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AN EVALUATION OF THE PERFORMANCE OF THE KOBE STRATEGY MATRIX: AN EXAMPLE BASED UPON 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). This is essentially a decision table showing the time taken to achieve management objectives (e.g., stock recovery) for different levels of TAC or effort. The role of the K2SM as an important tool to communicate efficiently among all stakeholders and to assist in the decision-making process according to different levels of risk has been recognised. However, substantial uncertainties still remain in assessments, and at Kobe III it was recommended that the scientific committees and bodies of the tRFMOs develop research activities to better quantify the uncertainty and understand how this uncertainty is reflected in the risk assessment inherent in the K2SM. Therefore, in this study we evaluate how uncertainty impacts the advice presented in the form of the Kobe II Strategy Matrix. We do this for 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). Il s'agit essentiellement d'un tableau de décision indiquant le temps nécessaire à la réalisation des objectifs de gestion (p.ex. rétablissement du stock) avec différents niveaux de TAC ou d'effort. On a reconnu le rôle de la K2SM comme étant un outil important de communication efficace entre toutes les parties prenantes et d'aide au processus de prise de décisions selon différents niveaux de risques. Toutefois, d'importantes incertitudes demeurent encore dans les évaluations et, lors de Kobe III, il a été recommandé que les comités et les organes scientifiques des ORGP thonières élaborent des activités de recherche visant à mieux quantifier l'incertitude et à comprendre la façon dont cette incertitude est reflétée dans l'évaluation des risques inhérente à la matrice K2SM. C'est pourquoi nous évaluons dans la présente étude la façon dont l'incertitude a un impact sur l'avis présenté sous la forme de la Matrice de stratégie de Kobe II. Nous faisons ceci pour un modèle d'évaluation de stock de dynamique de la 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 trata básicamente de 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. Se ha reconocido el papel desempeñado por K2SM como importante herramienta para una comunicación eficaz entre todas las partes interesadas y para contribuir al proceso de toma de decisiones en función de los niveles de riesgo. Sin embargo, siguen existiendo importantes incertidumbres en las evaluaciones, y en

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Kobe III se recomendó que los comités científicos y los organismos de las OROP de túnidos desarrollen actividades de investigación para cuantificar mejor la incertidumbre y para comprender el modo en que dicha incertidumbre se refleja en la evaluación de riesgo inherente en la K2SM. Por tanto, en este estudio se ha evaluado el modo en que la incertidumbre afecta al asesoramiento presentado en forma de matriz de estrategia de Kobe II. Se ha realizado esto para un modelo de evaluación de stock de dinámica de biomasa.

KEYWORDS

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

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 commonly interpreted as using maximum sustainable yield (MSY) as a target, obtained as a model-based reference point. This is typically derived either from a biomass dynamic model or a yield per recruit analysis combined with a stock recruitment relationship.

Within ICCAT, and in common with other tuna Regional Fisheries Management Organisations (tRFMOs), management advice designed to meet this objective is presented in the form of the Kobe II Strategy Matrix (K2SM). This is in essence a decision table that shows the probabilities of achieving a management objective for different options (e.g. catch or effort levels) over various time frames.

The K2SM is an important tool for communicating efficiently among all stakeholders, and assists in the decision-making process by considering the levels of risk associated with different management choices. However it was recognized at the Kobe III meeting (Document K3-REC-A) that substantial uncertainties still remain in assessments. It was therefore recommended that the Scientific Committees and Bodies of the tRFMOs develop research activities to better quantify the uncertainty and understand how this uncertainty is reflected in the risk assessment inherent in the K2SM.

Within ICCAT and other tuna RFMOs, biomass dynamic models are commonly used to perform stock assessment and provide input for the K2SM. Therefore in this study we evaluate how uncertainty affects the ability of biomass dynamic models to estimate MSY-based reference points and stock status. We then discuss how this impacts the ability to provide management advice in the form of the Kobe Strategy Matrix.

Explaining all the dynamics of a population by the three parameters characterizing a surplus production model is a gross simplification, as is assuming that all individuals of a species in a fishery are from a single homogeneous population. However, it does provide a simple example for evaluating uncertainty without excessive modeling and computational requirements.

2. Material and methods

The Russell equation (Russell 1931)

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

relates to 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, this is simplified to:

$$B_{t+1} = B_t - C_t + P_t \quad (2)$$

i.e., next year biomass is this year's biomass less catch (C) plus surplus production (P).

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.

In this study dynamics were modeled by a Pella-Tomlinson surplus production function Pella and Tomlinson (1969), where population growth is modeled 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**).

2.1 Simulations

A simulated time series was generated assuming that harvest rate had increased linearly from 0 in year 1 to 1.5 times F_{MSY} by year 40 and then linearly decreased to 0.5 times F_{MSY} by year 80 (**Figure 2**). This exploitation history was chosen since the time series generated are simple enough to understand the consequences of the assumptions within the simulations. K was fixed at a value of 1000, while r =0.5, and the shape parameter (p) was equal to 1, i.e. the production function was symmetric.

Data were then simulated from these time series to generate input data of catch and catch per unit effort (CPUE) for the assessment. Measurement error (with lognormal CV of either 30% or 50%) was also added to 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 using FLBioDym, a biomass stock assessment model implemented as an R package within the FLR suite (Kell et al. 2007), http://www.flr-project.org).

The same trajectories in **Figure 2** are shown in the form of a Kobe Phase plot in **Figure 3**; where the x-axis corresponds to B: B_{MSY} and the y-axis F: 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_{MSY}; i.e. red when B<B_{MSY} and F >F_{MSY}, green if BB_{MSY} and FF_{MSY}, and yellow otherwise.

The Kobe matrix based on the phase plot is basically a decision table summarising the probabilities of achieving biomass or fishing mortality rate targets under different management actions. Before a Kobe II matrix can be produced, the stock historical assessment has to be projected for a range of management options related to different values of total allowable catch (TAC).

Two experiments were performed related to: (1) scenarios corresponding to the assumptions made when performing the assessment; and (2) the length of the time series used in the assessment. The first allowed the effect of model uncertainty due to significant processes or relationships are wrongly specified to be evaluated. The second allowed the importance of the information content and length of the data to be evaluated.

In the first case, scenarios corresponded to:

1) No bias
2) b0 bias, assumed to be 50% of true value
3) p bias, assumed to be 0.5
4) p bias, assumed to be 1.5
5) Error model, incorrectly assumed to be a normal error model for CPUE in MP
6) CPUE with a CV of 50%

Uncertainties include model error due to value uncertainty; (i.e., due to missing or inaccurate data or poorly known parameters), and were modeled in the form of mis-specification of p and B0 (the biomass as a fraction of K). While model uncertainty was modeled by mis-specification of the error model used to fit the catch per unit effort (CPUE); i.e., although the simulated pseudo data had been generated with a normal error the assessment model assumed a log-normal error. Two different CVs for the CPUE were also evaluated (30% and 50%).

In the second case times series were generated starting in each year from year 1 through to year 51, in 10-year intervals, and ending in year 30 through to year 80, in 5 year intervals. This allows the importance of the length of the time series and its information content to be evaluated.

3. Results

The results from the first experiment are presented in **Figure 4**. These compare for the various scenarios (in rows) the frequency distributions of the estimates of the three reference points (MSY, B_{MSY} and F_{MSY}), and absolute and relative estimates of stock and harvest rate in the last year of the assessment (80).

Comparing the first three columns shows that MSY is more precisely estimated that either B_{MSY} or F_{MSY}, that stock and harvest are estimated with similar precision to the reference points, but that the relative values (i.e. the probabilities of being overfished and of overfishing) are better estimated.

Inspection down the rows shows that mis-specification of the shape parameter (p) has the largest effect, i.e. underestimating the probabilities of being overfished and of overfishing occurring. The next effect in importance is the CV of the CPUE series, which has a greater effect than mis-specifying B0, or the choice of error model used for CPUE.

The results of the second experiment are presented in **Figures 5** and **6**, and refer to an assessment where data are from different time periods. The column corresponds to the first, and the row to the last, year of data used in the assessment, **Figure 5** shows the biomass relative to B_{MSY}, and **Figure 6** the harvest rate relative to F_{MSY}. A quick inspection of column one shows that the stock was originally underexploited, then becoming over exploited, and then recovered by year 80.

A comparison between **Figures 5** and **6** shows that, initially, estimates of harvest rate relative to F_{MSY} are very uncertain while estimates biomass relative to B_{MSY} are estimated with better precision. A comparison across columns shows that the length of time series is less important than its information content, as can be observed by looking at the results from columns corresponding to data starting in years 1, 11, 21, 31, whose results are all very similar. Only when the assessment starts in year 65 is a large change in the precision observed. This suggests that data at higher fishing mortality rates and lower relative population sizes are more informative than data from large stock sizes at low fishing mortalities.

Examples of Kobe II Strategy matrices (K2SM) are presented in **Figure 8** by scenario; these show the probability of being in the green quadrant of **Figure 3** by year (x-axis) for different levels of TAC. For example, in the case of the first scenario, a TAC of 80 would result in a 60% probability of stock recovery by year 49. Of the other scenarios the bias in B0 and p have the biggest effects, the former predicts earlier recovery (by year 44), and the latter no recovery. Mis-specification of the error model has little effect, while a decrease in the quality of the data (i.e. an increase in the CV of CPUE index) results in the prediction of recovery being slightly delayed. Often the K2SMs are combined into a single matrix to summarise the advice, this is done in the bottom lefthand panel.

In the actual simulated data there are only single time series, with a TAC of 80 then the stock would recover by year 45; which corresponds to the 50th percentile of the first scenario.

4. Discussion

The objective of the study was to identify the relative impact of different sources of uncertainty on advice based upon the K2SM. The sources of uncertainty considered were value uncertainty (i.e. what is the stock status at the time of start of the data series and the shape of the production function), measurement error (i.e. CV of the CPUE used in the assessment) and model mis-specification (i.e. the error model of the CPUE). These scenarios were not intended to be realistic, being arbitrarily chosen to illustrate how advice is affected by uncertainty.

However, the study does allow important issues that have to be considered when providing advice to be discussed. For example it appears to be more important to increase sampling effort in order to reduce measurement error, or resolve hypotheses about the dynamics (i.e. what is the shape of the production function). From the K2SM it would appear that the assumed value of B0 has the biggest effect, since if the stock is assumed to be initially more depleted than it is, it will incorrectly be predicted to recover in a shorter period than will be the case. This is because the biomass target for rebuilding, i.e. B_{MSY}, is underestimated; although F_{MSY} is well estimated. Since the K2SM is derived from the product of F : F_{MSY} and B : B_{MSY} the K2SM is optimistically biased. However, when providing scientific advice the fact that you can provide advice on F (and hence sustainable effort and capacity levels) but not actual stock levels is important. For example it implies that an effort-based management system would be more appropriate in this case than a TAC-based one (which relies upon precise biomass estimates).

A comparison of the biases in **Figure 5** would lead us to believe that bias in p had the biggest effect, although this is not the case when examining the advice based on the K2SM. The time series window analysis (**Figure 7**), and a comparison of **Figures 4** and **5**, showed that data from a period of decline and recovery had the most information, and stock status and benchmark were relatively well estimated in this case. However, it would be difficult to estimated B0 from fisheries if initial data is only available after the fishery had been in operation for many years.

An alternative solution would be to reparameterise the model so that rather than using a forward projection when an estimate of B0 is needed, it would project the stock backwards, and use instead current stock or catch relative to B_{MSY} or MSY Martell et al. (2007). An advantage of this method is that priors might be more easily obtained (e.g. if there was an index of occupation of optimal habitat), but also that stating B:B_{MSY} as a direct parameter would also allow for direct estimates of uncertainty of various quantities of management interest, making sensitivity analyses and projections an easier task. Other possibilities include using a reference year when the fishery was at B_{MSY}; for example Sparholt and Cook (2010), estimated when stocks were at B_{MSY} from examining time series of catch and assuming that B_{MSY} occurred when catches started to decline.

5. Acknowledgements

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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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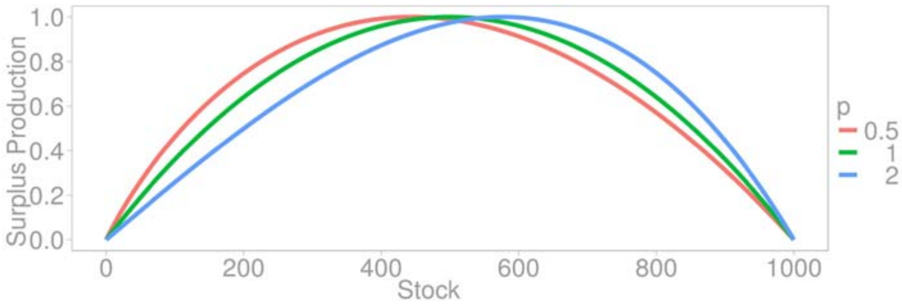

Figure 1. Surplus production curve; with shape parameters equal to 0.5, 1.0 and 1.5.

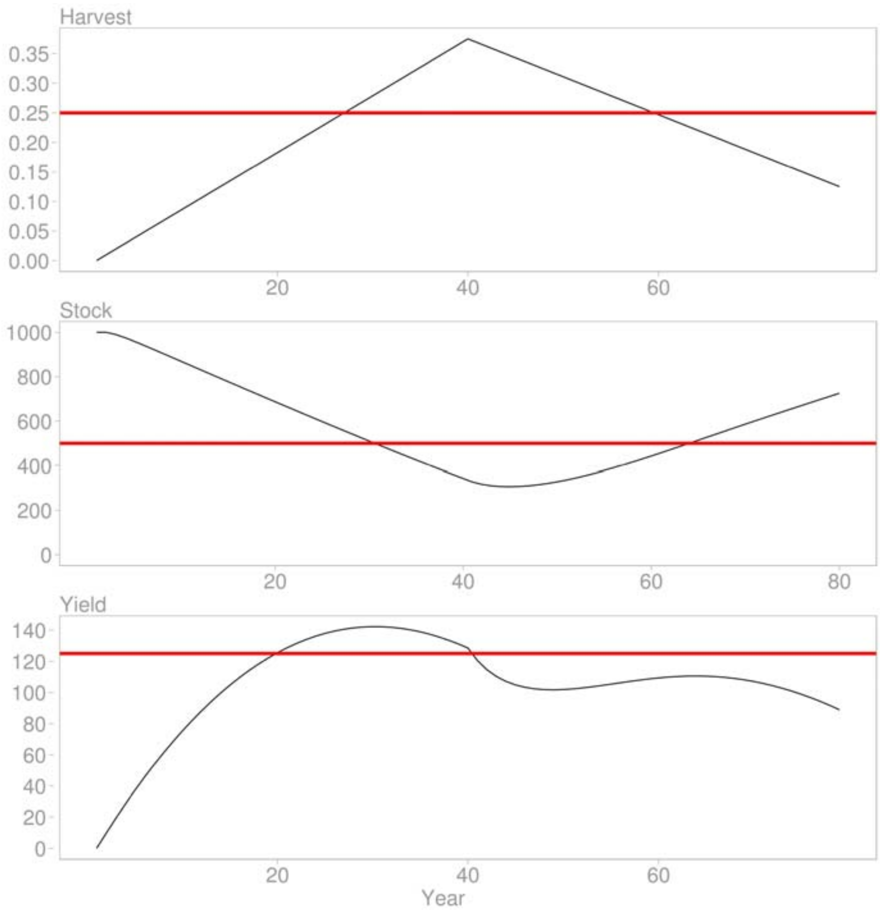

Figure 2. Time series of harvest rate, stock biomass and yield for the simulated population. Red lines are the MSY-based benchmarks.

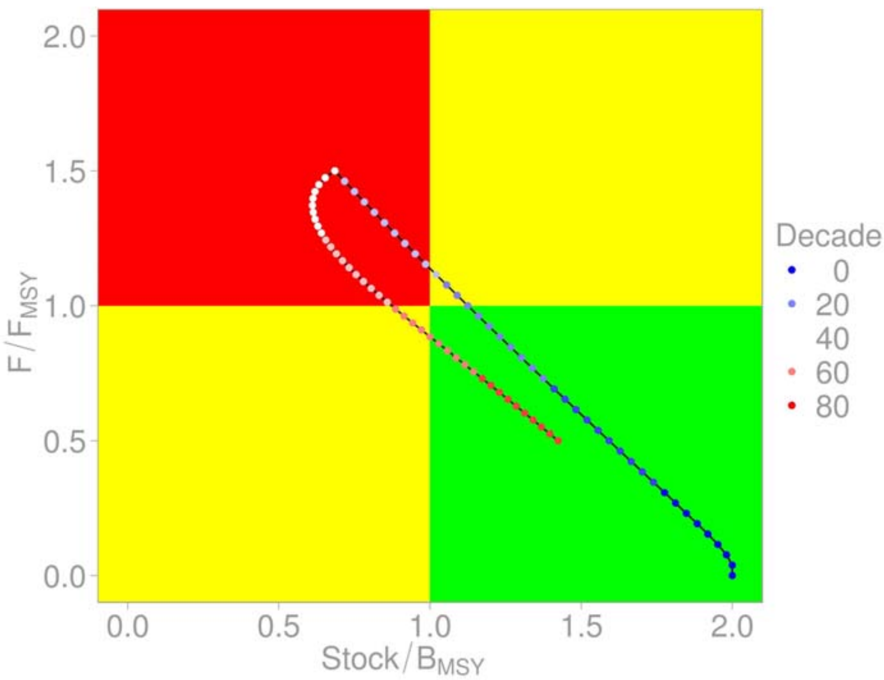

Figure 3. Phase plot of the simulated population, showing stock against harvest rate scaled by MSY benchmarks.

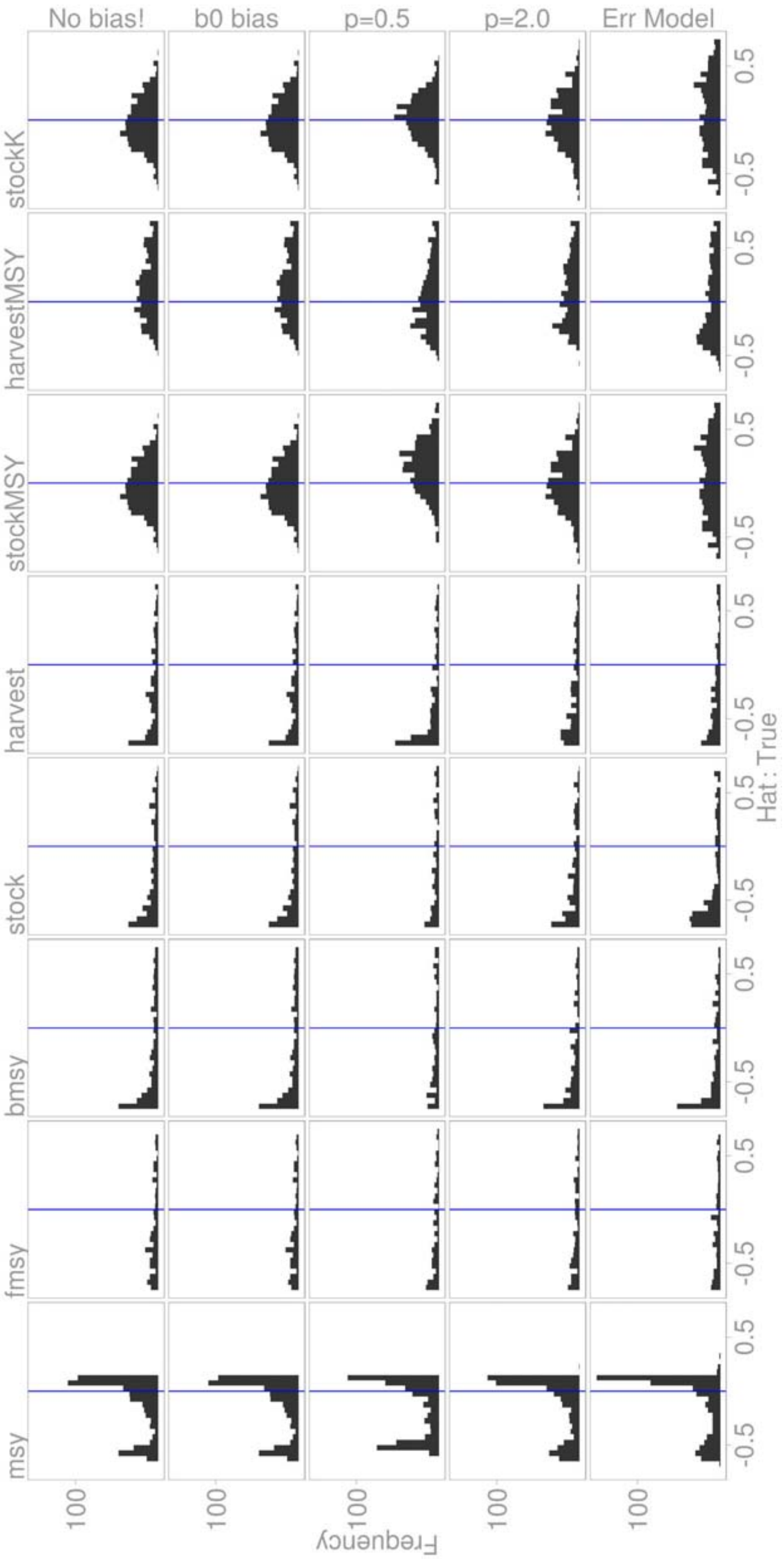

Figure 4. Frequency distributions of estimates from assessment with year 40 as last year of data; MSY benchmarks, absolute and relative estimates of stock and harvest rate.

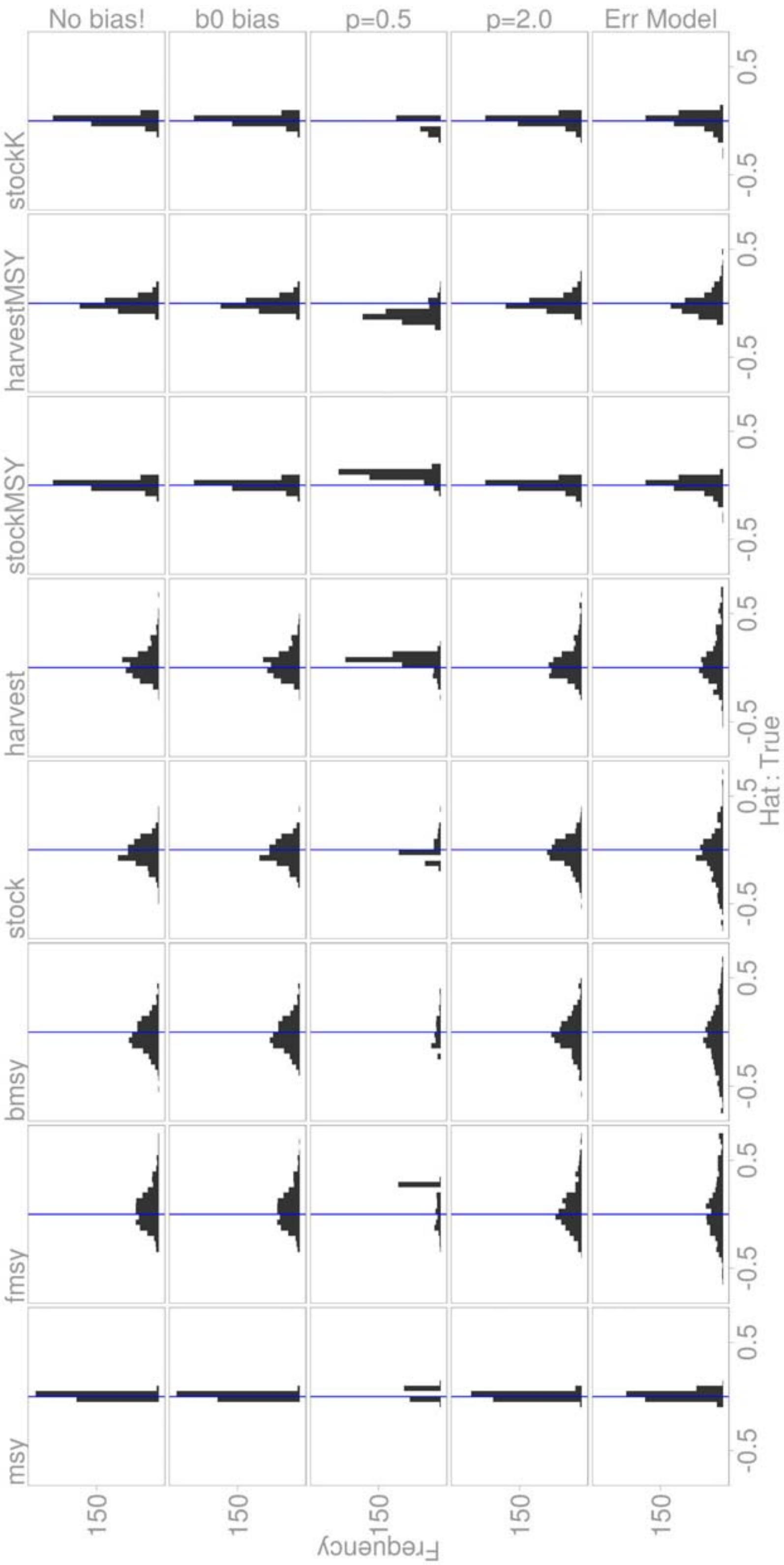

Figure 5. Frequency distributions of estimates from assessment with year 80 as last year of data; MSY benchmarks, absolute and relative estimates of stock and harvest rate.

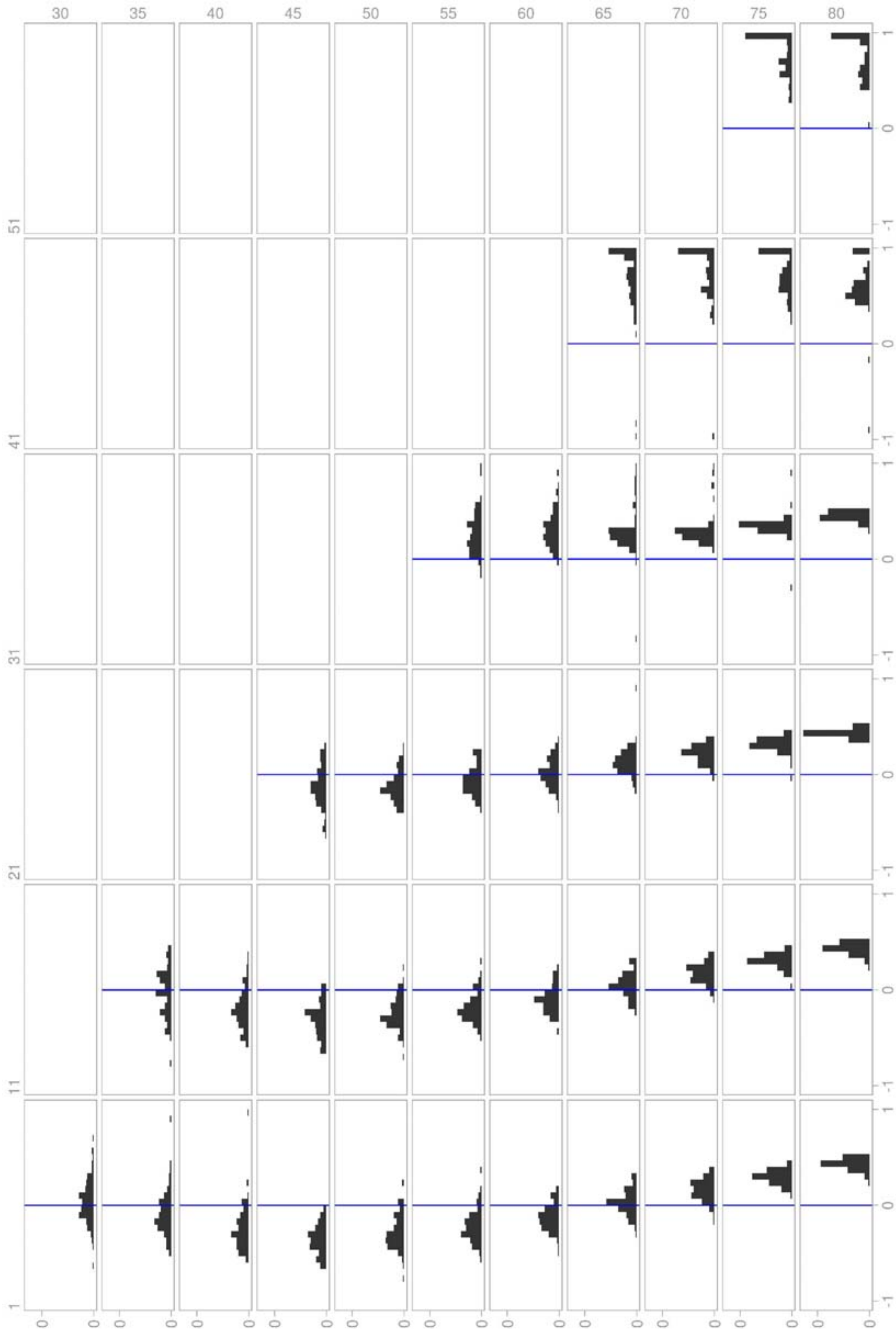

Figure 6. Frequency distributions of estimates of stock relative to B_{MSY}, column corresponds to first year and row to last year of data series.

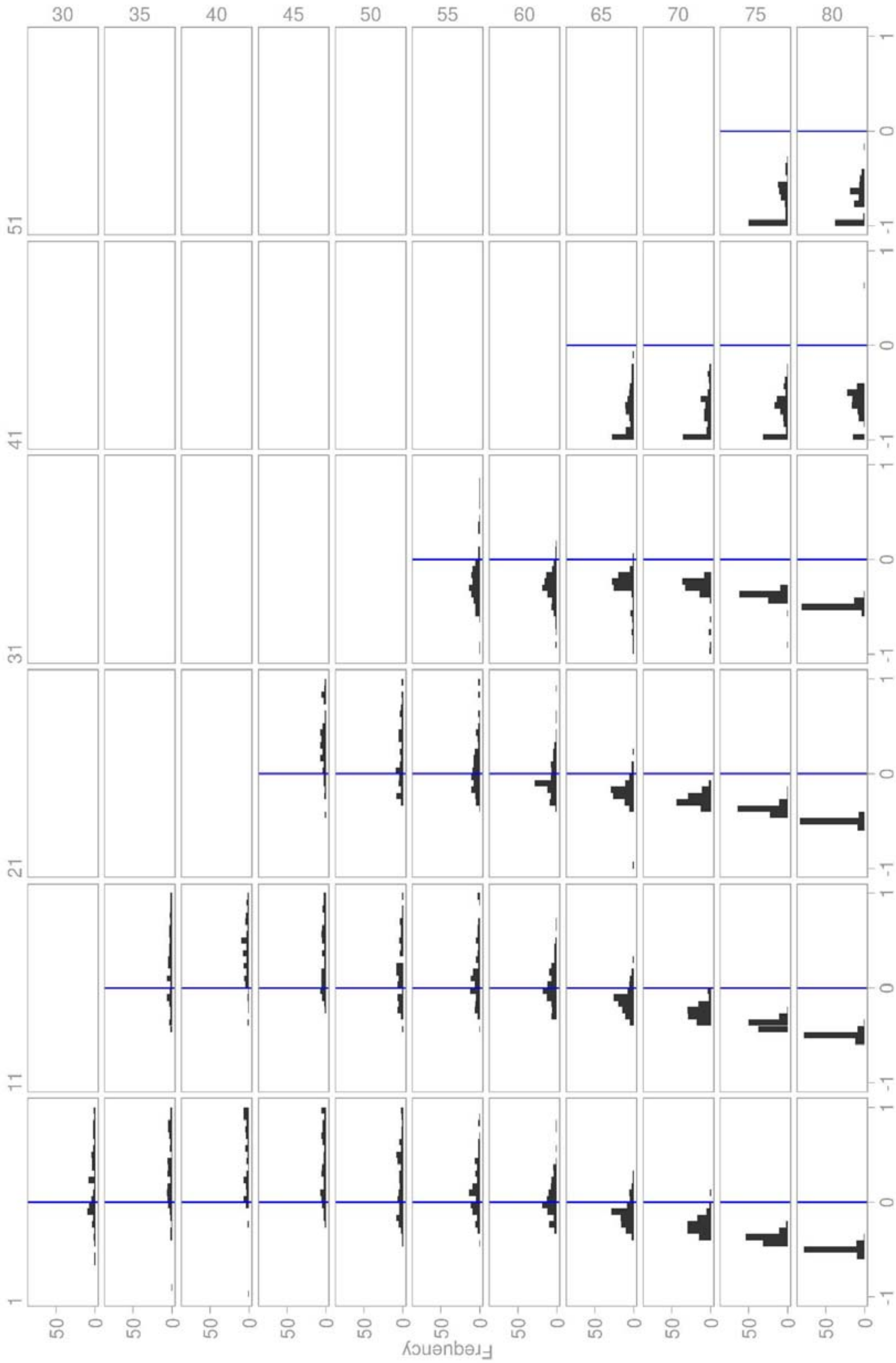

Figure 7. Frequency distributions of estimates of harvest rate relative to F_{MSY}, column corresponds to first year and row to last year of data series.

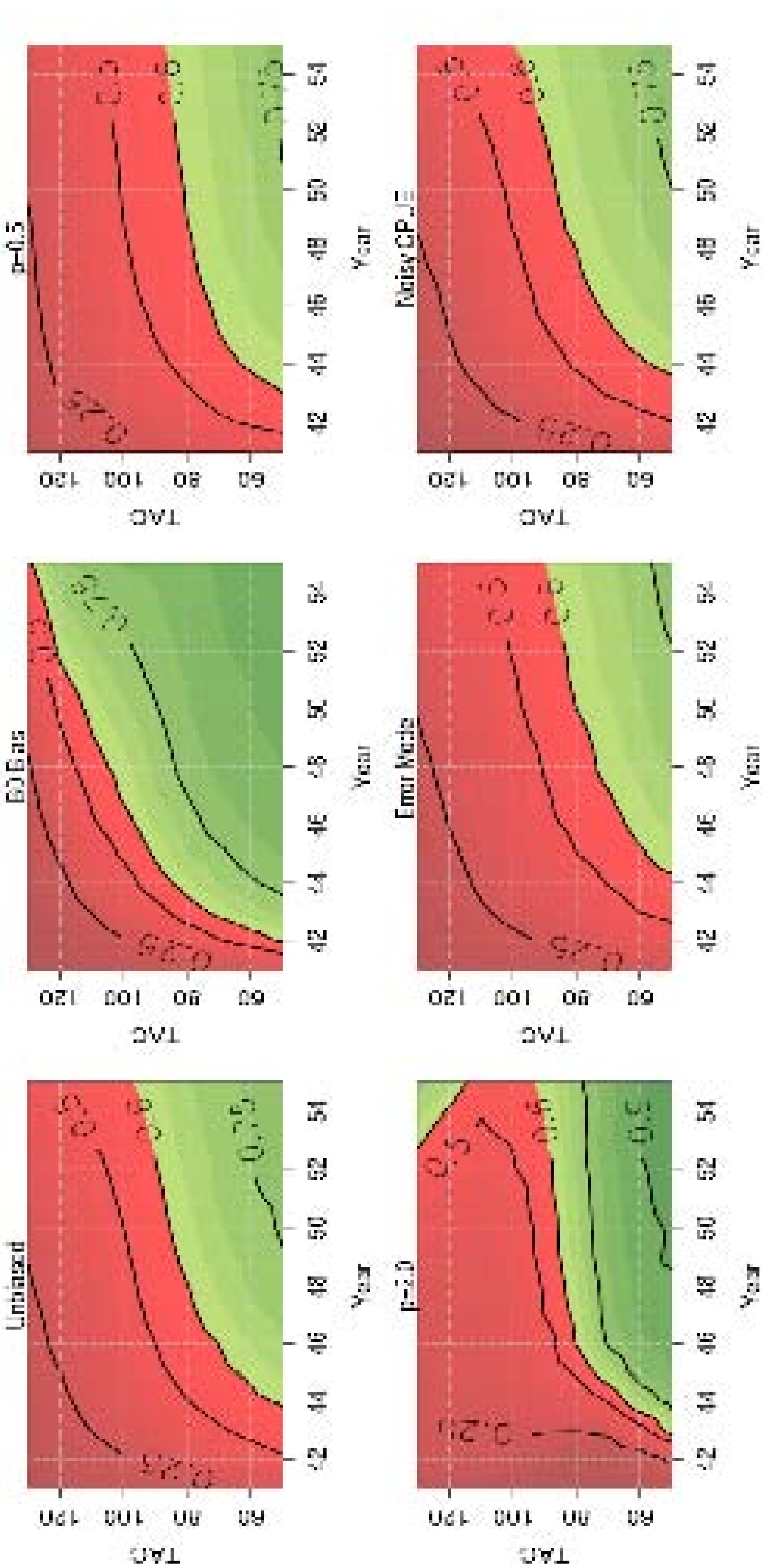

Figure 8. Kobe II Strategy Matrices by scenario; the contours are the probabilities of being in the green quadrant of the phase plot (i.e. not overfished or overfishing).