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A KOBE STRATEGY MAATRIX BASED UPON PROBABILISTIC REFERENCE POINTS: AN EXAMPLE USING A BIOMASS DYNAMIC ASSESSMENT MODEL

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SUMMARY

The main management objective of ICCAT is to maintain the populations of tuna and tuna-like fishes at levels which will permit the maximum sustainable catch. Scientific advice designed to meet this objective, in common with other tuna Regional Fisheries Management Organisations (tRFMO) scientific committees, is presented in the form of the Kobe II Strategy Matrix (K2SM). A decision table is given showing the time taken to achieve management objectives (e.g., stock recovery) for different levels of TAC or effort. However, substantial uncertainties still remain in assessments and therefore a key area of research is to show how uncertainty and improvements in information, consistent with the principles of the precautionary approach, can be incorporated into advice, so that for any level of uncertainty there is the same risk of depletion. For example, when there is great uncertainty, total allowable catches (TACs) are set low, while as the quantity of information increases, so do TACs. This means that there is a positive relationship between information and utilisation. In this study, we evaluate how reference points and estimates of stock status based on probability distribution can be used to reward reductions in uncertainty based on a biomass dynamic stock assessment model.

RÉSUMÉ

Le principal objectif de gestion de l'ICCAT vise à maintenir les populations de thonidés et d'espèces apparentées à des niveaux qui permettront la prise maximale équilibrée. L'avis scientifique conçu pour répondre à cet objectif, commun aux comités scientifiques d'autres organisations régionales de gestion des pêcheries (ORGP), est présenté sous la forme de la Matrice de Stratégie de Kobe II (K2SM). Un tableau de décision est fourni, lequel indique le temps nécessaire à la réalisation des objectifs de gestion (p.ex. rétablissement du stock) avec différents niveaux de TAC ou d'effort. Toutefois, d'importantes incertitudes demeurent encore dans les évaluations et un domaine clef de la recherche consiste donc à montrer la façon dont l'incertitude et les améliorations dans l'information, conformément aux principes de l'approche de précaution, peuvent être incorporées dans l'avis, de telle façon qu'il y ait le même risque de raréfaction, quel que soit le niveau d'incertitude. À titre d'exemple, lorsqu'il existe une grande incertitude, le total des prises admissibles (TAC) est établi à un faible niveau, tandis qu'au fur et à mesure que le volume d'information s'accroît, les TAC en font autant. Cela signifie qu'il y a une relation positive entre l'information et l'utilisation. Dans la présente étude, nous évaluons la façon dont les points de référence et les estimations de l'état des stocks basés sur la distribution de probabilités peuvent être utilisés pour réduire l'incertitude sur la base du modèle d'évaluation des stocks dynamique de biomasse

RESUMEN

El principal objetivo de ICCAT es mantener las poblaciones de túnidos y especies afines en niveles que permitan capturas máximas sostenibles. El asesoramiento científico concebido para alcanzar este objetivo, común a los comités científicos de otras organizaciones regionales de ordenación pesquera de túnidos (OROP de túnidos) se presenta en forma de matriz de estrategia de Kobe II (K2SM). Se presenta una tabla de decisión que muestra el tiempo requerido para alcanzar los objetivos de ordenación (por ejemplo, recuperación del stock) con diferentes niveles de TAC o esfuerzo. Sin embargo, siguen existiendo importantes incertidumbres en las evaluaciones y, por tanto, un campo clave de investigación es mostrar el

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modo en que la incertidumbre y las mejoras en la información, de un modo conforme con los principios de precaución, pueden incorporarse en el asesoramiento, de tal modo que para cualquier nivel de incertidumbre exista el mismo riesgo de merma. Por ejemplo, cuando existe una gran incertidumbre, el total admisible de capturas (TAC) se establece en un nivel bajo, mientras que a medida que la cantidad de información se incrementa, también se incrementan los TAC. Esto significa que hay una relación positiva entre la información y la utilización. En este estudio se evalúa el modo en que los puntos de referencia y las estimaciones sobre el estado del stock establecidos a partir de la distribución de probabilidades pueden utilizarse para establecer reducciones en la incertidumbre, básandose en un modelo de evaluación de stock de dinámica de biomasa.

KEYWORDS

Biomass dynamic, Kobe Matrix MSY, Pella-Tomlinson, probabilistic, reference points

1. Introduction

The main management objective of ICCAT is to maintain the populations of tuna and tuna-like fishes at levels which will permit the maximum sustainable catch. This is interpreted as using maximum sustainable yield (MSY) as a target. Scientific advice within ICCAT is therefore based on MSY-based reference points generally derived either from a biomass dynamic stock assessment model or a yield per recruit analysis combined with a stock recruitment relationship.

ICCAT management advice, in common with other tuna Regional Fisheries Management Organisations (tRFMOs), is presented in the form of a decision table (known as the Kobe Strategy Matrix or K2SM) that shows the probabilities of achieving a management objective for different options (e.g. catch or effort levels) over vrious time frames. Advice given by the Scientific Committe of ICCAT in the form of the K2SM, has up until now been for recovery plans, where the stock is currently overfished and overfishing is occurring, and the objective is to recover the stock to a level that will support MSY in the long-term. Advice for stocks that are not currently over exploited has historically been to not allow fishing capacity to increase above the current level.

Recognising the need to provide a consistent advice framework for stocks (i.e. both depleted stocks and those that currently can support MSY) the SCRS has recommended that Harvest Control Rules (HCRs) be developed. A HCR specifies in advance what actions should be taken depending upon the status of the stock relative to target and limit reference points. For example, when a stock is assessed and found to be overfished (i.e. below a biomass limit such as 75% of B_{MSY}) the reduction in TAC to promote stock recovery is based upon an rule known in advance. When the stock has recovered the TAC will then be based on a target fishing mortality.

Harvest control rules are recommended as part of the Precautionary Approach Garcia [1996], an important principle of which is that uncertainty and an improvement in information have to be taken into account within management advice. [Cooke, 1999] gives an example from the International Whaling Commission (IWC) where the TAC is set so that for any information level there is the same risk of depletion. In this case, where uncertainty over stock size is high, TACs are set low and, conversely, better knowledge leads to an increase in TACs. Therefore, there is a positive relationship between information and utilisation. This is in contrast to the conventional approach where harvest levels are only reduced when there is sufficient information to indicate the need for such limits. Under these circumstances, information has a negative value to the fishery in the short term.

Although in the past F_{MSY} has been considered a target, fishing at F_{MSY} will mean that 50% of the time biomass will be below B_{MSY} and so should really be thought of as a limit. The fishing mortality target instead being based upon a multiple of F_{MSY}, e.g. 75% of F_{MSY}. However, taking a point estimate or expected value, if stock assessments and reference points are highly uncertain, will not necessarily link information quality to risk within the K2SM advice framework. Taking 75% of F_{MSY} will have different consequences depending on the uncertainty associated with the assessment and appropriate multipliers will need to be derived on a case-specific basis.
We therefore evaluate how data quality impacts on the estimates used in the K2SM, i.e. stock, harvest rate, B_{MSY} and F_{MSY}. We do this by using a biomass dynamic model to both simulate data where data have different information content and levels of measurement error. Information content depends upon the length of the time series and the contrast in the data, i.e. have periods of underexploited and overexploitation been seen? so that the productivity of the resource can be estimated. Measurement error refers to the quality of the data (i.e. how much

random noise is on individual observations). Uncertainty is estimated using a jack-knife, a relatively quick and non-intensive computational procedure.

We then discuss how advice based upon such estimates of uncertainty could be used with the current ICCAT advice framework.

2. Material and methods

Within the K2SM advice framework, once estimates of stock status have been obtained projections are made for different levels of TAC, and the joint probability of the stock being greater than B_{MSY} and fishing mortality being below BF_{MSY} is calculated by year and TAC level. This allows managers to set a quota for a given probability of stock recovery within an agreed time scale. Uncertainty in estimates of stock status and reference points can be considered from within a single model and across different models, e.g. from different parameterisation of a single model or competing models. Typically the results from bootstrap or MCMC runs are used to provide estimates of current stock status and reference points. Each run is then projected under the same range of TACs and the values of stock and harvest rates to B_{MSY} and F_{MSY} calculated. The probabilities for use in the K2SM are calculated from all the runs combined (within and across models) with appropriate weightings.

We use a biomass dynamic model to simulate a time series for a stock that was initially underexploited before becoming overfished, following which fishing mortality was reduced and the stock recovered. We then simulated data with noise added from this time series for use within a biomass dynamic stock assessment model, which was used to estimated stock status and reference points.

3. Stock dynamics

The Russell equation Russell (1931)

$$B = I - E + G + R - F + M \quad (1)$$

relates changes in stock biomass (B) to gains due to growth (G), recruitment (R) and immigration

(I) and losses due to fishing mortality (F), natural mortality (M) and emigration (E). In the case of a biomass dynamic model biomass next year is modelled by the biomass this less catch plus surplus production (P).

$$Bt+1 = Bt+1 - Ct+1 + Pt+1 \quad (2)$$

In common with most single species stock assessment methods there is no immigration to or emigration from the stock. Since stocks tend to be defined by the area within which a fishery operates, rather than in terms of biological understanding of population structure Reiss et al. (2009), it should be noted that this may have unforeseen ecological and evolutionary impacts.

Modelled by an S-shaped curve, i.e. it is low at low and high population sizes. In this study dynamics were modelled by a Pella-Tomlinson surplus production function Pella and Tomlinson (1969), where population growth is modelled by an S-shaped curve, i.e. productivity is low at low and high population sizes.

$$r/p * B * (1 - (B/K)^{p}) \quad (3)$$

The three parameters of Pella-Tomlinson are the intrinsic rate of increase (r), carry capacity (K) and shape of the surplus production function (p).

The dynamics, i.e. the response of the stock to perturbations, are determined by r and the shape of the production function p; if p = 1 then MSY is found halfway between 0 and K, as p increases MSY shifts to the right (**Figure 1**).

Obviously explaining all the dynamics of a population by three parameters is a gross simplification as is assuming that all individuals of a species in a fisheries are from a single population. However, even in more complicated models such as virtual population analysis the parameters and models used for natural mortality, stock recruitment and even growth are poorly known.

The assessment model used was FLBioDym a biomass stock assessment model implemented as an R package within FLR (Kell et al. 2007; http://www.flr-project.org). A jack-knife procedure was also applied (i.e. where an individual CUPE data point was dropped from the estimation procedure) to estimate the standard errors of the estimated statistics.

3.1 Simulations

A simulated time series was generated to mimic a stock where fishing was initially stable at a level below F_{MSY}, before increasing to a level greater than F_{MSY} , after which a recovery plan was implemented to reduce fishing mortality to below F_{MSY} (**Figure 1**). This results in the stock declining then recovering.

Fishing mortality was 50% of F_{MSY} for the first twenty years then increasing linearly to 150% of F_{MSY} over the next thirty years, then declining to F_{MSY} over the next fifteen years before settling at F_{MSY} for 5 years.

K was fixed at a value of 1000, r =0.5, and the shape parameter (p) was equal to 1, so the production function was symetric. The same trajectories are shown in **Figure 2** in the form of a Kobe Phase plot; where the x-axis corresponds to biomass: B_{MSY} and the y-axis harvest: F_{MSY}. The red zone corresponds to a stock that is both over fished and over fishing is occurring. Quadrants are defined for the stock and fishing mortality relative to B_{MSY} and F_{MS}, i.e. red when $B<B_{MSY}$ and $F >F_{MSY}$, green if BB_{MSY} and FF_{MSY} , and yellow otherwise.

Data were then simulated from the time series to generated inputs, i.e. catch and catch per unit effort (CPUE), for the biomass dynamic assessment model. Measurement error (in the form of a lognormal pdf) was also modelled for the CPUE.

Time series of stock biomass and harvest rate, the parameters r & K and MSY benchmarks (MSY, F_{MSY} and B_{MSY}) were then estimated for time series starting in year 1 and ending in each year from year 20 to year 70, for three scenarios where measurement error on the CPUE corresponded to a CV of 20, 30 or 40%. This allowed the impact of the information content of the data and measurement error to be evaluated.

Next to evaluate how uncertainty from an assessment impacts advice based on the K2SM, we simulated stock assessments with given levels of uncertainty. This was done using the catch in **Figure 2** but by assuming that r had been estimated with uncertainty; i.e. a CV of 15, 30 or 60%. Time series of biomass and reference points were then generated by performing a forward projection assuming B_0 and K were known without error.

The K2SM was then generated by projecting for multiples of F_{MSY}, i.e. rather than for catch. This allows the performance of a target harvest rate to be evaluated with the K2SM framework.

The performance of probabilistic reference points and multipliers on point estimates or expected values were then compared for projections based upon a multiple of 50% of F_{MSY} and for a probabilistic reference points set at the 35th percentile of F_{MSY}. Chosen since at the 30% stock assessment uncertainty level, this was equal to 50% F_{MSY}, making comparisons easier.

4. Results

The medians and inter-quartiles of the point estimates relative to the true values for MSY, B_{MSY} ,F_{MSY} , r, harvest rate, stock, harvest rate relative to F_{MSY}) and stock relative to B_{MSY}) are presented in **Figure 3**, while in **Figure 4** the CVs from the jack knife are presented for the same quantities.

Figure 3 shows that uncertainty is greater in the estimates from the earlier periods declining as the time series grows. The greatest relative reduction in uncertainty occurs at between years 30 and 40 when fishing mortality increases and contrast is seen in the data, i.e. when it contains more information. For the reference points uncertainty is greatest for B_{MSY} and F_{MSY} with MSY being well estimated. The relative estimates of stock and harvest rate (i.e. B : B_{MSY} and F : F_{MSY}) as used in the K2SM are much better estimated than the absolute values. There is also a bias in the early period due to r being overestimated.

Contrasting the effect of measurement error shows, as expected, that the greatest uncertainty is seen when the CV is 40%, but interestingly reducing the CV from 30 to 20% has little effect. The CVs presented in **Figure 4** show that the standard errors of the relative estimates are smaller than for the absolute values, although MSY is not more precisely estimated than B_{MSY} and F_{MSY}. Again reducing measurement error from 30 to 20% has little effect. This would imply that management advice based upon relative quantities is more precise than advice based upon harvest rate and absolute values.

In **Figure 5** K2SM are plotted for constant harvest rate projections for the simulated stock assessment. For management objective of achieving stock recovery by year 50 with a 75% probability then this would be achieved with F_{MSY} times 0.7, 0.6 and 0.5 for uncertainty levels of 20, 30 and 40%, respectively. That is for a given risk level of stock depletion as uncertainty increases fishing mortality should decrease.

The performance of probabilistic reference points and multipliers on point estimates or expected values are compared in **Figure 6**. These plots are of the probability of being in the green zone of the Kobe phase plot (i.e. F $<F_{MSY}$ and $S>B_{MSY}$) by year for the three levels of stock assessment uncertainty. In the case of the multiplier F was set at 50% of F_{MSY} while in the case of the probabilistic reference points the 30th percentile of F_{MSY} was taken as the target harvest rate. Chosen since at the 30% stock assessment uncertainty level this was equal to 35th percentile of F_{MSY}, making comparisons easier. It can be seen that in year 50 using the probabilistic reference point achieved the same risk level, i.e. there is about a 70% probability of stock recovery, while using a multiple of F_{MSY} results in the probability of stock recovery depends on assessment uncertainty. While in the case of the probabilistic reference points the performance of 30 and 40% stock assessment levels of uncertainty are very similar, for a 20% level initial stock recovery is delayed.

The corresponding yields are shown in **Figure 7**. In the case of the target harvest rate being a multiple of F_{MSY}, higher yields occur when uncertainty is greatest, while in the case of probabilistic reference points, the reverse is seen.

5. Discussion

This study looked at uncertainty in stock assessment and its impact on estimates of stock status, harvest rates and MSY based reference points used to provide management advice. The impact of uncertainty was evaluated by looking at how uncertainty affected risk, e.g. probability of future stock depletion.

The first part of the study evaluated the relative importance of information content and measurement error. Information content was modelled by length of the data used by the stock assessment and the level of contrast in the data, i.e. had periods of over exploitation and under exploitation been seem allowing estimates of productivity to be obtain. The second compared the performance of reference points based on a multiplier of a point or expected reference point with reference points based on the lower percentile of a probabilistic reference point. This was done within the Kobe advice framework adopted by the tuna RFMOs.

A main finding was that information content is important. If only a short time period of data are available where little contrast has been seen in the dynamics of the stock, then reference points and stock status as required for harvest control rules will be poorly estimated. Measurement error was also important but there was little gain in reducing error from 30 to 20%. This implies that implementing data collection schemes based solely on catch and CPUE will not show immediate benefits, and additional information that helps estimate key stock parameters is also needed.

Relative values of stock status and fishing mortality were more precisely estimated than absolute values, a finding also found by Kell and Fromentin (2007). This is consistent with the practice of the K2SM where probabilities are created based on relative values calculated within a bootstrap or MCMC run (i.e. for each run both the stock value and reference point are estimated). There were differences between f and biomass reference points and it MSY was much better estimated than B_{MSY} or F_{MSY}.

Although the usual preference by stock assessments scientists is for methods that provide absolute values (e.g. VPA), these estimates can also be thought of as relative. For example, in the case of VPA natural mortality and plus-group dynamics are poorly known, and changing either can result in large differences in stock estimates and reference points. Methods that only generate relative indices, e.g. Trenkel and Skaug (2005) should be explored in this context. However, this needs to be done within the framework of a management procedure that links the data and assumed level of knowledge with a stock assessment procedure and, depending upon the perceived stock status and reference points, the HCR determines the appropriate management action.

The K2SM framework provides for such advice, however to date it has only been used to evaluate constant catch strategies. In this study we show how it can be used to evaluate target reference points. This is a clear necessity if management plans that consider stocks at different levels of depletion, i.e. both recovery and long term management plans, are to be used. We evaluated both targets based on point estimates and probabilistic estimates and showed that the risk related performance of probabilistic reference points was better than point estimates, and that across the range of uncertainties considered, the risk of depletion and the probabilities of recovery were constant for the target based upon the probabilistic estimates. These also linked utilisation to uncertainty, i.e. as uncertainty increased the realised yield declined. This means that in the case of probabilistic reference points there is a positive relationship between information and yield while in the case of point estimates that relationship is negative.

That relative estimates are less uncertain than absolute estimates supports the use of empirical HCRS in which the control variables are directly measurable quantities (e.g., catch rate, size composition, tag recovery rate, survey estimates of abundance and species composition). There is thus no need to come up with an absolute estimate, and relative procedures that use year to year changes and trends may perform as well or better. A problem is in choosing appropriate reference levels (e.g. an absolute value to initiate the process) which may be based on historical catch and or effort and be tuned to meet management objectives.

For sustainable utilisation consistent with the precautionary approach and economic development, it is important to develop management systems where there is a positive relationship between the value-of-information and economic yield Mäntyniemi et al. (2009). Likewise for the value-of-control, i.e. better management regulations should also result in increased benefits from a fishery. Historically information, particularly in fisheries which there is over capacity, has had a negative effect, i.e. wait until there is evidence of a decline before taking management action. Linking information and control via risk to utilisation is therefore an important task for scientific advice frameworks.

Development of such frameworks is ideally done through Management Strategy Evaluation (MSE). An important aspect of the MSE approach is that a wide range of uncertainty is considered and that management outcomes from the HCR are fed back into the operating model so that their influence on the simulated stock and hence on the future simulated fisheries data is propagated through the stock dynamics. A reason for this is because stock assessment mainly considers only uncertainty in observations and process (e.g. recruitment) and uncertainty about the actual dynamics (i.e. model uncertainty) has a larger impact on achieving management objectives (Punt 2008). In this study we only considered data quality (e.g. measurement error and information content) and stock assessment, to develop appropriate management plans on a case specific basis requires a wider range of uncertainty to be considered and also the recognition of the importance of feedback and management measures rather than stock assessment in isolation, since Management will get you through times of no assessment better than assessment will get you through times of no management (Franklin pers comm.).

6. Conclusions

Data. The information content of the data used to provide management advice, not just the level of sampling and hence precision of observations, is important. Since management advice requires estimates of current status but also reference points related to productivity. The former can be estimated from a fishery in a steady state or even from a short-time series of data. The latter may require a longer time series and changes in stock status.

Biology. Biological reference points are important for use within management frameworks and harvest control rules in order to trigger management action and set targets. To reduce uncertainty about appropriate targets and triggers for implementing management actions such as recovery plans requires a reduction in uncertainty about those reference points. Biological and ecological information can be important in order to reduce such uncertainty.

Relative. The study showed that estimates of stock status relative to reference points are more precise that absolute estimates of stock status or reference points. This supports the use of relative indices that could be used as part of empirical HCRs

Risk. An important issue for management is to relate utilisation to uncertainty, so that there is a positive relationship between information and use. Since this will lead to better use of renewable resources in the long-term.

Probabilistic Reference Points. It was shown that using a lower percentile of an estimated reference point performs better that using a point estimate. Since this helps ensures that the level of risk, a key management objective is independent of the level of uncertainty. So that as uncertainty increases the risk stays the same, but also importantly there is economic benefit to reducing uncertainty.

MSE. Although this study only considered a limited range of uncertainty, it illustrated the benefits of using reference points that explicitly incorporate uncertainty. However, before such reference points can be used within a management advice framework they should be tested as part of HCRs using MSE that fully considers the main sources of uncertain.

7. Acknowlegements

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This document does not necessarily reflect the view of the European Commission and in no way anticipates the Commission's future policy in this area.

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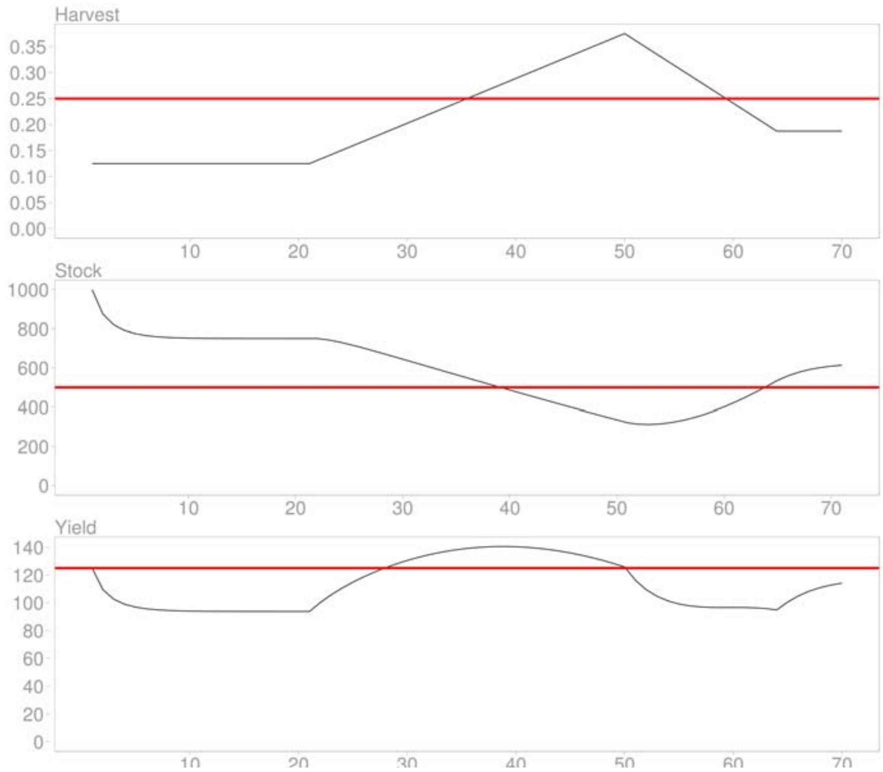

Figure 1. Time series of harvest rate, stock biomass and yield for the simulated population; red horizontal lines are the MSY based bench marks.

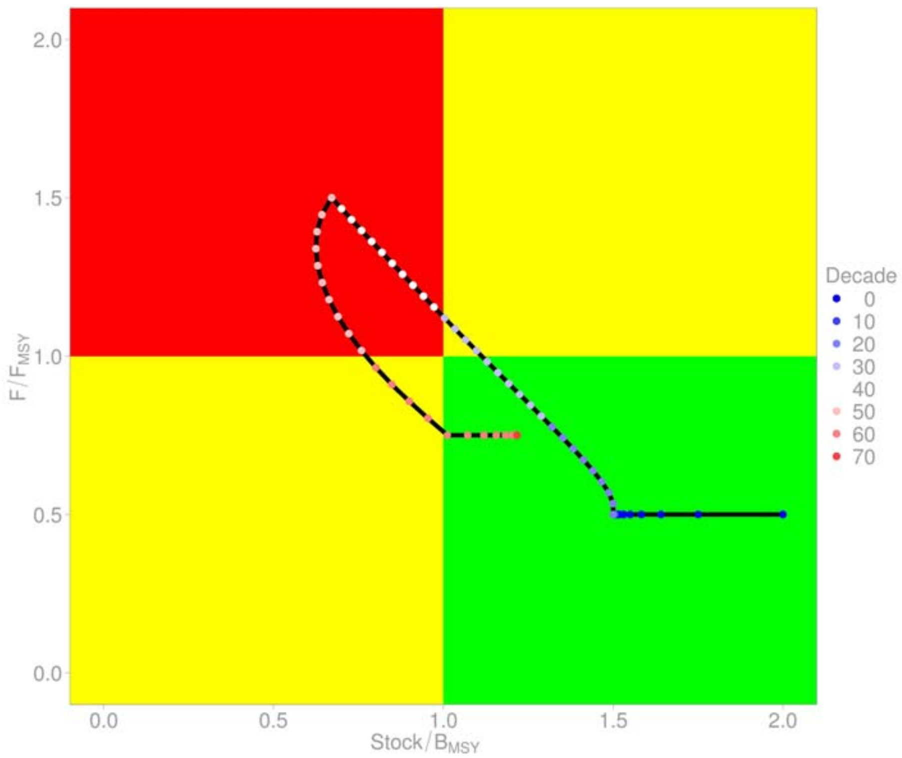

Figure 2. Phase plot for the simulated population, showing stock against harvest rate scaled by MSY benchmarks; the red zone corresponds to overfishing and overfished and green to a stock that is currently greater than B_{MSY} and is being fished at a level below F_{MSY}.

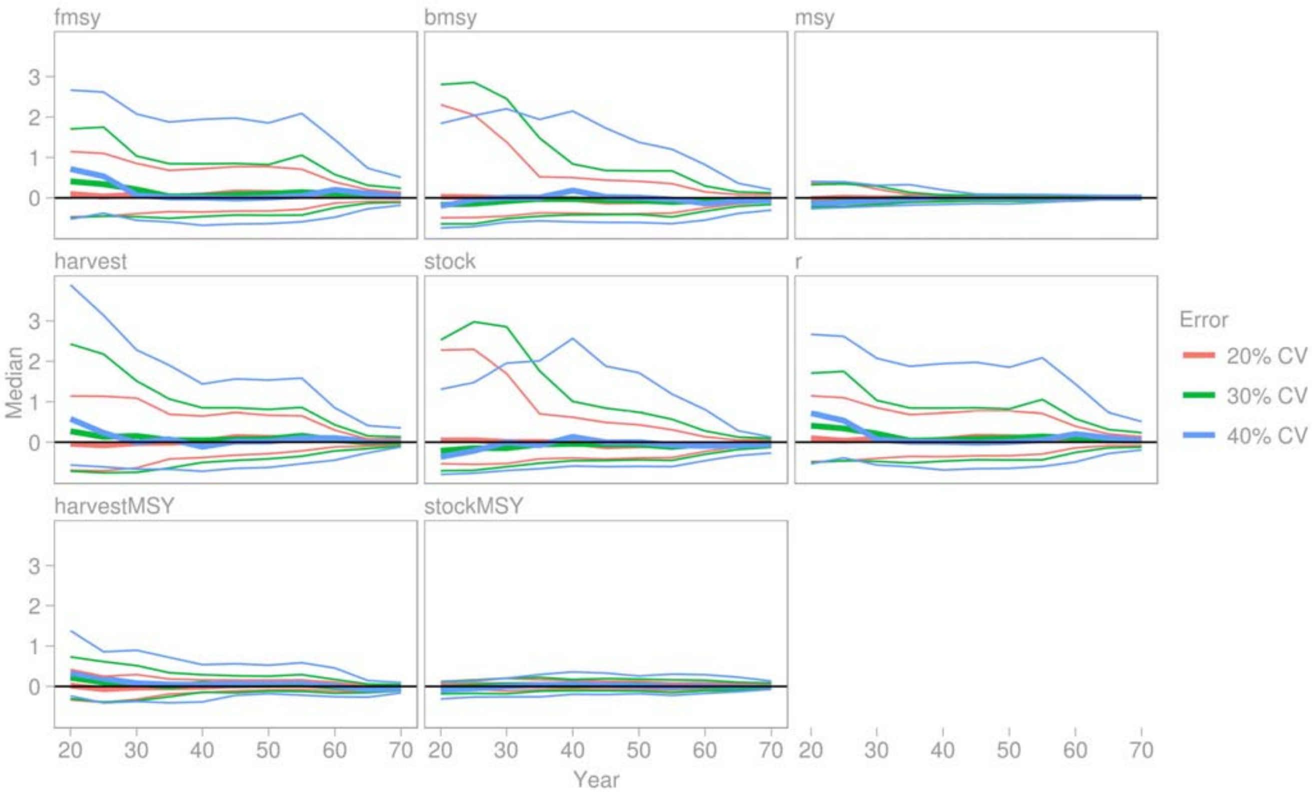

Figure 3. Time series of probability distributions for the stock assessment point estimates relative to true values. Quantities shown are MSY benchmarks, harvest rate and stock status, and harvest rate and stock status relative to benchmarks, by year for the three uncertainty levels. Lines are medians (thick) and inter-quartiles (thin).

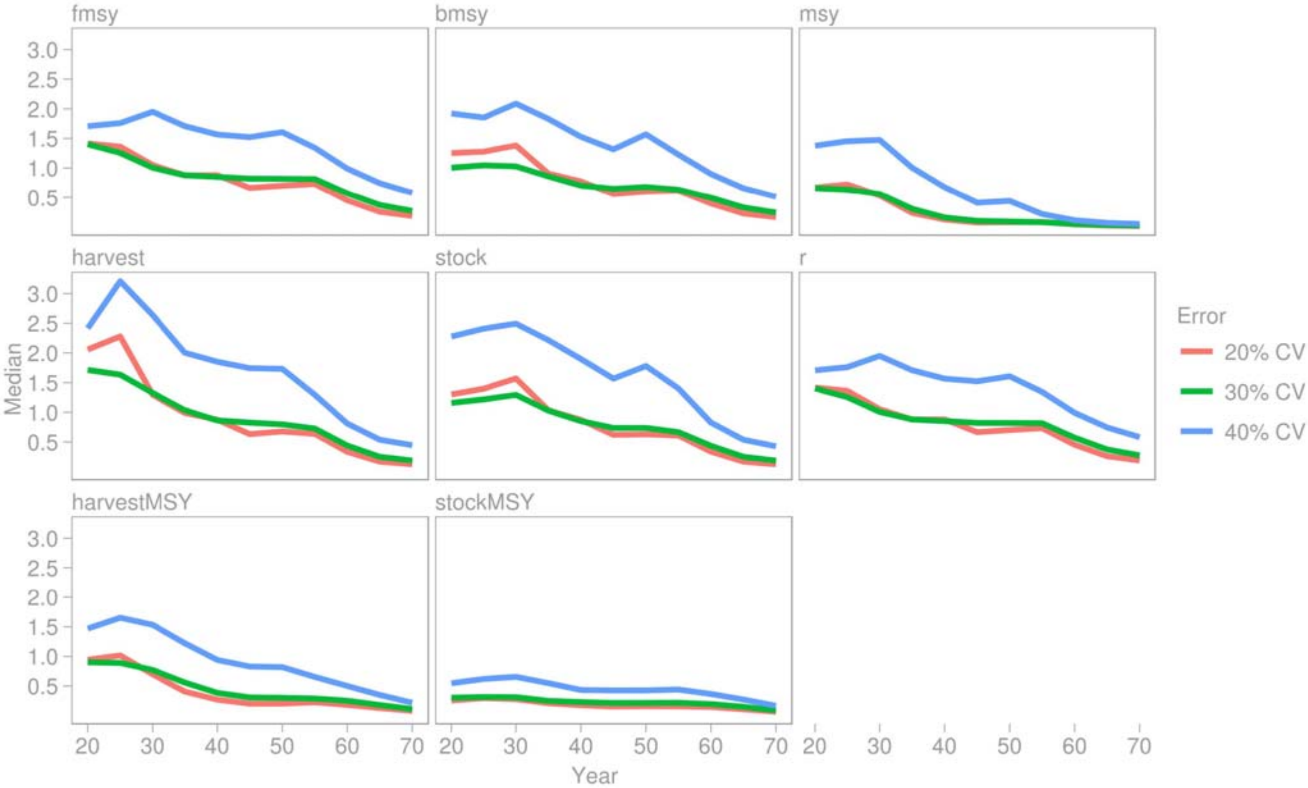

Figure 4. Time series of the CVs of the estimates of MSY benchmarks, harvest rate and stock status, and harvest rate and stock status relative to benchmarks, by year for the three uncertainty levels.

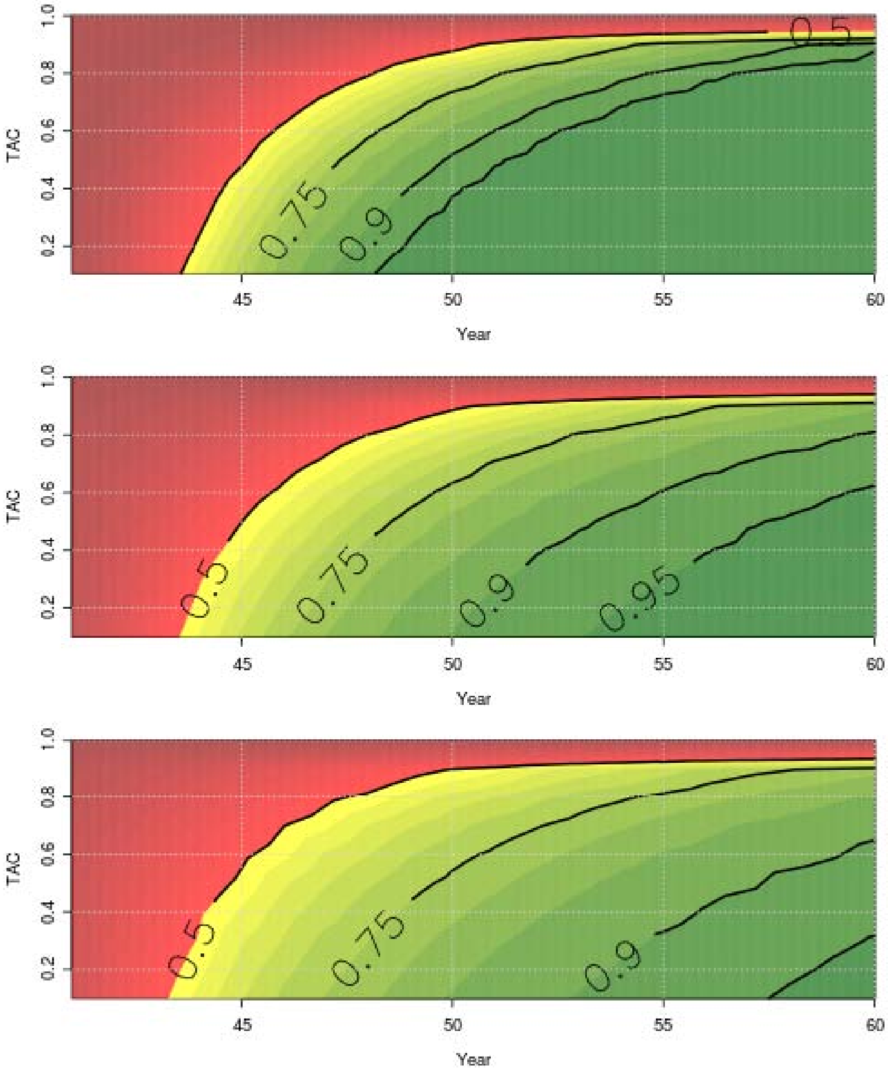

Figure 5. Kobe II Strategy Matrices by scenario; the contours are the probabilities of being in the green quadrant of the phase plot (i.e. not overfished or overfishing).

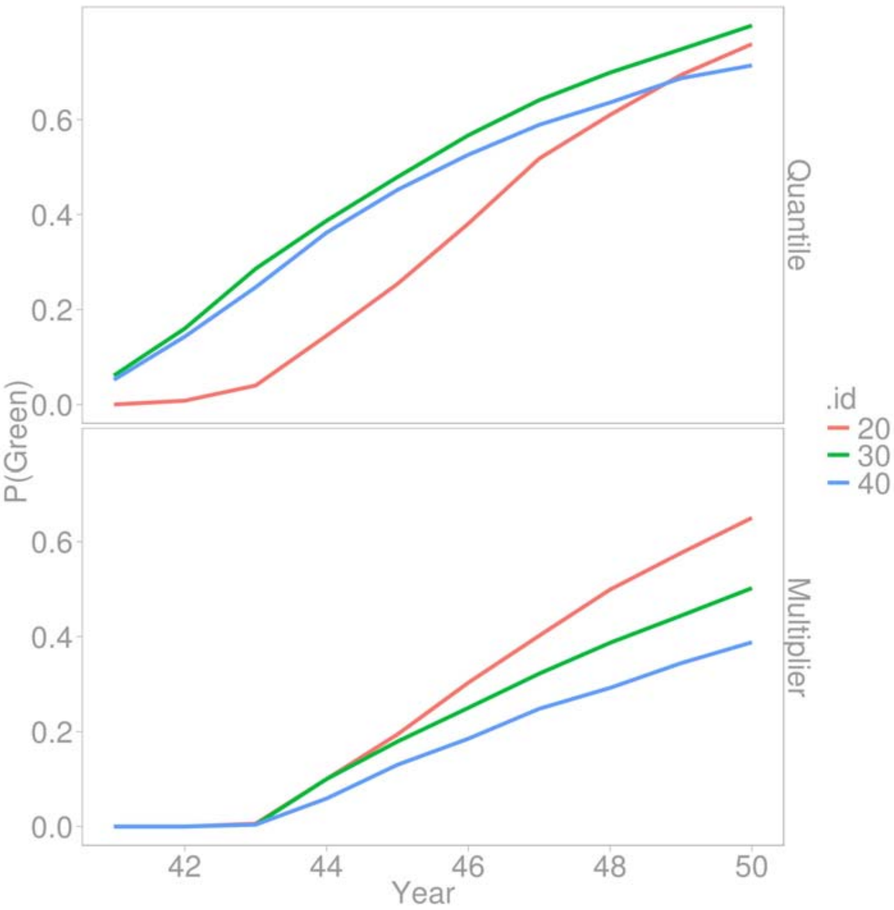

Figure 6. Probability of being in the green zone of the K2SM for the three uncertainty levels, top panel is for probabilistic reference points and bottom for point estimates.

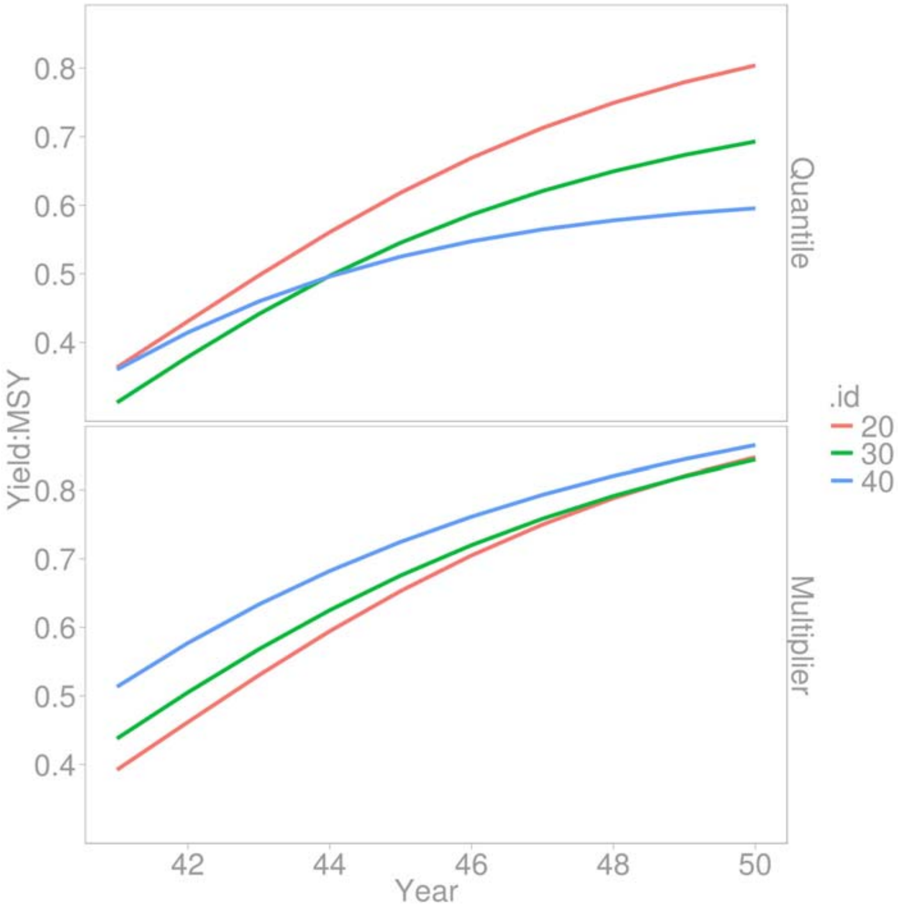

Figure 7. Median yields, top panel is for probabilistic reference points and bottom for point estimates.