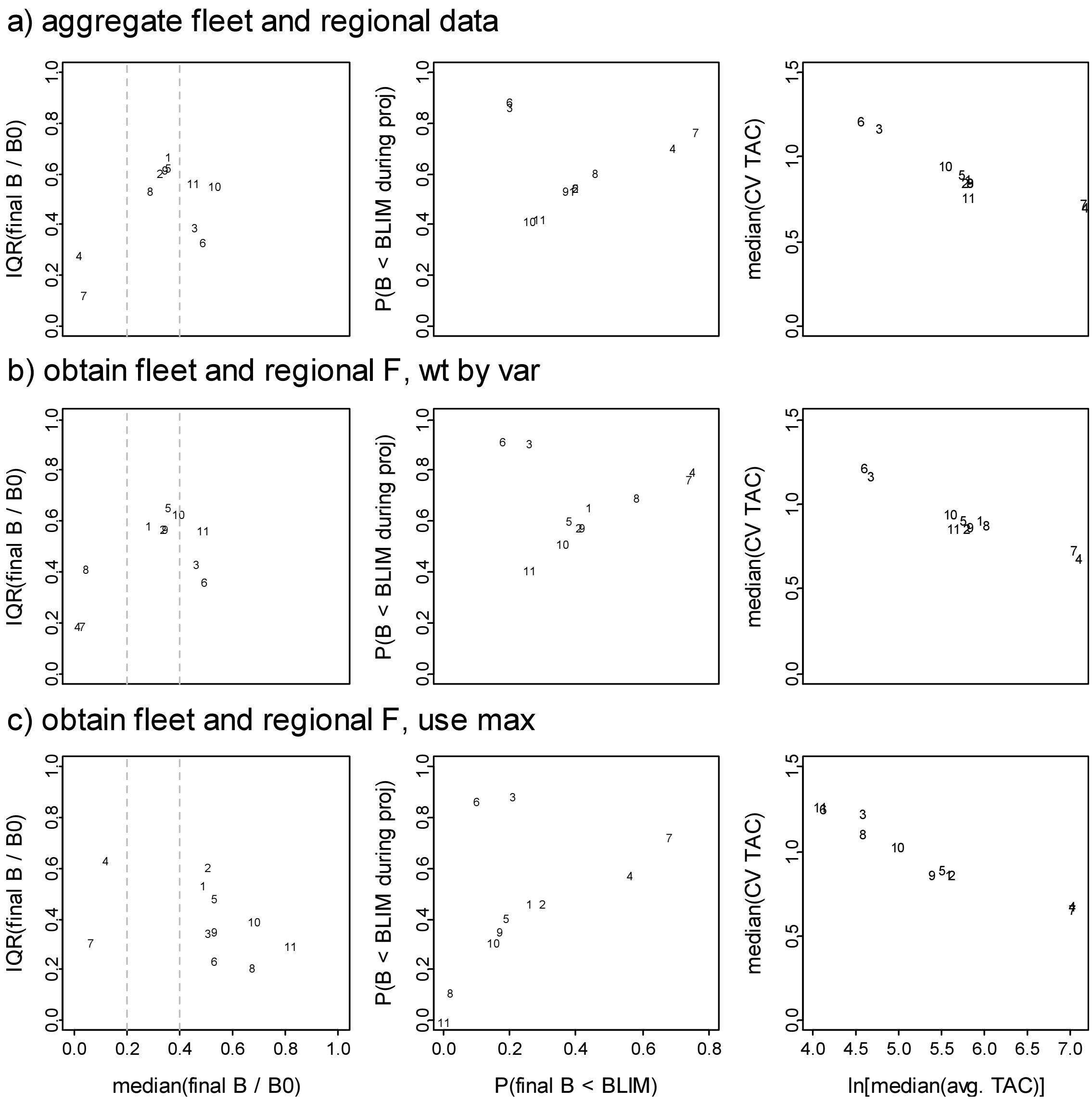

Figure 8.8: Impact of choice of F estimate on performance of spatial analyses in Table 8.2 governed by the new Tier 3 HCR with $F_{\mathrm{TARG}} = F_{40}$.

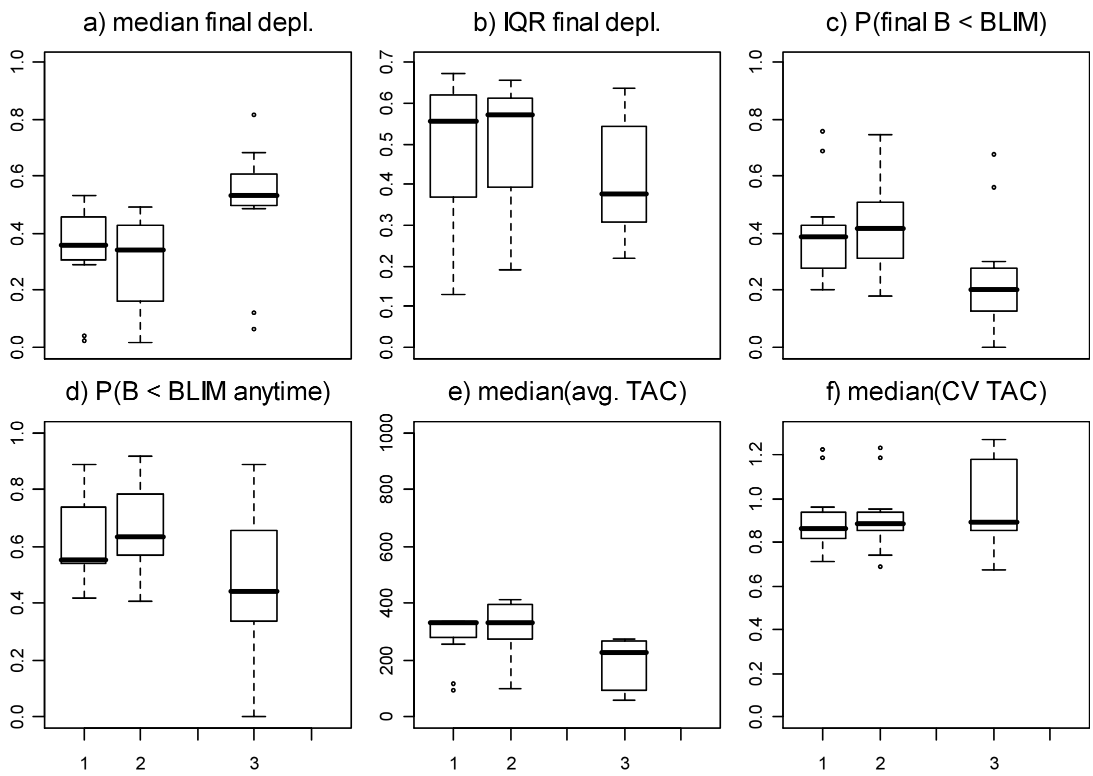

Figure 8.9: Distribution of the performance measures across scenarios for the spatial analyses, for the different ways of choosing the annual F estimate (1 = aggregate data, 2 = analyse by region, weight estimates by variance, 3 = analyse by region and choose the maximum estimated F). Estimation is using MYEF with the new Tier 3 HCR with $F_{TARG}= F_{40}$ and $F_{LIM}= F_{20}$.

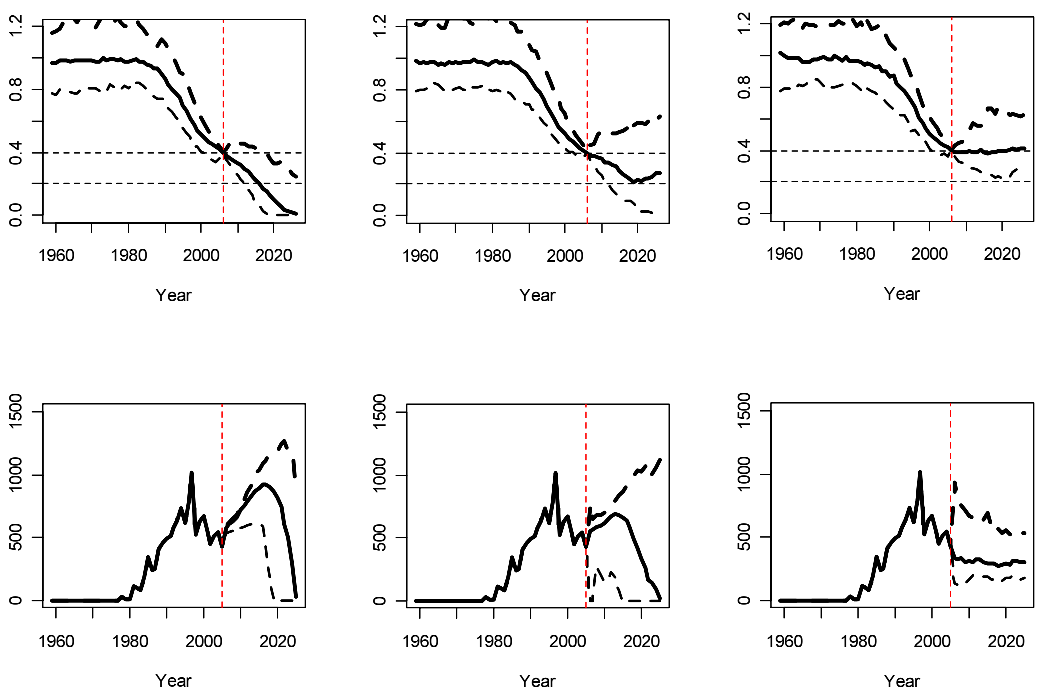

Figure 8.10: Spawning biomass and catch trajectories for scenario 1 of the non-spatial analyses for (left) old Tier 3 HCR, (centre) new Tier 3 HCR with MYEF and F_{TARG}=F_{40}, and (right) Tier 1.

9. Testing an alternative Tier 4 control rule and CPUE reference points for the SESSF

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9.1 Introduction

The original Tier 4 control rule determines an RBC by using the trend in recent CPUE to scale average recent catches. Two of the basic principles of the Tier 4 rule are that it should be more precautionary than the other Tier levels that have potentially greater quality and quantity of stock information, and that it should recover depleted stocks. Unfortunately, recent applications of the current formulation, both in practice and under management strategy evaluation simulations, have shown that it has not been consistent in these principles. The original Tier 4 rule is defined as,

$$RBC = (1 + \alpha m_{CPUE})\bar{C}$$

where

RBC	is the Recommended Biological Catch
m_{CPUE}	is the slope of the historical CPUE series over the past *c* years
$\bar{C}$	is the average harvest over the past *k* years
α	is a factor controlling the response to m_{CPUE}

The rule's inability to re-build the resource when it falls below a desired level is a direct consequence of there not being a target CPUE in the rule. In practice, the control rule has resulted in relatively static TAC recommendations, even under extreme resource states (Little *et al*. 2008a). Several alternative methods for setting TACs for species with minimal amounts of data have been proposed. However published methods, including Pope (1983) and Shephard (1991), require more information and might apply better to Tier 3. Campbell *et al*. (2007), and Prince *et al*. (submitted) have proposed a variation on the current Tier 4 rule that adds a CPUE target to be attained at a time in the future. The rule uses the angle of the recent CPUE trajectory combined with the angle needed to achieve the CPUE target and a timeframe to achieve it.

9.2 Alternative rule

We provide a different approach that is more in line with the existing Tier 1 and proposed Tier 3 harvest control rules (Klaer *et al*., this volume Section 7). The proposed Tier 4 control rule is of the form

$$RBC = \min\left[C_{\max}, C^* \max\left(0, \frac{\overline{CPUE} - CPUE_{\lim}}{CPUE_{\text{targ}} - CPUE_{\lim}}\right)\right]$$

where

$CPUE_{\text{targ}}$	is the target CPUE for the species
$CPUE_{\lim}$	is the limit CPUE for the species
$\overline{CPUE}$	is the average CPUE over the past *m* years
$C_{\max}$	is the maximum level of catch that the harvest control rule can select
C^*	is a catch target derived either from 1. recent historical catches (e.g. the average catch in the past 4 years), or 2. a period of historical catches that has been identified as a desirable target in terms of CPUE, catches and status of fishery (Little *et al.* 2008)

The form of the rule is shown in Figure 9.1. Because this linear form can result in large catches at high CPUE levels which could deplete the stock very quickly, a maximum catch level $C_{\max}$ is imposed when the CPUE is above the target level. The RBC is set to zero when the CPUE is below the limit.

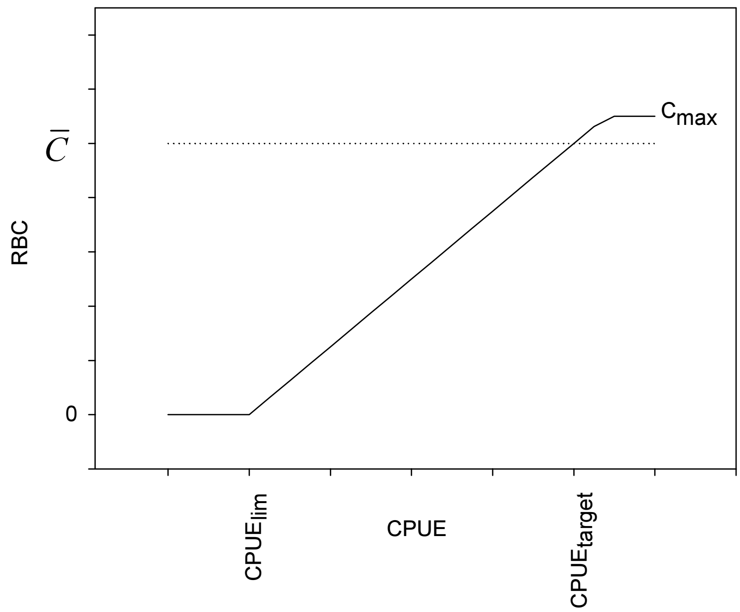

Figure 9.1 Graphical representation of the proposed alternative Tier 4 harvest control rule.

9.3 Selection of reference points

Little *et al.* (2008b) discuss how the target and limit CPUE might be selected for particular SESSF stocks. The requirement is to select CPUE reference points corresponding to B_{20} and B_{48} (limit and target reference points). The most straightforward way to do this is to assume that CPUE is proportional to stock abundance, an assumption that is made in most SESSF stock assessments. If this were true and CPUE not too "noisy", and the CPUE time series was available for the entire exploitation history of the fishery, then assuming that the stock was at unexploited equilibrium at the start of fishing, the initial CPUE level at the start of the time series would correspond to B_{100} (unexploited equilibrium, often referred to as B_0), and the other reference points would simply be the appropriate fractions of this level (eg 20% for B_{20}).

Where the full CPUE time series back to the start of fishing is not available, other options will need to be considered. The suggested method here is to assume a level of depletion at the start of the existing CPUE time series and to scale the existing CPUE series to that. We have assumed that the average CPUE from 1986 to 1995 corresponds to that which would be attained if the stock were at the level that provides the maximum economic yield, B_{MEY}. The limit CPUE is 40% of this CPUE.

Some species were not believed to have been fully exploited by 1986, so that the CPUE at 1986 was considered to be more representative of that at the beginning of exploitation. For such species, the average CPUE over 1986-1995 was halved to approximate the CPUE that might occur at B_{MEY}.

Some species also had relatively low catches that extended into the data period (1986-2007). For these species, the 10 year period over which the target CPUE was based started in the year where total catches exceeded 100 t.

For most species, a period from 1986 – 1995 was identified either as a period of relatively stable CPUEs and catches, or to capture a cycle of increasing CPUE and catches, followed by a decline. The mean CPUE during this period was calculated, and assuming that the fishery was fully exploited at this time, it was considered that this CPUE value corresponded to B_{MEY}, and was therefore a potential target CPUE. The limit CPUE was then taken to be 40% of the target CPUE, and assuming $B_{\mathrm{MEY}} = 0.48\,B_0$, the limit is $0.192\,B_0$, (~$0.2\,B_0$).

In summary, the three proposed rules for determining CPUE targets are:

1. the CPUE target for stocks fully exploited at or prior to 1986 is based on the average CPUE from 1986-1994
2. where fishing exploitation up to 1986 is thought to be minimal, the CPUE determined in step 1 is halved (to provide a catch rate proxy for B_{MEY})
3. where fishing exploitation after 1986 is low, the first year in which catches are above 100 t signifies the start of the 10 year period for which the CPUE target is calculated

9.4 Methods

Simulations are performed for the alternative Tier 4 harvest control rule using the SESSF management strategy evaluation (MSE) procedure. The biological component of the operating model is conditioned on the biology of flathead or school whiting. Different depletion levels at the start of the projection period in which the harvest control rule was implemented are considered. Variations on the proposed Tier 4 harvest control rule included different historical reference periods from which the CPUE and catch targets were derived, and $C_{\max}$, the maximum value that the control rule could take. We also perform scenarios where the target catch, C^*, is calculated annually based on the average catch of the most recent four years and where it is fixed at the average catch taken from the historical reference period. These are referred to as $\mathbf{T4C_{recent}}$ and $\mathbf{T4C_{historical}}$, respectively (Table 9.1).

Table 9.1. Scenarios used in MSE simulations representing SESSF species, the reference period in which the target CPUE and catch were derived, the method by which the target catch was calculated, the value of the maximum catch value above C^*, and the stock state (relative biomass) prior to the implementation of the harvest control rule. **Bold face** indicates factors that differ from Scenario 1.

Scenario	species	reference period	Target catch, C^*	C_{max}	B/B_0
1	flathead	1986-1995	last 4 yrs: $T4C_{recent}$	$1.25C^*$	Low
2	flathead	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*$	Low
3	flathead	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*$	**Target**
4	flathead	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*_g$	**High**
5	**whiting**	1986-1995	last 4 yrs: $T4C_{recent}$	$1.25\ C^*$	Low
6	**whiting**	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*$	Low
7	**whiting**	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*$	**Target**
8	**whiting**	1986-1995	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*_g$	**High**
9	**whiting**	**1998-2002**	**ref period: $\mathbf{T4C_{historical}}$**	$1.25\ C^*$	Low

9.5 Results and Discussion

The results from Scenario 1 (see Table 9.1) are shown in Figure 9.2. This scenario assumes (i) a flathead-like stock and catch history, (ii) a depletion at about 35% of B_0 at the beginning of the projection period, (iii) a target CPUE calculated as the average CPUE for the species from 1986 – 1995 (shaded upper panels), (iv) the control rule maximum is bounded by 125% of the target catch and (v) the harvest control rule is $\mathbf{T4C_{recent}}$, in which target catch, C^*, is calculated by obtaining the running average catch of the most recent 4 years. The control rule responded quickly and the RBC was reduced during the initial years of the projection period. In response the biomass increased, but beyond the desired biomass level. Even with increased RBCs toward the later part of the projection, the relative biomass remained close to $0.6B_0$, despite the reference period (from which the target CPUE was taken) corresponding to 0.48 B_0 (Figure 9.2 upper left panel). At the same time the control rule sent the biomass past the 0.48 B_0 reference level, the CPUE went past the target (Figure 9.2, bottom panels).

To understand the poor performance of this version of the harvest control rule, we performed a simulation under the $\mathbf{T4C_{historical}}$ harvest control rule, in which the target catch C^* is calculated based on the average annual catch from the historical reference period. Under this version of the control rule the reference level of 0.48 B_0 was achieved, and maintained (Figure 9.3). Catches initially decline in response to relatively low CPUE, but then increase to approximately their level during the historical reference period (Figure 9.3 upper right panel). However, although the catch rates approach the target CPUE, they never actually achieve it (Figure 9.3 bottom panels). The reason for this is the implicit assumption that the stock is at equilibrium during the reference period. The results in Figure 9.3 show that this is not the case.

If the state of the stock at the beginning of the projection period was at 0.48 B_0, and the stock state during the reference period was not at the target but above it, the harvest control rule will guide the fishery to a state corresponding roughly to that state specified by the reference period (Figure 9.4). Thus it is not surprising that if the state of the stock at the beginning of the projection period was above 0.48 B_0, then the harvest control rule will again guide the fishery to the catch rates experienced during the reference period - above the 0.48 B_0 reference level (Figure 9.5). Again in both these scenarios the stock was not at equilibrium during the reference period, and so the target CPUE specified by the reference period was not attained. Given its limited data requirements (catch and catch rates), these figures illustrate that the ability of the Tier 4 rule to achieve relative biomass targets is reliant upon the choice of CPUE targets to approximate those which may have corresponded to the stock being at the desired biomass levels. The true relative biomasses shown here are only known through the operating model.

The results for a school whiting–like species show similarly that when C^* is based on most recent catches experienced in the fishery, the reduction in RBC was too drastic, leading to biomass levels well above the 0.48 B_0 reference level (Figure 9.6). When C^* is based on the average catches during the historical reference period the control rule was better at guiding the biomass to the 0.48 B_0 reference level (Figure 9.7) but again overcompensated, mainly because the relative biomass during the reference period tended to be above the 0.48 B_0 reference level (Figure 9.7 upper left panel). Not surprisingly, when the initial biomass level at the start of the projection period was at or above the 0.48 B_0 reference level (Figure 9.8 and Figure 9.9) the control kept the fishery above the reference level, again because the biomass during the historical period over which the CPUE targets were derived was above the 0.48 B_0 reference level.

The effects of changes to the historical period are shown in Figure 9.10. This scenario showed the effect of having the reference period at a different stock level. In this case, the control rule was able to guide the biomass to the 0.48 B_0 reference level because the reference stock level was close to this value.

These results show that the $\mathbf{T4C_{historical}}$ harvest control rule tends to work better than the $\mathbf{T4C_{recent}}$, because there is no lag effect that would lead to either a “ratchet effect”, (e.g. a series of low catch years, as a result of some external factor such as market forces) or to oscillatory behaviour in the fishing dynamics (Little *et al.* 2008b). It is important to remember when considering these results of the Tier 4 harvest control rule, that the relationship between the management reference level of 0.48 B_0, which is an implicit management target, and the target CPUE, which is the explicit target, is not known. For example, we do not know if the target CPUE, to which the harvest control rule is aiming, will lead to desired relative biomasses that approximate 0.48 B_0. An estimation of B_0 requires a Tier 1 assessment. Therefore, it is imperative that a well considered CPUE target is developed, and set from a time period during which the fishery is thought to have been economically and biologically stable. This could be inferred to be B_{MEY}.

These results also stress the importance of selecting CPUE targets and the associated C^* appropriately. The **T4C$_{\text{historical}}$** harvest control rule will tend to guide the fishery to its state during the reference period, therefore selecting a reference period during which the fishery corresponded to the management goal is imperative. These results also stress the importance of setting C^* in order to achieve the CPUE target, because catches and CPUE may not have been in equilibrium during the reference period. This again underscores the importance of careful setting of the CPUE target, and reference periods for Tier 4 assessments.

9.6 References

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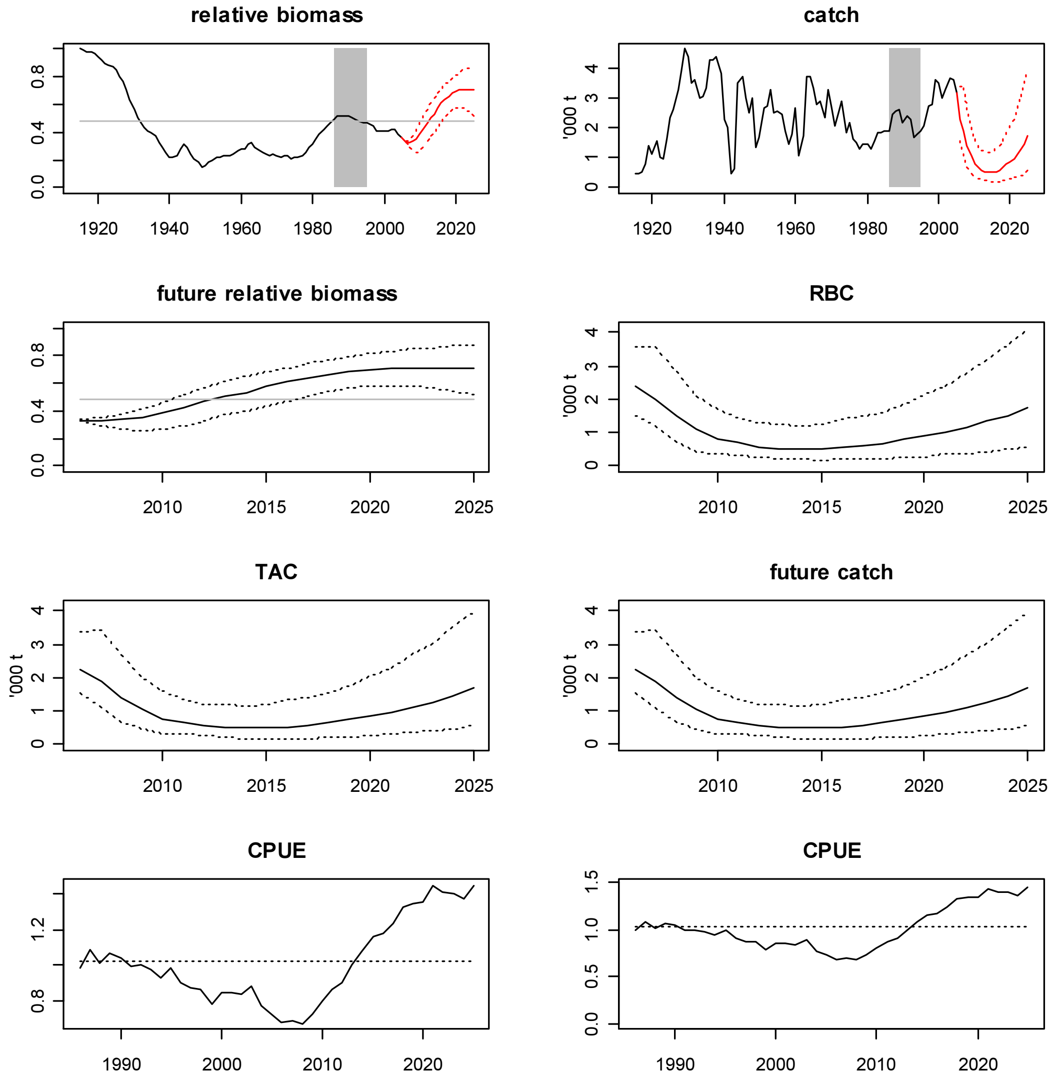

Figure 9.2 MSE simulation results for Scenario 1 (species: flathead, relative biomass: low, reference period: 1986 – 1995, C_{targ}: recent 4 years ($T4C_{recent}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

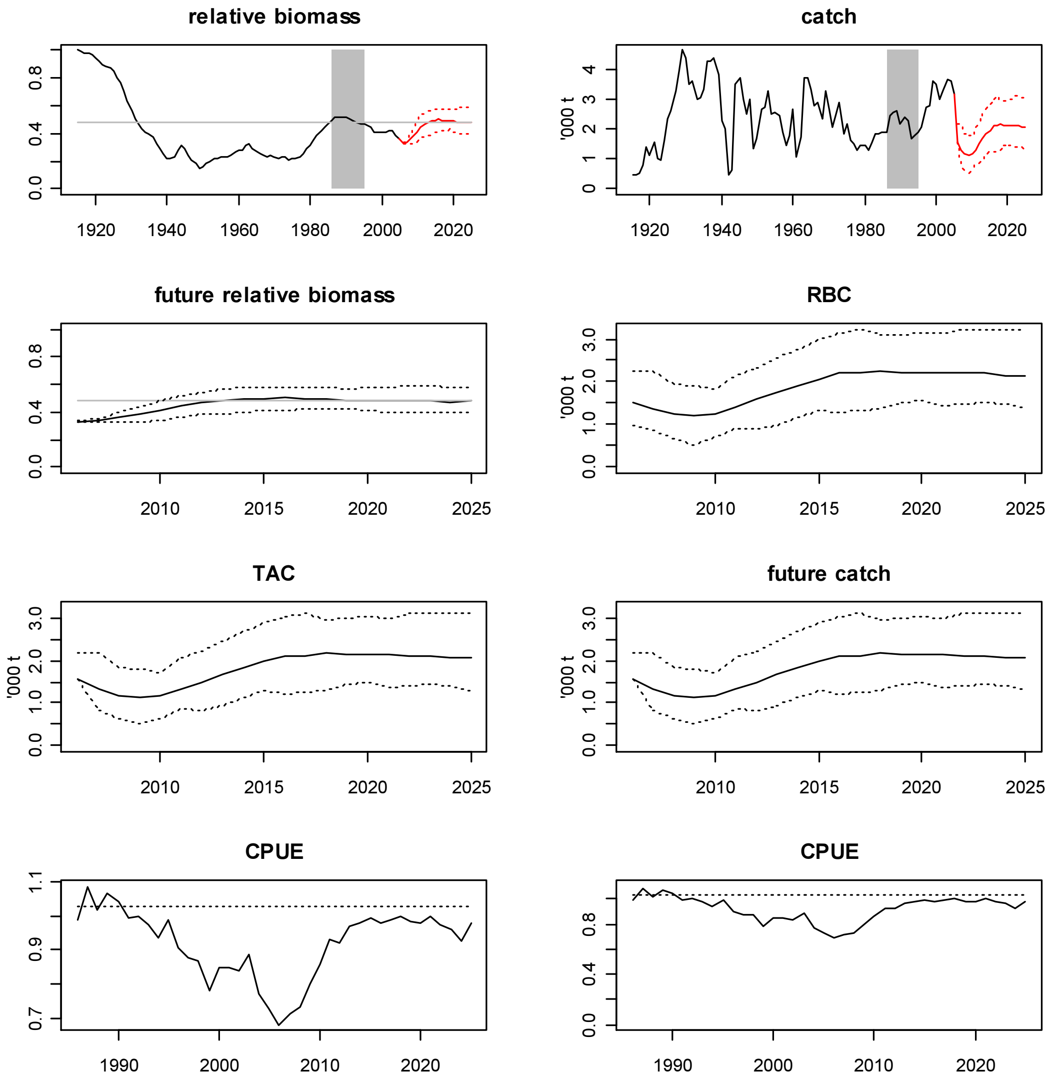

Figure 9.3 MSE simulation results for Scenario 2 (species: flathead, relative biomass: low, reference period: 1986 – 1995, C_{targ}: 1986 – 1995 (T4$C_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

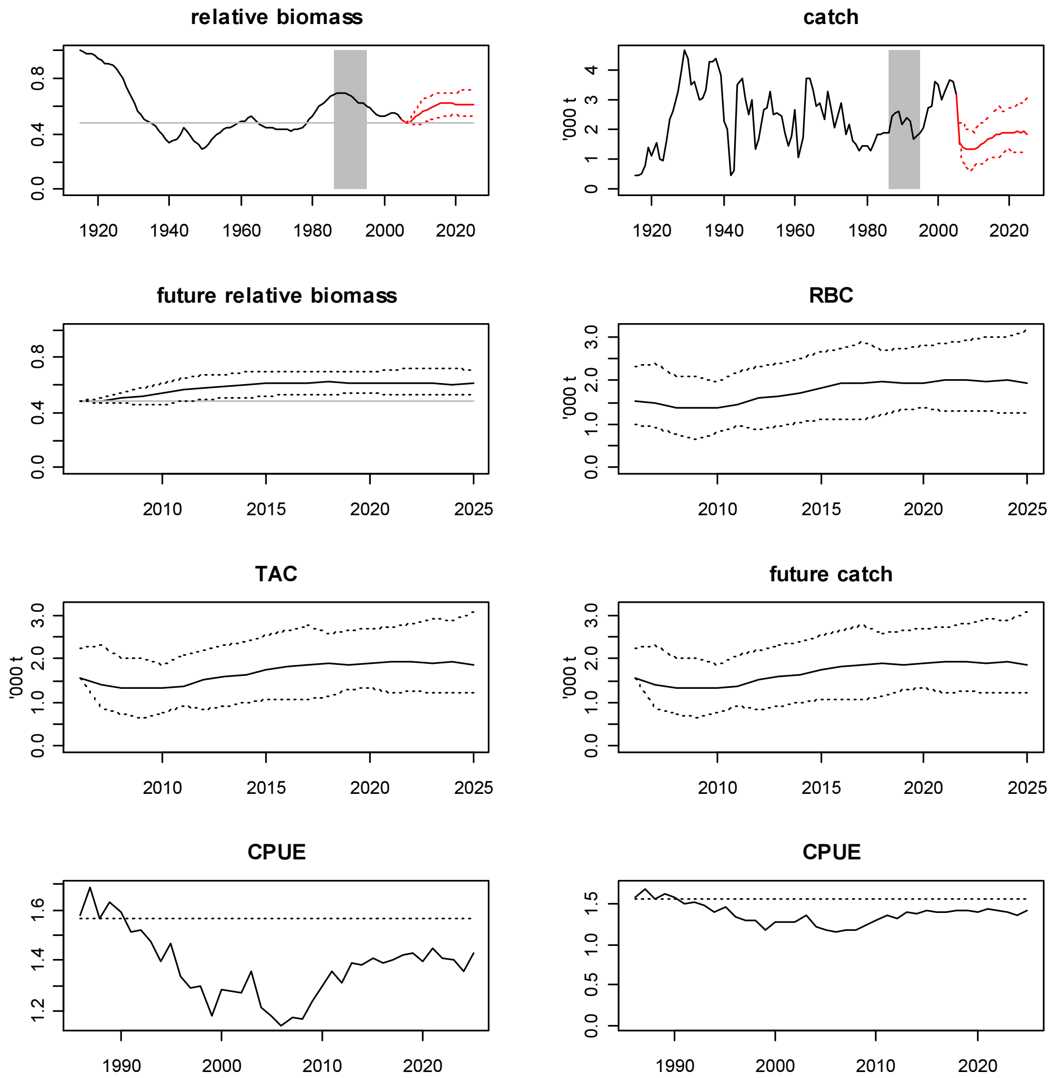

Figure 9.4 MSE simulation results for Scenario 3 (species: flathead, relative biomass: at target, reference period: 1986 – 1995, C_{targ}: 1986 – 1995 (T4C$_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

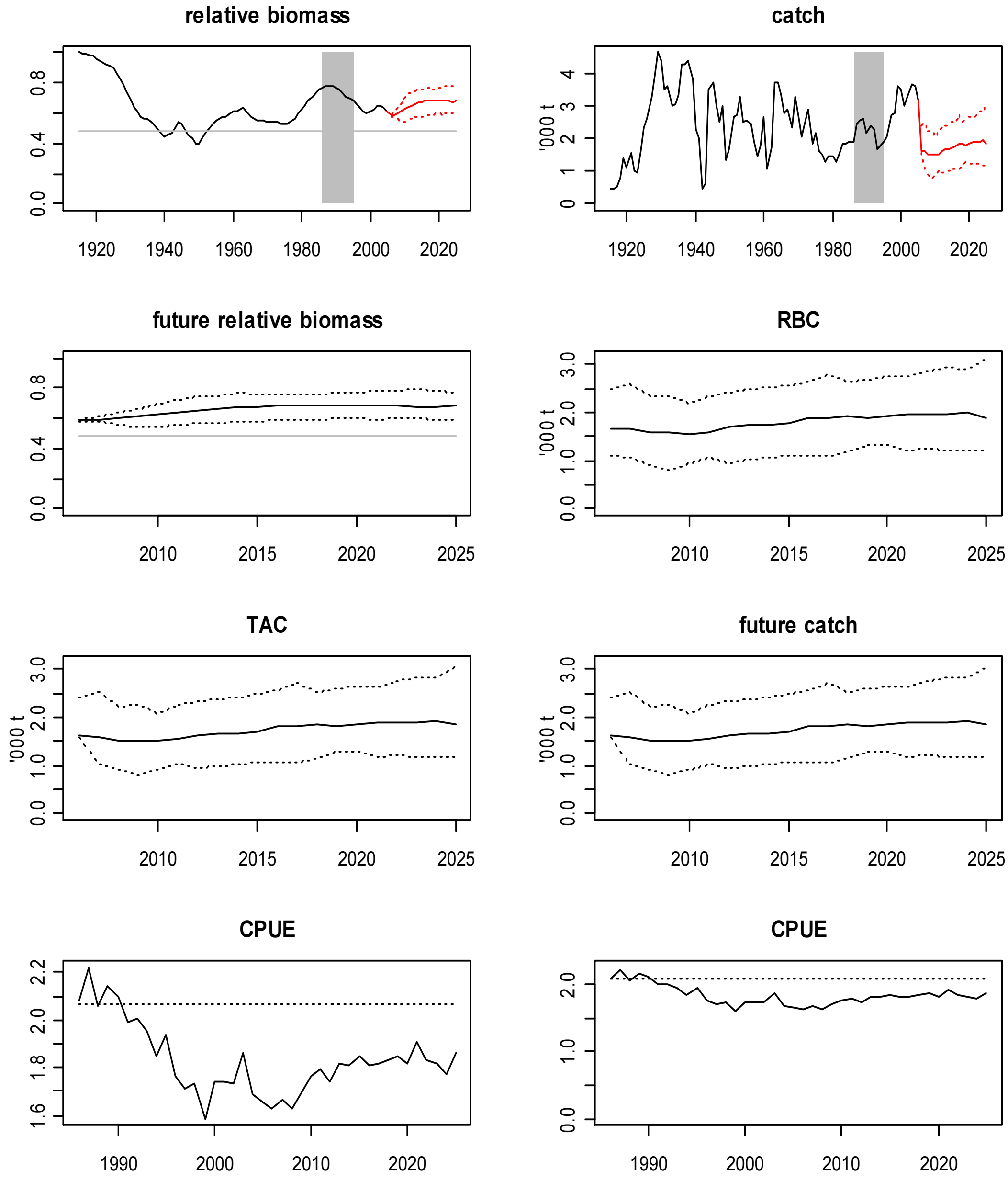

Figure 9.5 MSE simulation results for Scenario 4 (species: flathead, relative biomass: high, reference period: 1986 – 1995, C_{targ}: 1986 – 1995 (T4C$_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

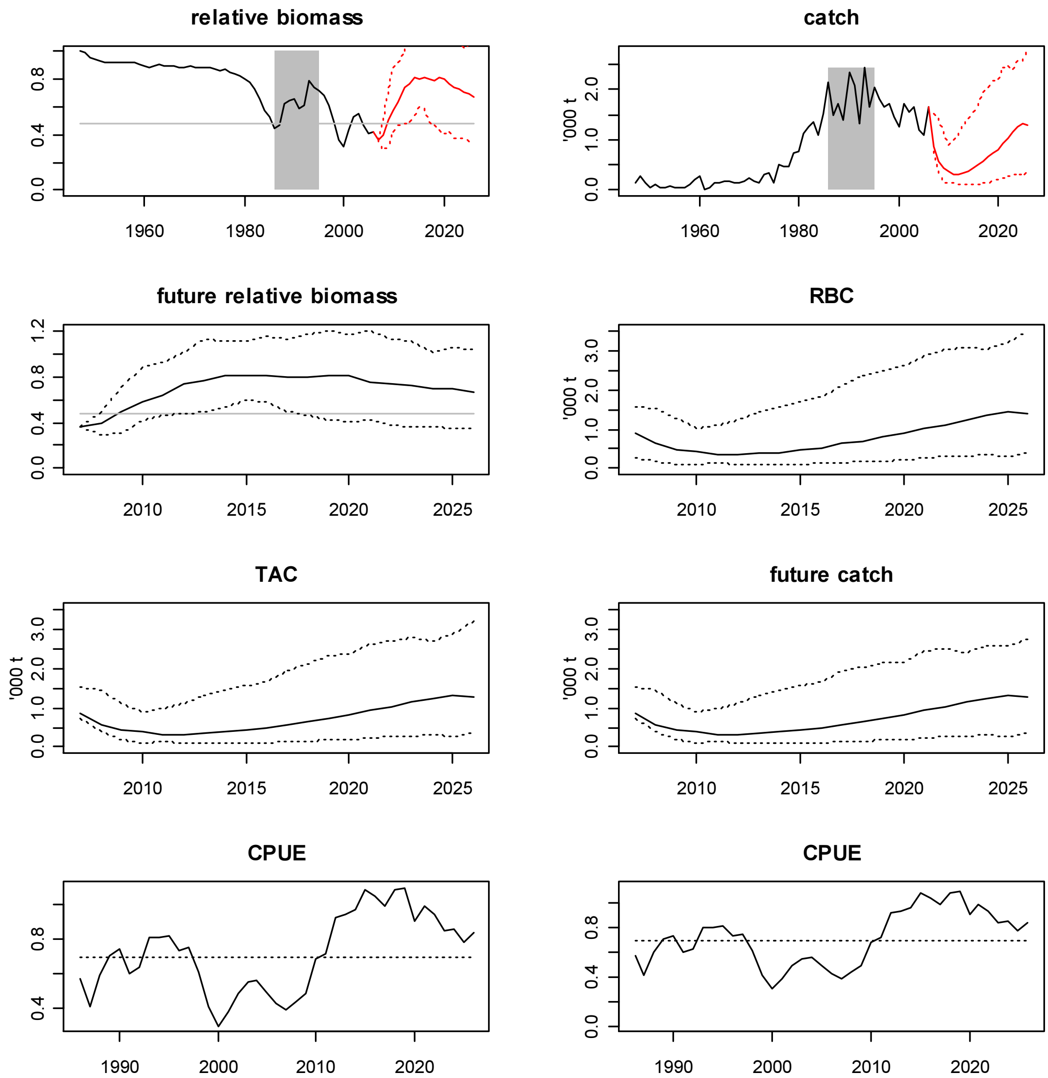

Figure 9.6 MSE simulation results for Scenario 5 (species: whiting, relative biomass: low, reference period: 1986 – 1995, C_{targ}: recent 4 years (T4C$_{recent}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

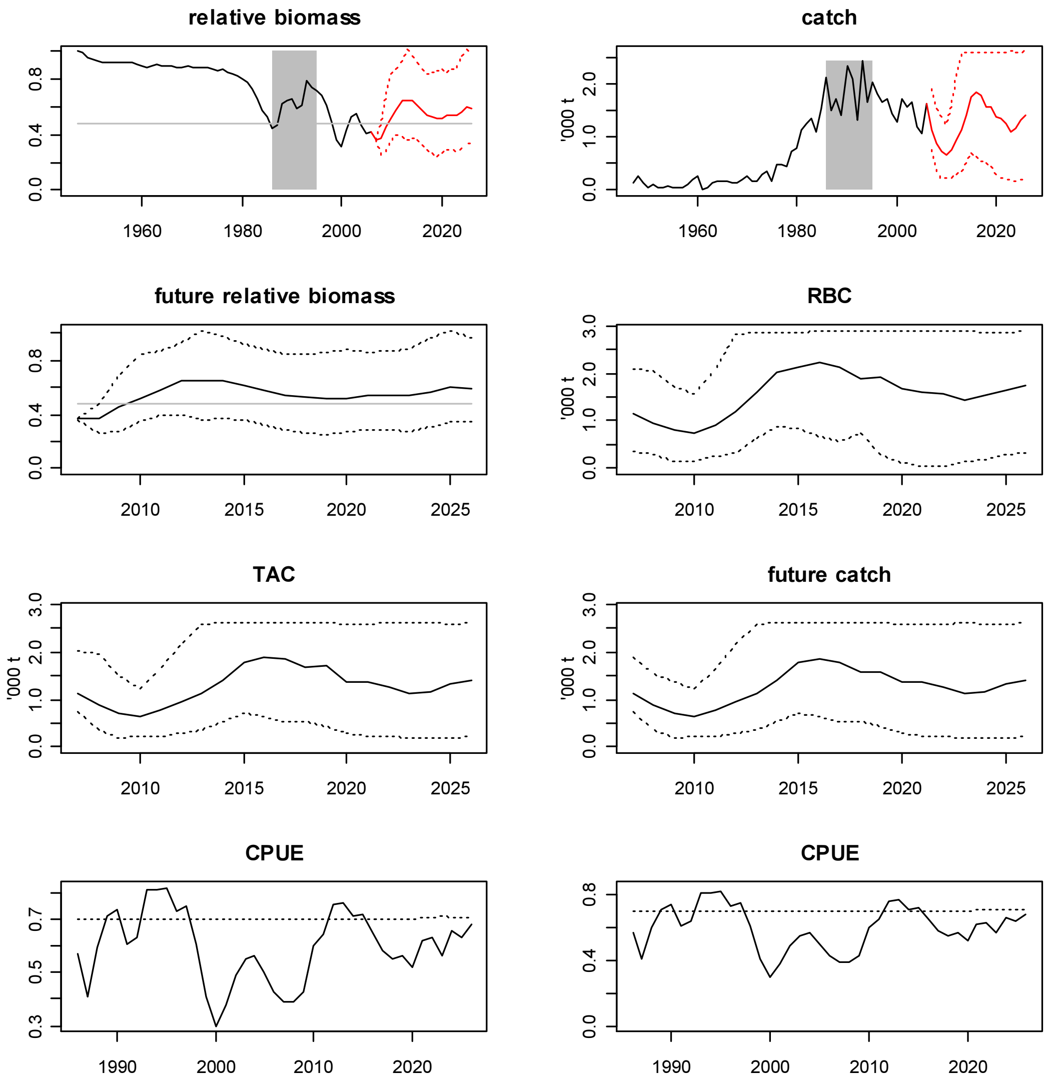

Figure 9.7 MSE simulation results for Scenario 6 (species: whiting, relative biomass: low, reference period: 1986 – 1995, C_{targ}: 1986 - 1995 (T4$C_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

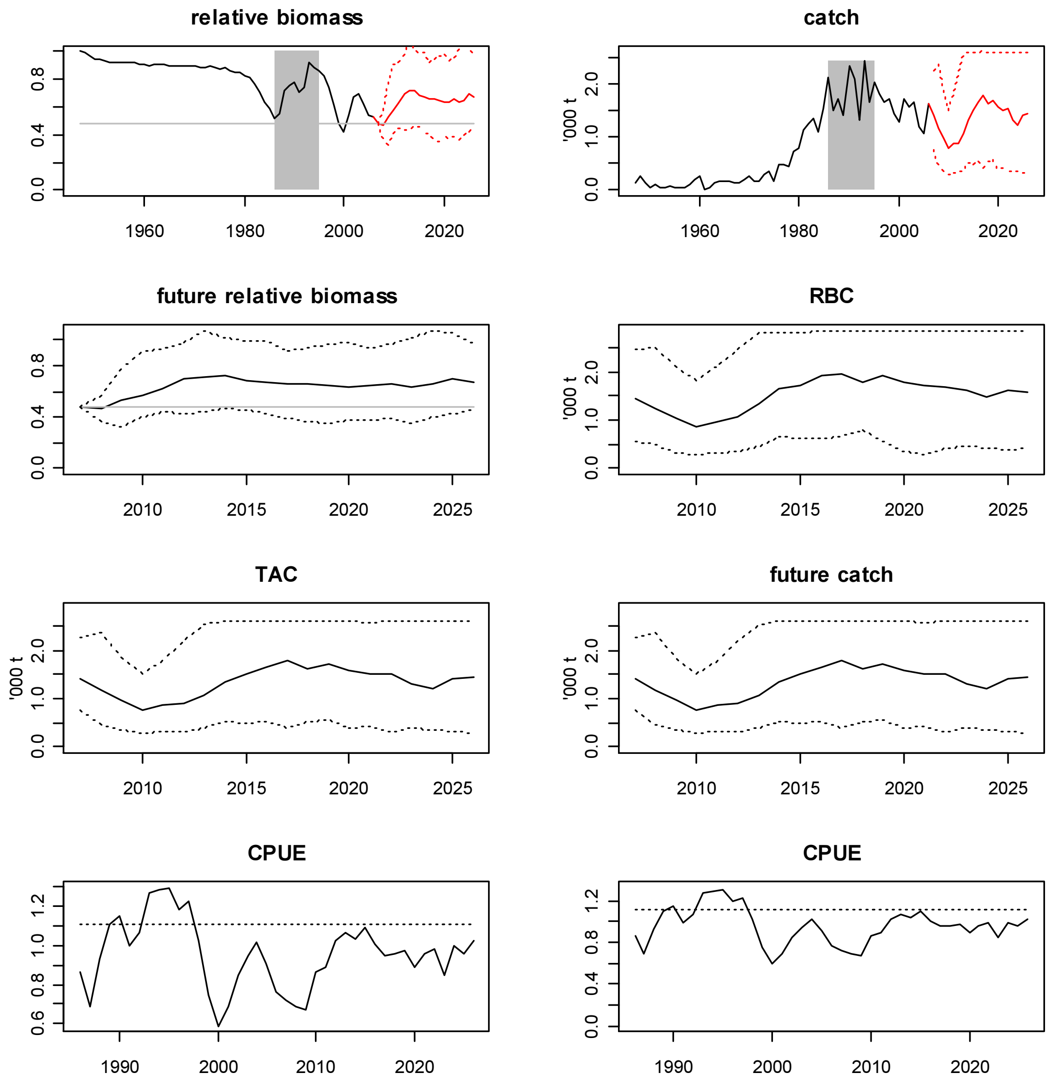

Figure 9.8 MSE simulation results for Scenario 7 (species: whiting, relative biomass: at target, reference period: 1986 – 1995, C_{targ}: 1986 – 1995 (T4C$_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

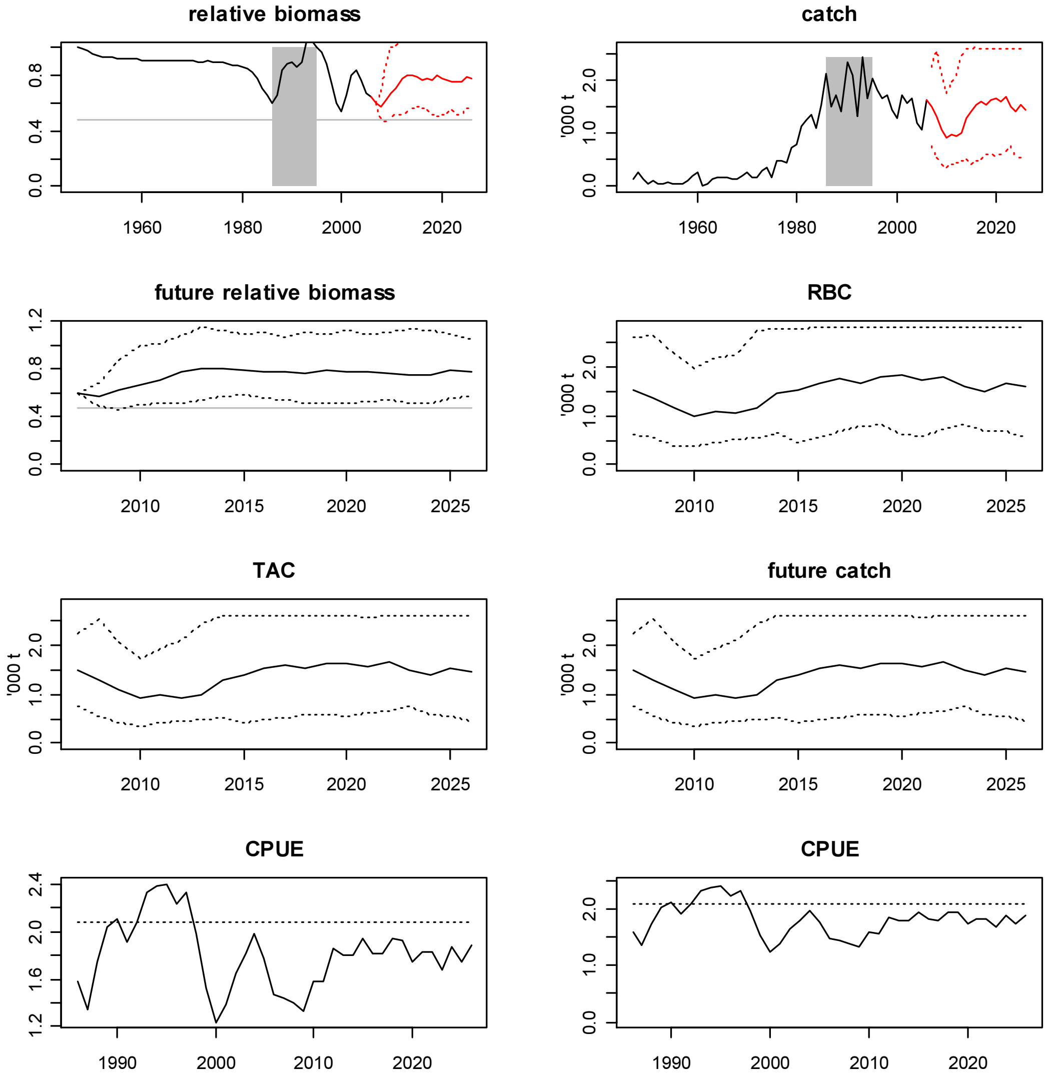

Figure 9.9 MSE simulation results for Scenario 8 (species: whiting, relative biomass: high, reference period: 1986 – 1995, C_{targ}: 1986 – 1995 (T4C$_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

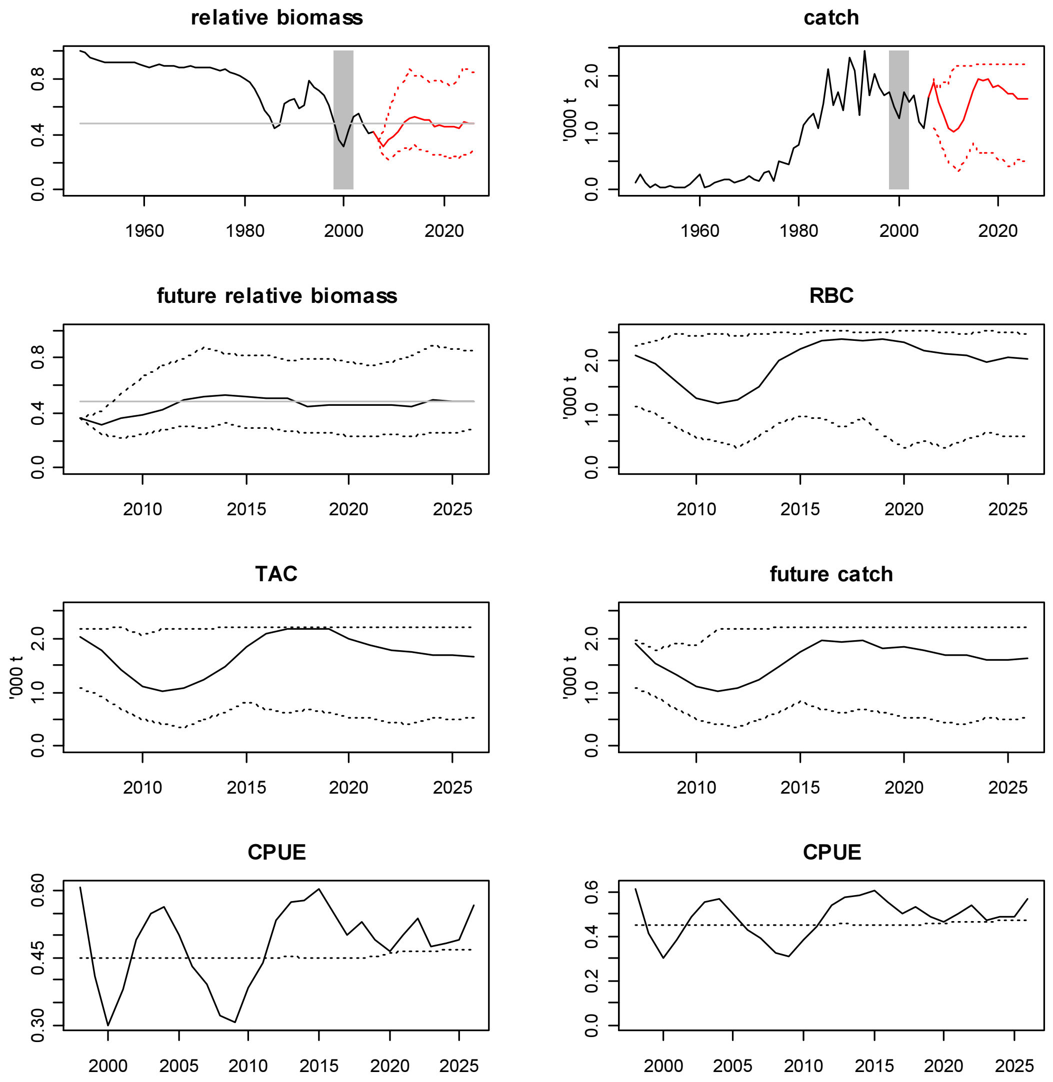

Figure 9.10 MSE simulation results for Scenario 9 (species: whiting, relative biomass: low, reference period: 1998 – 2002, C_{targ}: 1998 – 2002 (T4C$_{historical}$), C_{max}: 1.25 C_{targ}) showing the relative biomass for the entire simulation period (top left panel), catch for the entire simulation period (top right panel), relative biomass for the projection period (upper middle left panel), recommended biological catch (RBC) for the projection period (upper middle right panel), total allowable catch (TAC) for the projection period (lower bottom left panel) the actual catch for the projection period (lower bottom right panel). The bottom two panels show the time series of CPUE in relation to the specified CPUE target. Solid lines show the median and dotted lines show the 0.025 and 0.975 percentile from 100 projections.

10. Simulation testing of an adjustment to the TAC in response to the most recent year's CPUE

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10.1 Summary

The current method of calculating total allowable catches (TACs) in the Southern and Eastern Scalefish and Shark Fishery (SESSF) does not utilise information from the most recent fishing year, as the stock assessments only have complete data up to the end of the previous year available to them. We examine two rules that adjust the TAC from the assessment based on the most recent trend in standardised catch per unit effort (CPUE). The first proposed rule (Rule 1) shows proportionality in that it leads to changes in TAC that are equal, in proportion, to the changes in CPUE. However, the rule lacks symmetry in that it increases the TAC in response to an increase in CPUE more strongly than it decreases it. The second rule (Rule 2) does show symmetry to increases and decreases in catch rate and it preserves multiplicative (geometric) proportionality.

Simulation tests show that the application of both versions of the post-assessment rule does not significantly alter the performance of the harvest strategy procedures in terms of risk to the stock or overall catch levels, but it does significantly increase the year-to-year catch variability. Rule 1 leads to greater catch variability than Rule 2. If the post-assessment rules are applied with no restrictions on the magnitude of the subsequent change in TAC, Rule 1 is slightly less precautionary than Rule 2. If the post-assessment rules only increase TAC in response to increasing catch rates, and do not decrease TAC in response to decreasing catch rates, then both post-assessment rules increase the risk of stock collapse.

10.2 Introduction

Due to the timing of data availability, assessments and TAC-setting, CPUE data from the SESSF are being used in assessments that ultimately set TACs that will be applied 12-30 months from the time the data were collected. While it is recognised that there will always be a time lag, given the need to (i) enter and verify logbook information, (ii) prepare all the data required for a stock assessment and then (iii) apply the harvest strategy for the TAC-setting process, industry have expressed concern that this lag prevents the assessments from reflecting what is currently happening on the water. Industry has asserted there is a mismatch between the logbook CPUE data that is being used in assessments relative to the catch rates they are seeing during their fishing operations.

At a workshop in October 2007 between AFMA, CSIRO and SETFIA to discuss the stock assessment process, this lag and its impact on industry was one of the main issues discussed. One of the potential solutions was that as part of the harvest strategy, a decision rule could be developed which would allow the most recent year's logbook information to influence the following year's TAC. This paper presents two such decision rules, the results of simulation testing of the rules, and discusses the likely consequences of their implementation.

10.3 Methods

Discussions subsequent to the workshop in October 2007 highlighted the following points:

- Any additional decision rule used to alter the TAC setting process would need to be consistent with the goals of the Commonwealth Harvest Strategy Policy
- Given the time constraints and importance of any alteration to RBCs/TACs subsequent to the stock assessments, any indicator would need to be easily obtained and calculated, and the decision rule would need to be robust to apply, simple to understand and unambiguous.
- There is currently no quantitative industry-based data that would be suitable as an indicator for the basis of such a decision rule.
- Logbook CPUE data is currently the only appropriate data that could be used as a quantitative indicator in the decision rule.
- Any decision rule that included logbook CPUE data from the previous year would have to be applied subsequent to the RBC output that is derived from the stock assessment.
- A standardised annual CPUE figure would be preferable as an index of stock abundance to one derived from raw catch and effort data.
- Methods are already established to obtain standardised annual CPUE and are required as an input into the current assessments.

Given these points, we have endeavoured to develop and evaluate potential indicators and decision rules as outlined below.

10.3.1 Indicator

The current assessments use all data available up until 31st December; 16 months prior to the TAC setting period beginning on 1st May. The proposed post-assessment indicator will be the standardised CPUE determined from the commercial logbook data submitted from January to December; four months prior 1st May. In practice, it is likely that data up to the end of November will be used, as the December data will probably not be available in time for this analysis.

For example, the assessments that will determine the RBC for the 2009/10 fishing year incorporate data available up until December 2007. The post-assessment logbook indicator used in this decision rule will be the standardised catch rate from the commercial logbook data included from January – November 2008.

As such, the indicator for each species will be the annual standardised catch rate from the calendar year immediately prior to the May TAC-setting period. It will be calculated from the optimal model identified in the most recent SESSF catch rate standardisation (e.g. Haddon, 2008) using exactly the same data filters.

10.3.2 Rule 1

A possible rule for setting TACs in the SESSF is that the recommended TAC for year *y+2* (TAC_{new}) will be based on the TAC calculated using the results of a stock assessment (TAC_{ass}), which uses data up to and including year *y*, adjusted by the ratio of CPUE in the most recent year ($CPUE_{y+1}$) to that in the previous year ($CPUE_y$)

$$TAC_{new} = TAC_{ass}[1 + \alpha_1 (R - 1)]$$

$$R = CPUE_{y+1} / CPUE_y$$

where $\alpha_1 = 0.5$ is a factor that moderates the impact of the rule, i.e. a larger value for α_1 would result in greater changes to the TAC.

10.3.3 Rule 2

Alternatively, the CPUE ratio can be modified so that TAC_{new} changes in proportion to the multiplicative (geometric) change in CPUE

$$TAC_{new} = TAC_{ass}[1 + \alpha_2 \widetilde{R}]$$

$$\widetilde{R} = \frac{\ln\left(CPUE_{y+1} / CPUE_y\right)}{e^1}$$

A value of $\alpha_2 = 1$ was found to produce results in a similar range to those of Rule 1 (with $\alpha_1 = 0.5$).

Both rules include the restriction that changes to TAC_{new} should be capped at 25% up or down relative to TAC_{ass}.

10.3.4 Comparison of Rules 1 and 2

For any given pair of CPUE values, Rule 1 results in a greater increase in TAC if the trend in CPUE is upwards, than a decrease if the trend is downwards (Figure 10.1 “Rule 1”). That is, for any given pair of CPUE values, if the larger value is the more recent, then the change to the TAC is greater than if the smaller value is the more recent. Ideally, any pair of CPUE values should result in the same magnitude of change to the TAC, irrespective of the direction.

Figure 10.1“Rule 1” shows that the percentage change in the TAC when the larger value is the more recent (“*Up”* - an increase in TAC in response to an increasing CPUE) versus the percentage change in the TAC when the smaller value is the more recent ("*Down*" - a decrease in TAC in response to a decreasing CPUE).

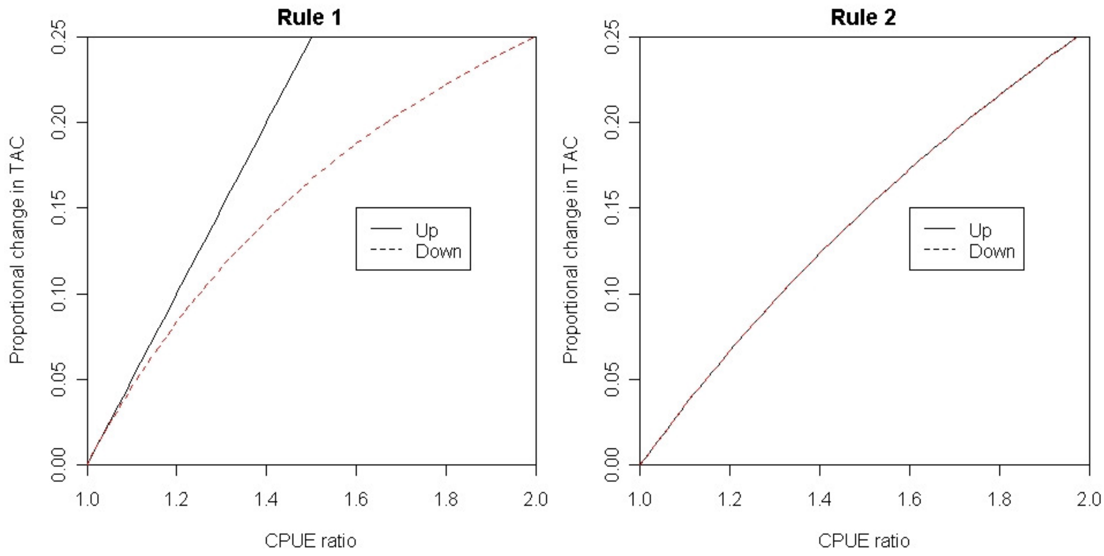

Figure 10.1 Plots of the percentage change in TAC when the trend in CPUE is upwards 'Up' (solid line) or downwards 'Down' (dotted line). Lines are plotted against the ratio of the smaller to the larger of the two CPUE values. Results are shown for the two proposed rules.

Rule 2 provides a symmetrical relationship between changes in CPUE and in TAC (Figure 10.1 "Rule 2") in that for any pair of CPUE values the percentage change in TAC is the same whether the CPUE steps up from the smaller to the larger, or down from the larger to the smaller. This rule does not result in a linearly proportional change in TAC with changes in CPUE, but rather a multiplicative (or geometric) proportional change.

Table 10.1 shows the percentage change in the TAC for cases where the CPUE steps up from 0.32 to 0.45, or alternatively down from 0.45 to 0.32. Under Rule 2, the percentage change to the TAC is the same for both increasing and decreasing CPUE trends (Table 1). This is not the case for Rule 1.

Table 10.1. Percentage change in the recommended TAC for year $y+2$ for cases in which CPUE steps up from 0.32 to 0.45, or down from 0.45 to 0.32 from year y to year $y+1$ for Rule 1 (with α = 0.5) and Rule 2 (with α = 1).

CPUE trend	Rule 1	Rule 2
Up 40%	Up 20%	Up 13%
Down 29%	Down 14%	Down 13%

Rule 1 for modifying the TAC given two recent CPUE figures conserves the percentage change in TAC either up or down with percentage change in CPUE. That is, if CPUE goes up by 10%, then the TAC is adjusted up by α*10%. Likewise, if the CPUE goes down by 10% then the TAC is adjusted down by α*10%. However, if the CPUE goes up from 0.32 to 0.45 (a 40% increase) the TAC goes up 20% (when α=0.5), but if CPUE goes down from 0.45 to 0.32 (a 29% decrease) the TAC goes down only 14%

(Table 10.1). This property of the rule suggests a lack of precaution that may not be desirable for the fishery.

Rule 2 conserves the percentage change in TAC with multiplicative (geometric) change in CPUE, i.e. if the CPUE doubles or halves, then the percentage change in TAC is the same (but in the opposite direction). This rule displays symmetry so that, all else being equal, if the CPUE steps from 0.32 to 0.45 and back to 0.32 over three successive years, the TAC will increase, and then decrease back to its original level. This would not occur with Rule 1 (the TAC would be greater).

Rule 1 is not symmetric, and the asymmetry is such that the rule is not conservative, as the TAC responds more strongly to increases in CPUE than to decreases. Rule 2 is symmetric, and is therefore more conservative than Rule 1, because it responds equally to both increasing and decreasing trends in CPUE.

10.3.5 Simulation testing

The performances of the two post-assessment rules for changing the TAC in response to the most recent year's CPUE are simulation tested using the SESSF management strategy evaluation (MSE) procedure. A fishery is projected for 20 years into the future, using a detailed "operating model" to represent the future dynamics of the stock and to generate future "data". For each scenario, the future of the fishery is simulated 100 times, using different future recruitments and generating different data sets for input into the assessment procedures. The initial conditions for each scenario are based on the results of stock assessments using historic data.

The post-assessment rules are tested for two types of species characteristics ("flathead-like" and "whiting-like") with the Tier 1, 3 and 4 harvest control rules. All scenarios shown assumed an initial stock level below the target level. Other scenarios with the initial stock level above the target, and with different values of the CPUE multiplier, α, are run. These are not shown here, as the results were similar to those shown. In all the simulation tests, α_1 is set at 0.5, and α_2 to 1.0. The maximum change in TAC due to the application of the post-assessment rule is capped at 25%.

The outcomes when the post-assessment rules were applied only to an increase and only to a decrease in CPUE were also separately examined.

The performance of the post-assessment rules is evaluated using six performance measures relating to stock level, catch, and variability in catch. Specifically, the performance measures are:

1. Average catch over the 20 year projection period
2. Average catch over the first five years of the projection period
3. Depletion in final year : final biomass/B_0
4. Lowest depletion : lowest biomass/B_0 in the 20 year projection period
5. Catch variability : average percentage change in catch from year to year
6. Probability of the biomass in the projection period being below the limit ($0.2B_0$)

10.4 Results

The first five performance measures for each scenario are summarised in box plots. The horizontal line shows the median value. The bottom and top of the box show the 25th and 75th percentiles, respectively (i.e. the middle 50 % of the data). The vertical dashed lines show either the maximum and minimum values, or, if there are outliers in the data, they correspond to approximately two standard deviations. Outliers are plotted individually.

For both species types and all harvest control rules examined, the post-assessment rules behave similarly to each other and to the scenario with no post-assessment rule for all performance measures, with the exception of catch variability (Figure 10.2 to Figure 10.7). Year-to-year catch variability increases significantly when the post-assessment rules are used. Rule 1 leads to greater catch variability than does Rule 2.

Rule 1 is less precautionary than Rule 2, in that it responds more strongly to an increasing CPUE trend. Therefore it is initially surprising that, apart from increased catch variability, it performs as well as Rule 2. The expected difference between the two rules is diminished by the use of the restriction that the post-assessment rule cannot increase the TAC calculated using the results of a stock assessment by more than 25%. As Rule 1 increases the TAC by a greater amount than Rule 2, this restriction is invoked more than three times more often for Rule 1 than for Rule 2. Another restriction placed on the TAC is that it cannot change by more than 50% from one year to the next. If both of these restrictions are removed, the probability of the stock falling below the limit ($0.2B_0$) is increased by 30% for Rule 1, but is unchanged for Rule 2 **(**Figure 10.8).

Another factor that reduces the differences between the rules is that although Rule 1 increases the TAC by more than Rule 2 when the CPUE trend is increasing, it also decreases it by more when the CPUE trend is decreasing. For the whiting-like species Tier 3 assessment, the average TAC increase (over all future years and simulations) for Rule 1 when the CPUE trend is increasing is 16 %, whereas when the CPUE trend is decreasing, the average TAC decrease for this rule is 13 %. For Rule 2, the average TAC change is 12 % for both an increasing and decreasing trend in CPUE. Note that the magnitude of the change, in both cases, is governed by the values used for the α parameters.

The consequences of only applying the post-assessment rule when the CPUE is increasing were also examined. Likewise, results were examined if the rules are only applied when the CPUE is decreasing. For the whiting-like species Tier 3 assessment, if the TAC is only increased in response to an increasing CPUE trend, but not decreased due to a decreasing CPUE trend, overall catches are slightly higher, but the probability of the stock falling below 20% B_0 during the 20 year projection period increases from 10% to 16% for Rule 1, and from 11% to 14% for Rule 2 (Figure 10.9). Conversely, if the TAC is only ever decreased in response to a decreasing CPUE trend, the catch is reduced, as is the probability of the stock falling below 20% B_0 **(**Figure 10.10).

10.5 Discussion

The application of both versions of the post-assessment rule does not significantly alter the performance of the harvest strategy procedures in terms of risk to the stock or overall catch levels, but it does significantly increase the year-to-year catch variability. Rule 1 leads to greater catch variability than Rule 2. If the rules are applied with no restrictions on the change in TAC, Rule 1 is slightly less precautionary than Rule 2 (for the whiting Tier 3 example). If the post-assessment rules only increase TAC in response to increasing catch rates, and do not decrease TAC in response to decreasing catch rates, then the risk of stock collapse is increased.

Under a recovering stock scenario, the CPUE is expected to increase as a result of increasing stock biomass. In this case, it has been surmised that the rule may slow the recovery by taking catches above those determined using the appropriate harvest control rule. However, this outcome is not evident in the results shown here. In fact, for the example with the whiting-like species and the Tier 3 HCR, the scenario with no post-assessment rule is the least precautionary - that is, the probability of the stock falling below $0.2B_0$ is greatest when post-assessment rules are not applied (Figure 10.6). This may be explained by the fact that the scenarios utilising the post-assessment rules have more recent information available to them than the scenario with no post-assessment rule, as they have one more year's CPUE data. The rules may also be self-correcting – if a higher catch is taken one year, this may cause the stock (and CPUE) to decline, so that in the following year, catches are reduced. This will lead to greater year-to-year catch variability.

Notable characteristics of any rule for adjusting TAC based on the recent trend in CPUE are likely to include the following:

(a) The rules, and consequent adjustments to the TAC, will respond to changes in CPUE, even for cases where all other data sources (e.g. length and age compositions) indicate that a recent trend in CPUE is spurious or misleading.
(b) As CPUE series for many species are naturally noisy, TAC adjustments using these rules will also be noisy (i.e. increased variation in TAC).
(c) If the CPUE increases in one year, and then decreases by the same proportional amount the following year, the expected overall change in TAC will be close to zero (but not exactly so if the asymmetric Rule 1 is used), assuming that the RBC calculated from the results of stock assessments remain unchanged.
(d) If the CPUE increases in one year and then remains at the same level the following year, the TAC will only be adjusted upwards by this rule in the first year. In the following year the rule will apply no adjustment to the TAC calculated by the Tier rule.

10.6 References

Haddon, M. 2008. Catch Rate Standardizations 2008 (for data 1986 – 2007). Technical paper presented to Slope Resource Assessment Group. 17-18 November 2008. Hobart, Tasmania

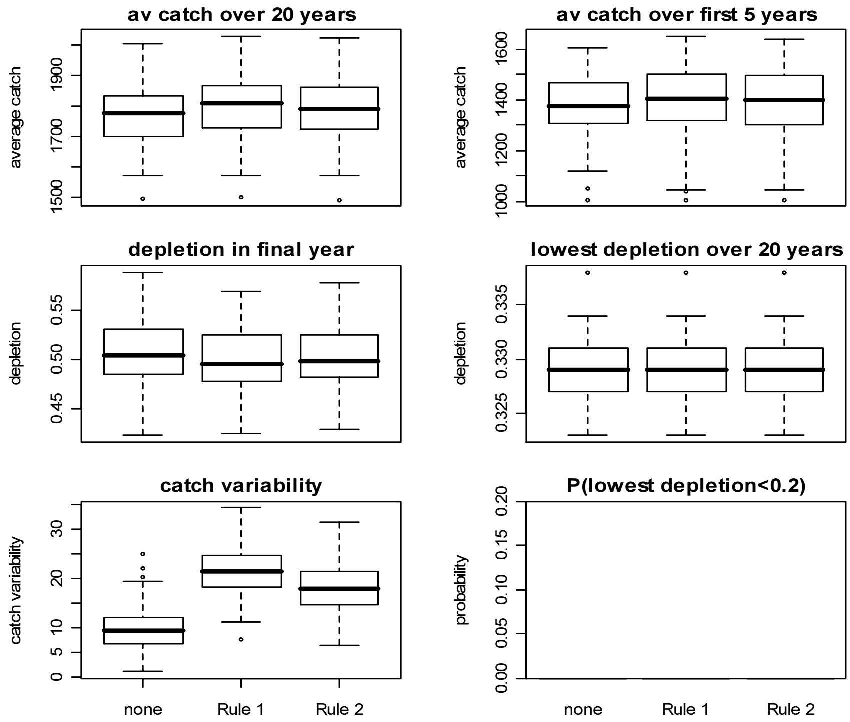

Figure 10.2 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **flathead-like species using the Tier 1** harvest control rule.

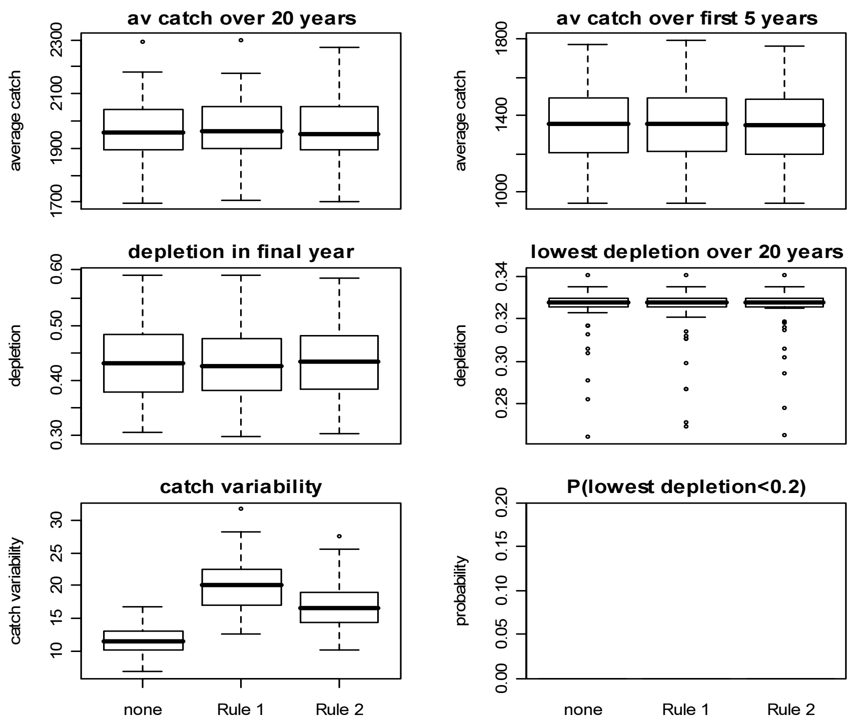

Figure 10.3 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **flathead-like species using the Tier 3** harvest control rule.

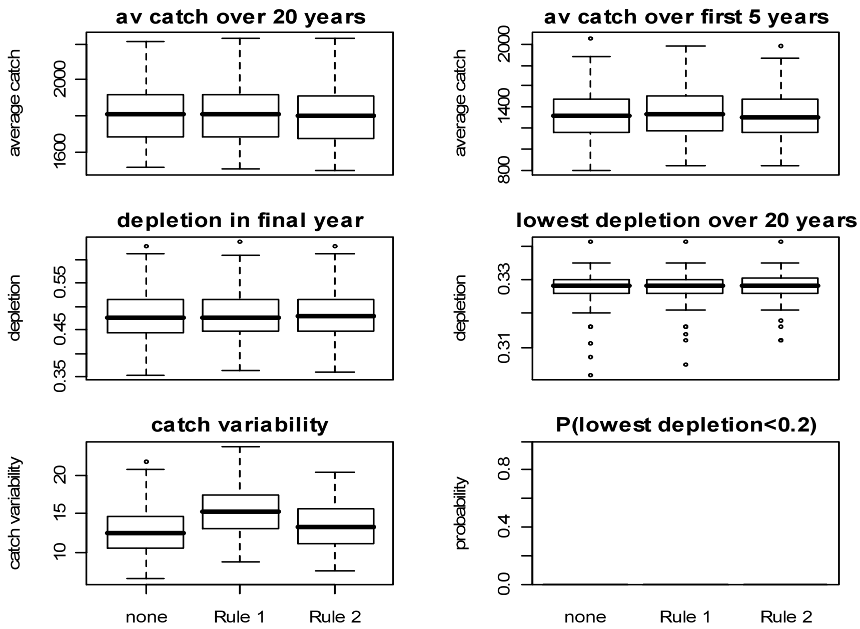

Figure 10.4 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **flathead-like species using the Tier 4** harvest control rule.

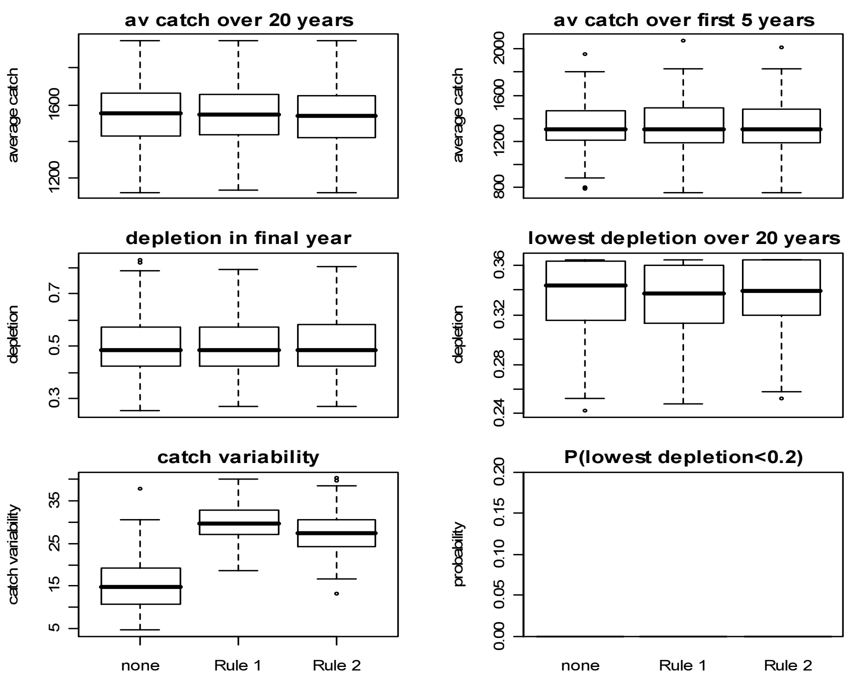

Figure 10.5 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **whiting-like species using the Tier 1** harvest control rule.

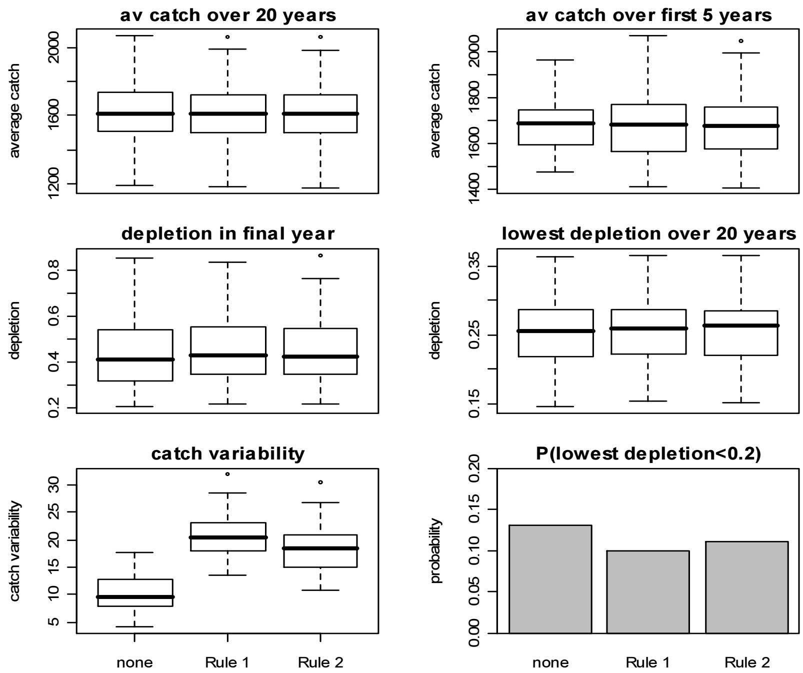

Figure 10.6 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **whiting-like species using the Tier 3** harvest control rule.

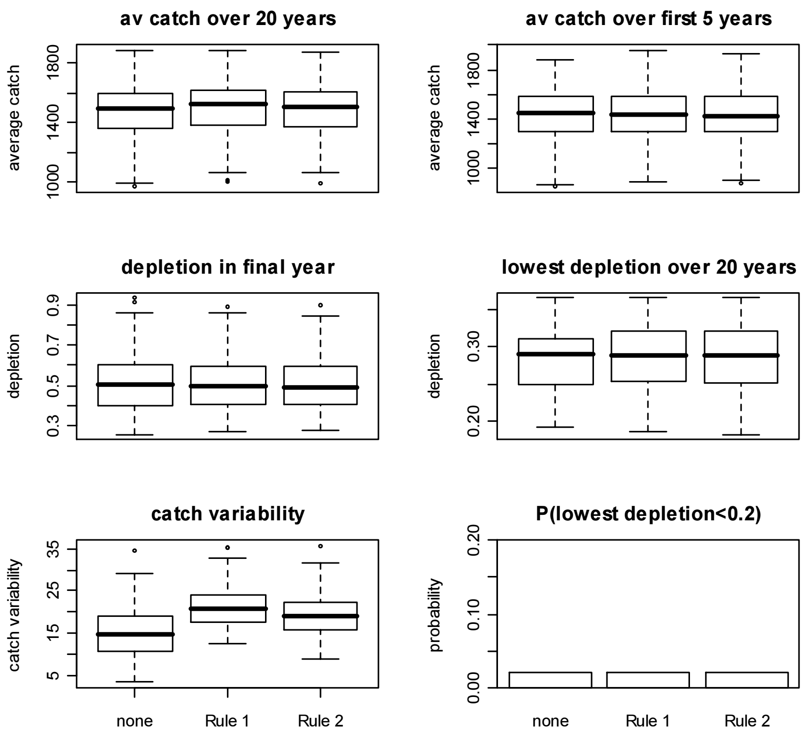

Figure 10.7 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **whiting-like species using the Tier 4** harvest control rule.

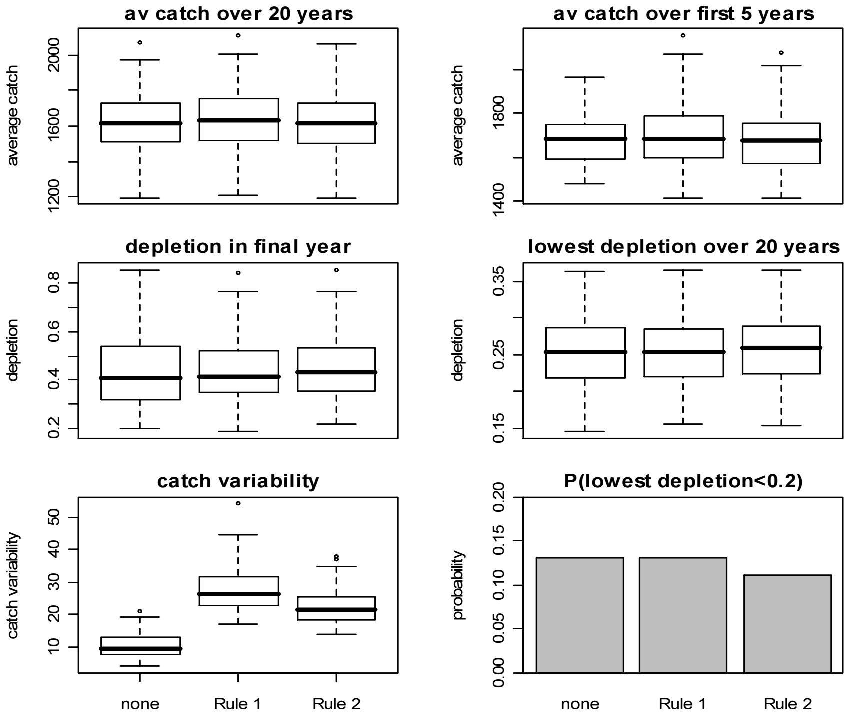

Figure 10.8 Box plots summarising the performance measures after application of the post- assessment rules **with no TAC change restrictions** to an assessment of a **whiting-like species using the Tier 3** harvest control rule.

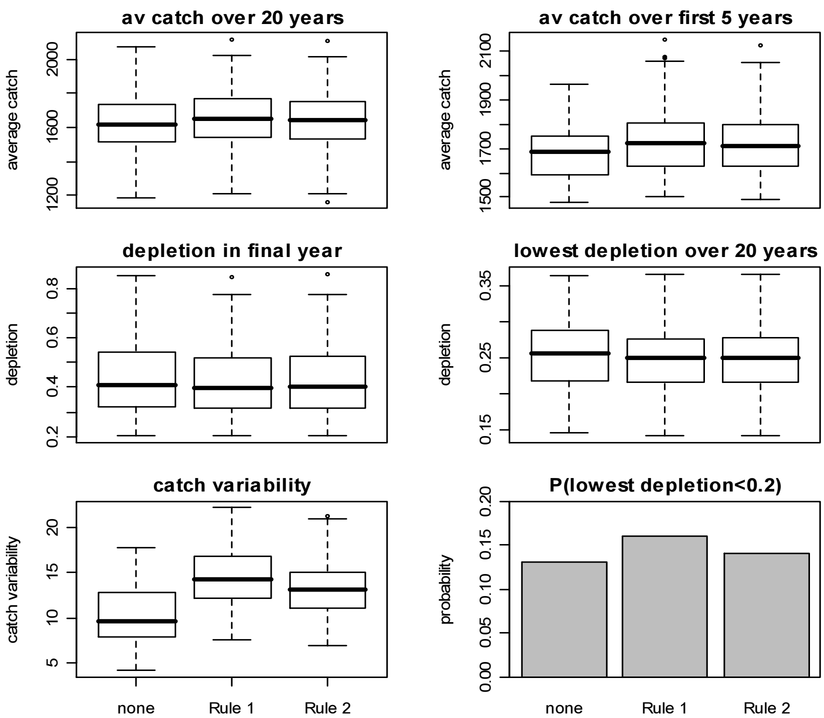

Figure 10.9 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **whiting-like species using the Tier 3 harvest control rule**, **where the post-assessment rule only allows an *increase* in the TAC.**

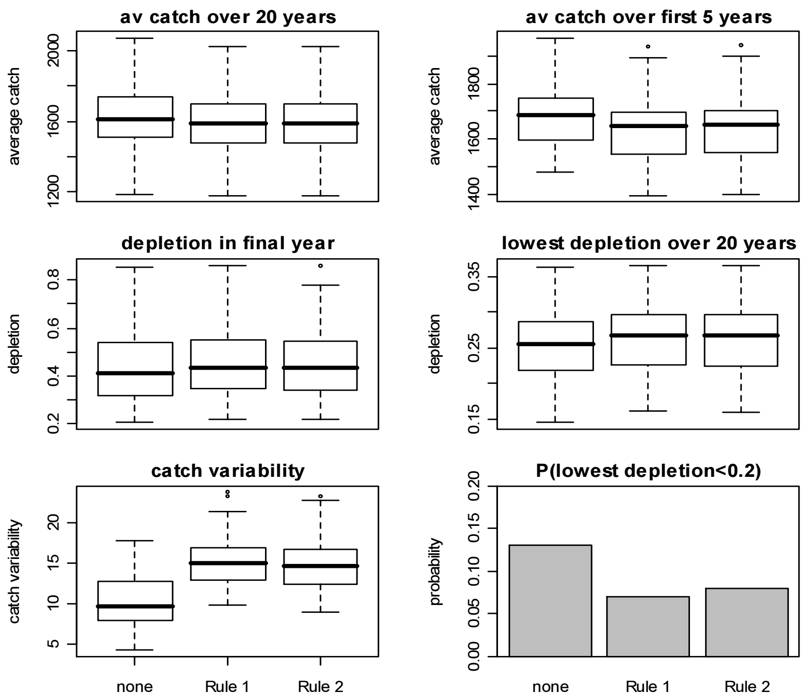

Figure 10.10 Box plots summarising the performance measures after application of the post- assessment rules to an assessment of a **whiting-like species using the Tier 3 harvest control rule**, **where the post-assessment rule only allows a *decrease* in the TAC.**

11. Operating model specifications

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11.1 Introduction

This section contains the technical specifications for the SESSF operating model used for this project. The model consists of an age-structured population dynamics model, a data-generation module, and a component to allow future projections of the population model given input from estimation methods and harvest control rules (HCRs). The model can be appropriately dimensioned and parameterised to account for several spatial regions, multiple stocks, and multiple fleets, in order to capture key dynamics for a range of species of interest within the SESSF.

11.2 Population dynamics

The operating model is composed of several regions (SEF areas), within which exist one or more stocks of a fish species. The population dynamics operate at the level of the stock, with stocks occupying one or more regions. Fishing fleets operate in one or more regions.

11.2.1 Abundance dynamics

The number of animals of stock *j*, sex *s* and age *a* in region *r* at the start of year *t*, $N^{j,r}_{s,a,t}$ is given by:

$$N^{j,r}_{s,a,t} = \begin{cases} \tilde{N}^{j,r}_{s,a-1,t-1} & \text{if } 1 \le a < x \\ \tilde{N}^{j,r}_{s,x-1,t-1} + \tilde{N}^{j,r}_{s,x,t-1} & \text{otherwise} \end{cases} \tag{1}$$

where $\tilde{N}^{j,r}_{s,a,t}$ is the number of animals of stock *j*, sex *s* and age *a* in region *r* following mortality (all sources) and movement during year *t*:

$$\tilde{N}^{j,r}_{s,a,t} = \bar{N}^{j,r}_{s,a,t} + \sum_{r'\neq r} \bar{N}^{j,r'}_{s,a,t} X^{j,r',r}_{s,a,t} - \sum_{r'\neq r} \bar{N}^{j,r}_{s,a,t} X^{j,r,r'}_{s,a,t} \tag{2}$$

$$\bar{N}^{j,r}_{s,a,t} = N^{j,r}_{s,a,t} e^{-M^{j,r}_{s,a,t}} (1 - u^{j,r}_{s,a,t}) \tag{3}$$

$X^{j,r',r}_{s,a,t}$ is the probability of an animal of stock *j*, sex *s* and age *a* moving from region *r*' to region *r*, during year *t*,

$M^{j,r}_{s,a,t}$ is the (potentially) sex, stock, age, time, and region-specific rate of natural mortality,

$u^{j,r}_{s,a,t}$ the exploitation rate (due to all fleets) on animals of stock *j*, sex *s* and age *a* in region *r* during year *t*:

$$u^{j,r}_{s,a,t} = \sum_f \tilde{u}^{f,r}_t s^{f,j}_{s,a,t} \tag{4}$$

where:

$$\tilde{u}_t^{f,r} = \frac{C_t^{f,r}}{\sum_j \sum_s \sum_L w_{L,s}^j \varphi_{L,t}^f S_{L,t}^f \sum_a \Phi_{L,s,a,t}^j N_{s,a,t}^{j,r} e^{-0.5M_{s,a,t}^r}} \tag{5}$$

$C_t^{f,r}$ is the retained catch by fleet *f* in region *r* during year *t*,

$\varphi_{L,t}^f$ is the fraction of animals in length bin *L* retained by fleet *f* during year *t*,

$s_{s,a,t}^{f,j}$ is the selectivity of fleet *f* on animals of stock *j*, sex *s* and age *a* during year *t*,

$w_{L,s}^j$ is the mean weight of a fish of stock *j*, sex *s* in length bin *L*, and

x is the maximum age (treated as a plus-group).

11.2.2 Selectivity

The sex- and age-specific selectivity pattern for fleet *f* on stock *j* is calculated from the length-specific selectivity pattern:

$$s_{s,a,t}^{f,j} = \sum_L S_{L,t}^f \Phi_{L,s,a,t}^j \tag{6}$$

where $L = l_L^{lo} + 0.5\left[l_L^{hi} - l_L^{lo}\right]$,

l_L^{hi} and l_L^{lo} are upper and lower limits of length bin *L*,

$\Phi_{L,s,a,t}^j$ is the proportion of fish of stock *j*, sex *s* and age *a* in length bin *L* during year *t*:

$$\Phi_{L,s,a,t}^j = \begin{cases} \tilde{\Phi}\left(\dfrac{l_L^{lo} - \overline{l}_{s,a,t}^j}{\sigma_{l_{s,a,t}^j}}\right) & \text{if } L = 1 \\ \tilde{\Phi}\left(\dfrac{l_{L+1}^{lo} - \overline{l}_{s,a,t}^j}{\sigma_{l_{s,a,t}^j}}\right) - \tilde{\Phi}\left(\dfrac{l_L^{lo} - \overline{l}_{s,a,t}^j}{\sigma_{l_{s,a,t}^j}}\right) & \text{if } 1 < L < N_L \\ 1 - \tilde{\Phi}\left(\dfrac{l_L^{lo} - \overline{l}_{s,a,t}^j}{\sigma_{l_{s,a,t}^j}}\right) & \text{if } L = N_L \end{cases} \tag{7}$$

$\tilde{\Phi}$ is the standard normal cumulative density function,

$\overline{l}_{s,a,t}^j$ is the mean length of a fish of stock *j*, sex *s* and age *a* in the middle of year *t*,

$\sigma_{l_{s,a,t}^j}$ is the standard deviation of the length of a fish of stock *j*, sex *s* and age *a* during year *t*,

$S_{L,t}^f$ is the fleet-specific selectivity at length during year *t*:

$$S_{L,t}^f = \frac{e^{\tilde{S}_{L,t}^f}}{\left(1 + e^{\tilde{S}_{L,t}^f}\right)}; \qquad \tilde{S}_{L,t}^f = \ln\left(\frac{S_{L,1}^f}{1 - S_{L,1}^f}\right) + \kappa_{L,t}^f \tag{8}$$

$S_{L,1}^f$ is the input initial (*t*=1) length-specific selectivity pattern for fleet *f*,

$\kappa_{L,t}^f$ is the deviation in the logit of selectivity at length *L* for fleet *f* at time *t*:

$$\boldsymbol{\kappa}_t^f \sim MVN(0,\mathbf{H}^f) \qquad \mathbf{H}^f = \sigma_{S,f}^2 \begin{pmatrix} 1 & \nu_{S,f}^{1,2} & \nu_{S,f}^{1,3} \\ \nu_{S,f}^{1,2} & 1 & \nu_{S,f}^{2,3} \\ \nu_{S,f}^{1,3} & \nu_{S,f}^{2,3} & 1 \end{pmatrix} \tag{9}$$

$\sigma_{S,f}^2$ is the variance of the random walk in the logit of selectivity for fleet *f*, and

$\nu_{S,f}^{i,j}$ is the correlation among length bins *i* and *j* in the annual deviations for fleet *f*:

$$\nu_{S,f}^{i,j} = \left(\Omega^f\right)^{|i-j|} \qquad 0 < \Omega^f \le 1 \tag{10}$$

Ω^f is the correlation between adjacent length bins.

11.2.3 Retention

The fraction of animals of each sex retained by age for each fleet during year *t* is:

$$\varphi_{s,a,t}^{f,j} = \sum_L \varphi_{L,t}^f \Phi_{L,s,a,t}^j \tag{11}$$

Discards can be modeled as market-based, whereby the $\varphi_{L,t}^f$'s are constant among length bins, or size-based, when the $\varphi_{L,t}^f$'s are governed by a retention function (*e.g.* logistic):

$$\varphi_{L,t}^f = \begin{cases} \gamma_{t,1}^f & \text{if discards are market-based} \\ \left(1+e^{-(L-\gamma_{t,1}^f)/\gamma_{t,2}^f}\right)^{-1} & \text{if discards are size-based} \\ \gamma_{t,1}^f\left(1+e^{-(L-\gamma_{t,2}^f)/\gamma_{t,3}^f}\right)^{-1} & \text{if both are present} \end{cases} \tag{12}$$

where the $\gamma_{t,i}^f$'s are the parameters of the retention pattern for fleet *f* and year *t*.

The discarded catch by fleet *f* in region *r* during year *t* $D_t^{f,r}$, is then:

$$D_t^{f,r} = \tilde{u}_t^{f,r} \sum_j \sum_s \sum_L (1-\varphi_{L,t}^f) w_{L,s}^j \sum_a \Phi_{L,s,a,t}^j N_{s,a,t}^{j,r} e^{-0.5 M_{s,a,t}^{j,r}} \tag{13}$$

11.2.4 Growth

The mean length-at-age by stock and sex in year *t* is calculated by:

$$\bar{l}_{s,a,t}^j = \begin{cases} \bar{l}_{s,a,t-1}^j & \text{if } a=0 \\ \bar{l}_{s,a-1,t-1}^j + \left(\bar{l}_{s,a-1,t-1}^j - L_{\infty,s}^j\right)\left(e^{-k_s^j}-1\right)e^{g_{s,t}^j - 0.5\sigma_g^2} & \text{otherwise} \end{cases} \tag{14}$$

where $g_{s,t}^j \sim N(0,\sigma_g^2)$ is the deviation in growth increment for year *t*,

$\sigma_{g,j}^2$ is the inter-annual variability in growth increment for stock *j*, and

$\bar{l}^{j}_{s,a,1}$ is the initial mean length-at-age by stock and sex, which is either pre-specified, or determined from the von Bertalanffy growth function (VBGF):

$$\bar{l}^{j}_{s,a,1} = L^{j}_{\infty,s}\left(1-\exp\left(-k^{j}_{s}\left[a-t^{j}_{0,s}\right]\right)\right) \tag{15}$$

where $L^{j}_{\infty,s}$, k^{j}_{s}, and $t^{j}_{0,s}$ are the growth parameters for animals of stock *j* and sex *s*.

The mean weight-at-length is similarly either input directly, or governed by a length-power relationship:

$$w^{j}_{L,s} = \alpha^{j}_{s}\left(L\right)^{\beta^{j}_{s}} \tag{16}$$

where α^{j}_{s} and β^{j}_{s} are the parameters of the weight-length relationship for stock *j* and sex *s*.

Unless the variance of the distribution of length-at-age is input directly (as with mean length and weight), the coefficient of variation in length-at-age is assumed to change linearly with age, with the standard deviation of length-at-age given by:

$$\sigma_{l^{j}_{s,a,t}} = CV^{j}_{s,0} + \frac{a}{x}\left(CV^{j}_{s,x} - CV^{j}_{s,0}\right)\bar{l}^{j}_{s,a,t} \tag{17}$$

where $CV^{j}_{s,0}$ is the CV in length-at-age-0, and

$CV^{j}_{s,x}$ is the CV in length-at-age-x.

11.2.5 Recruitment

The annual recruitments (by region) are log-normally distributed about an underlying Beverton-Holt stock-recruitment relationship (SRR):

$$N^{j,r}_{s,0,t} = 0.5\,R^{j,r}_{t}\,e^{\varepsilon^{r}_{t}-0.5\sigma^{2}_{R,t}} \tag{18}$$

$$R^{j,r}_{t} = \lambda^{j,r}_{t}\left(\frac{4hR^{j}_{0}SB^{j}_{t}}{SB^{j}_{0}(1-h)+SB^{j}_{t}(5h-1)}\right) \tag{19}$$

where ε^{r}_{t} is the recruitment residual for region *r* and year *t*, which can be correlated among regions:

$$\boldsymbol{\varepsilon}_{\mathbf{t}} = MVN(0,\Sigma_{t}) \tag{20}$$

$$\Sigma_{t} = \sigma^{2}_{R}\begin{pmatrix} 1 & \rho^{r_j r_i} & \rho^{r_k r_i} \\ \rho^{r_i r_j} & 1 & \rho^{r_k r_j} \\ \rho^{r_i r_k} & \rho^{r_j r_k} & 1 \end{pmatrix} \tag{21}$$

h is the steepness of the stock-recruitment relationship,

SB_0^j is the spawning biomass at pre-exploitation equilibrium (when recruitment equals R_0^j).

$\sigma_{R,t}$ is the standard deviation of recruitment during year *t*:

$$\sigma_{R,t} = \begin{cases} \sigma_{R1} & \text{with probability } p_{\sigma_{R1}} \\ \sigma_{R2} & \text{with probability } (1 - p_{\sigma_{R1}}) \end{cases} \tag{22}$$

which allows for episodic-style recruitment events by occasionally drawing the recruitment residuals from a distribution that has a larger σ_R).

$\rho^{r_i r_j}$ is the correlation between the recruitment residuals for regions r_i and r_j, and

$\lambda_t^{j,r}$ is the expected fraction of the number of age-0 animals in stock *j* assigned to region *r* during year *t*:

$$\lambda_t^{j,r} = \tilde{S}B_t^{j,r} / SB_t^j \tag{23}$$

The total spawning biomass of stock *j* during year *t* is given by:

$$SB_t^j = \sum_r \tilde{S}B_t^{j,r} = \sum_r \sum_{a=1}^{x} N_{\text{fem},a,t}^{j,r} \tilde{w}_{\text{fem},a,t}^j f_{a,t}^j \tag{24}$$

where $f_{a,t}^j$ is the fecundity of a female of age *a* in stock *j* during year *t*,

$\tilde{w}_{\text{fem},a,t}^j$ is the weight at age of a female of age *a* in stock *j* at the start of year *t*.

11.2.6 Movement

The probabilities of moving among regions are determined by:

$$X_{s,a,t}^{j,r',r} = \frac{\tilde{X}_{s,a,t}^{j,r',r}}{\sum_{r'} \tilde{X}_{s,a,t}^{j,r',r}} \tag{25}$$

where

$$\tilde{X}_{s,a,t}^{j,r',r} = \bar{X}_{s,a}^{j,r',r} e^{\chi_{s,a,t}^{j,r',r}} \tag{26}$$

where $\bar{X}_{s,a}^{j,r',r}$ is the average probability of an animal of sex *s* and age *a* from stock *j* moving from region *r'* to region *r*,

$$\bar{X}_{s,a}^{j,r',r} = \begin{cases} T_s^{j,r',r} m_{s,a}^j & \text{if } r' \neq r \\ 1 - \sum_{r' \neq r} T_s^{j,r',r} m_{s,a}^j & \text{otherwise} \end{cases} \tag{27}$$

$\chi_{s,a,t}^{j,r',r}$ is the random deviation in movement probability,

$$\boldsymbol{\chi}_{s,t}^{j,r',r} \sim MVN\left(0, \sigma_X^2 \mathbf{X}_s^j\right) \qquad \mathbf{X}_s^j = \begin{pmatrix} 1 & \nu_X^{1,2} & \nu_X^{1,3} \\ \nu_X^{1,2} & 1 & \nu_X^{2,3} \\ \nu_X^{1,3} & \nu_X^{2,3} & 1 \end{pmatrix} \tag{28}$$

σ_X^2 is the variance of the deviations in movement probability,

$\mathbf{X}_s^j$ is the correlation matrix among ages for the deviations in movement probability, with $\nu_X^{a_1,a_2}$ being the correlation between ages 1 and 2,

$T_s^{j,r',r}$ is the maximum average probability of moving from region *r'* to region *r*, with $T_s^{j,r'+} = 1$, and

$m_{s,a}^j$ is the relative age-specific movement rate for an animal of stock *j* and sex *s*.

11.2.7 Initial Conditions

The initial (*t*=1) numbers at age for each stock and sex by region are determined by solving the set of linear equations:

$$\mathbf{N}_{s,1}^j = \left(\mathbf{I} - \mathbf{G}_s^j\right)^{-1} \tilde{\mathbf{R}}_{s,1}^j \tag{29}$$

where $\mathbf{N}_{s,1}^j$ is an (*x*+1) x *Nreg* vector containing the initial age structure for animals of stock *j* and sex *s*,

$\mathbf{R}_{s,1}^j$ is the corresponding vector of recruits with elements:

$$\tilde{R}_{s,a,1}^{j,r} = \begin{cases} 0.5\,\lambda_0^{j,r}\,R_0^j & \text{if } a = 0 \\ 0 & \text{if } 1 \le a \le x \end{cases} \tag{30}$$

where $\lambda_0^{j,r}$ is the fraction of stock *j* recruits allocated to region *r* in equilibrium, the value for which is solved for in order to satisfy equation 23, and

$\mathbf{G}_s^j$ is a *p* x *q* transition matrix describing the mortality and movement pattern, the elements of which are obtained from the equations for the population update:

$$G_{s,a_p,a_q}^{j,r_p,r_q} = \begin{cases} X_{s,a_p}^{j,r_q,r_p} e^{-M_{s,a_q,1}^j} & \text{if } a_p = a_q - 1 \\ X_{s,a_p}^{j,r_q,r_p} e^{-M_{s,a_p,1}^j} & \text{if } a_p = a_q = x \\ 0 & \text{otherwise} \end{cases} \tag{31}$$

a_p is the age associated with row *p*,

a_q is the age associated with row *q*,

r_p is the region associated with row *p*, and

r_q is the region associated with row *q*.

11.3 Generating Data

11.3.1 Indices of abundance

11.3.1.1 CPUE

$$Y_t^{f,r} = q_t^{f,r} (B_t^{f,r})^{\omega_t^f} e^{\eta_t^{f,r}} \qquad \eta_t^{f,r} \sim N\left(0, (CV_t^f)^2\right) \tag{32}$$

where $Y_t^{f,r}$ is the CPUE observation for fleet *f* in region *r* during year *t*,

ω_t^f is the power parameter for fleet *f* (set equal to 1 if relationship between CPUE and vulnerable biomass is linear),

$B_t^{f,r}$ is the retainable vulnerable biomass in region *r* for fleet *f* in the middle of year *t*:

$$B_t^{f,r} = I^{f,r} \sum_j \sum_s \sum_L w_{L,s}^j \varphi_{L,t}^f S_{L,t}^f \sum_a \Phi_{L,s,a,t}^j N_{s,a,t}^{j,r} e^{-0.5 M_{s,a,t}^j} \tag{33}$$

$I^{f,r}$ is an indicator equal to 1 if fleet *f* operates in region *r*, and zero otherwise,

CV_t^f is the coefficient of variation of the observation error in CPUE for fleet *f* during year *t*,

$q_t^{f,r}$ is the catchability coefficient for fleet *f* in region *r* during year *t*:

$$q_t^{f,r} = \bar{q}^f e^{\upsilon_t^{f,r} - 0.5\sigma_{q_f}^2} \tag{34}$$

$\bar{q}^f$ is the average catchability for fleet *f*,

$\upsilon_t^{f,r}$ is the rate of change in *q* for fleet *f* in region *r* during year *t*, governed by a correlated random walk:

$$\upsilon_t^{f,r} = \rho_q^f \upsilon_{t-1}^{f,r} + \tilde{\upsilon}_t^{f,r} \sqrt{1 - \left(\rho_q^f\right)^2} \qquad \tilde{\upsilon}_t^{f,r} \sim N(0, \sigma_{q_f}^2) \tag{35}$$

$\sigma_{q_f}^2$ is the variance of the random walk in catchability, and

ρ_q^f is the degree of temporal correlation in the random walk in catchability.

11.3.1.2 Survey

Surveys are assumed to be either indices of exploitable or spawning biomass, with the estimate for survey *g* in region *r* during year *t* being:

$$Y_t^g = \sum_r B_t^{g,r} e^{\eta_t^{g,r}} \qquad \eta_t^{g,r} \sim N\left(0, (CV_t^g)^2\right) \tag{36}$$

$$B_t^{g,r} = \begin{cases} K^{g,r} \sum_j \sum_a N_{\text{fem},a,t}^{j,r} f_{a,t}^j \tilde{w}_{\text{fem},a,t}^j & \text{if } g \text{ is a spawning survey} \\ K^{g,r} \sum_j \sum_s w_{L,s}^j S_L^g \sum_a \Phi_{L,s,a,t}^j N_{s,a,t}^{j,r} e^{-\tilde{t}^g M_{s,a,t}^j} & \text{otherwise} \end{cases} \tag{37}$$

where $\tilde{t}^g$ is the fraction of year *t* when survey *g* takes place,

S_L^g is the survey-specific selectivity at length, and

$K^{g,r}$ is an indicator equal to 1 if region *r* is included in survey *g*, and zero otherwise.

11.3.2 Size composition

The observed proportion of the catch (discarded or retained) in each length bin by sex and fleet (or survey) is determined as a multinomial sample of given sample size $n_{L,t}^{f/g,r}$ from the catch proportions by length bin.

The proportion of the catch in length bin L by region during year t for fleet/survey *f/g* and sex s is:

$$p_{L,s,t}^{f/g,r} = \frac{\tilde{\varphi}_{L,t}^{f/g}\tilde{C}_{s,t,L}^{f/g,r}}{\sum_{L}\tilde{\varphi}_{L,t}^{f/g}\tilde{C}_{s,t,L}^{f/g,r}} \tag{38}$$

where:

$$\tilde{C}_{s,t,L}^{g/f,r} = \begin{cases} K^{g,r}S_{L,t}^{g}\sum_{j}\sum_{a=0}^{x}\Phi_{L,s,a,t}^{j}N_{s,a,t}^{j,r}e^{-\tilde{\tau}^{g}M_{s,a,t}^{j}} & \text{if } g \text{ is a survey} \\ I^{f,r}S_{L,t}^{f}\sum_{j}\sum_{a=0}^{x}\Phi_{L,s,a,t}^{j}N_{s,a,t}^{j,r}e^{-0.5M_{s,a,t}^{j,r}} & \text{otherwise} \end{cases} \tag{39}$$

and:

$$\tilde{\varphi}_{L,t}^{f/g} = \begin{cases} 1 & \text{if } g/f \text{ is a survey} \\ \varphi_{L,t}^{f} & \text{if } g/f \text{ is based on the retained catch} \\ 1-\varphi_{L,t}^{f} & \text{if } g/f \text{ is based on the discarded catch} \end{cases} \tag{40}$$

11.3.3 Age composition

The observed catch-at-age proportions (discarded or retained) by region, sex and fleet (or survey) are determined as a multinomial sample of given sample size $n_{A,t}^{f/g,r}$ from the true catch-at-age proportions. The proportion of the catch that is of age a during year t for fleet/survey *f/g* and sex s in region r is:

$$p_{a,s,t}^{f/g,r} = \frac{\tilde{C}_{s,a,t}^{f/g,r}}{\sum_{a}\tilde{C}_{s,a,t}^{f/g,r}} \tag{41}$$

where:

$$\tilde{C}_{s,a,t}^{g/f,r} = \begin{cases} K^{g,r}\sum_{L}S_{L}^{g}\sum_{j}\Phi_{L,s,a,t}^{j}N_{s,a,t}^{j,r}e^{-\tilde{\tau}^{g}M_{\text{fem},a,t}^{j}} & \text{if } g \text{ is a survey} \\ I^{f,r}\sum_{L}\tilde{\varphi}_{L,t}^{f}S_{L,t}^{f}\sum_{j}\Phi_{L,s,a,t}^{j}N_{s,a,t}^{j,r}e^{-0.5M_{s,a,t}^{j,r}} & \text{otherwise} \end{cases} \tag{42}$$

and:

$$\tilde{\varphi}_{s,a,t}^{f,j} = \begin{cases} 1 & \text{if } g \text{ is a survey} \\ \varphi_{s,a,t}^{f,j} & \text{if } g \text{ is based on the retained catch} \\ 1-\varphi_{s,a,t}^{f,j} & \text{if } g \text{ is based on the discarded catch} \end{cases} \tag{43}$$

The vector of proportions-at-age can be modified to accommodate the effects of ageing error, by applying a suitable ageing error matrix before sampling from the multinomial distribution.

11.4 Projection / Implementation of Harvest Strategy Framework

During the projection period, future catches are set using an appropriate control rule under the harvest strategy framework, following 'tuning' of the operating model using historical catches, input parameters, and stock structure hypotheses.

11.4.1 Allocating TAC by fleet and region (not currently implemented)

For each year of the projection period, the catches for each fleet and region are calculated using a multinomial (with overdispersion) allocation of the total TAC for that year. The expected proportions of the catch for each fleet/region are:

$$p_{C,t}^{f,r} = \frac{C_t^{f,r}}{\sum_{f'}\sum_{r'} C_t^{f',r'}} = \frac{\tilde{p}_{C,t}^{f,r} e^{\tau_{C,t}^{f,r}}}{\sum_{f'}\sum_{r'} \tilde{p}_{C,t}^{f',r'} e^{\tau_{C,t}^{f',r'}}}$$

$$\tilde{p}_{C,t}^{f,r} = \frac{\xi^{f,r} + \psi^{f,r}\left(B_t^{f,r}\right)^{\varsigma^{f,r}}}{\sum_{f'}\sum_{r'}\left[\xi^{f',r'} + \psi^{f',r'}\left(B_t^{f',r'}\right)^{\varsigma^{f',r'}}\right]} \tag{44}$$

where $\tau_{C,t}^{f,r} \sim N(0, \sigma_C^2)$ reflects the extent of over-dispersion, and

$\xi^{f,r}$, $\psi^{f,r}$, and $\varsigma^{f,r}$ are the parameters of the relationship between biomass distribution and catch allocation.

The values of the parameters $\xi^{f,r}$, $\psi^{f,r}$, and $\varsigma^{f,r}$ are determined by fitting the multinomial model in equation 44 to the (known) historical catch proportions by fleet and region.

12. Benefits

The results from this project have had direct benefits to management and the commercial fishing industry in the SESSF, due to the development and testing of improved TAC setting procedures. Problems with the initial implementation of the HSF were identified, improvements were developed, and then tested using the MSE approach. Improvements to the Tiers 3 and 4 Harvest Control Rules were developed and rapidly tested using the MSE framework. These improvements were then presented to and approved by the RAGs during 2008, and applied (where appropriate) to setting the RBCs for 2009. The MSE approach was also used to evaluate proposed rules for changing the total allowable catch in response to the most recent year's catch per unit effort.

The formal testing of the SESSF harvest strategy framework has demonstrated that the framework is consistent with, and meets the requirements of, the Commonwealth Harvest Strategy Policy. This provides all stakeholders with confidence that the fishery is being managed in accordance with agreed sustainability objectives.

13. Conclusion

- Collate the experience with the first year adoption of the SESSF harvest strategy framework, and recommend immediate improvements to the framework.

- Formally test the consistency and robustness of the harvest strategy framework using simulation approaches (management strategy evaluation), and recommend longer term improvements to the framework.

This project has formally tested the SESSF HSF in order to demonstrate that it meets the core elements of the Commonwealth Fisheries Harvest Strategy Policy.

A discussion paper collated the experience with the first year adoption of the SESSF harvest strategy framework, and made nine recommendations for modifications to this framework.

A MSE procedure was developed and used to test each Tier rule. The Tier 1 rule was shown to achieve its aims for a range of species with differing life histories.

Following its initial application, it became clear that the original Tier 3 procedure was not likely to perform in the manner for which it was originally designed. An alternative Tier 3 procedure (i.e. a new assessment method and control rule) was developed, and MSE testing was used to show how it performed for two species types, and a range of initial stock conditions and catch scenarios.

Several versions of the Tier 3 HCRs were tested for a model parameterisation for blue eye trevalla. Results suggest that implementation of age-structure based HCRs such as those examined can be used to effectively manage a species such as blue eye trevalla, given appropriate choice of reference points.

A number of problems had also been identified with the original Tier 4 control rule. An alternative Tier 4 control rule similar in form to the Tier 1 and 3 rules was developed. The MSE procedure was used to test and refine this rule.

The improvements to the Tiers 3 and 4 procedures were presented to, and approved by, the RAGs during 2008, and applied (where appropriate) to setting the RBCs for 2009.

The MSE approach was also used to evaluate rules for changing the total allowable catch in response to the most recent year's catch per unit effort.

The results from this study have provided direct benefits to management and industry, due to improved TAC setting procedures. The formal testing of the harvest strategy framework has provided all stakeholders with confidence that the fishery is being managed in accordance with agreed sustainability objectives.

The MSE testing framework developed in this project is now available for further testing of any future proposed revisions to elements of the HSF (e.g. multi-year TACs and the selection of appropriate discounting of RBCs between Tiers).

14. Appendix A - Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

15. Appendix B – Staff

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