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AN EVALUATION OF A HARVEST CONTROL RULE USING LIMITS AND TARGET REFERENCE POINTS: AN ATLANTIC YELLOWFIN EXAMPLE

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SUMMARY

Managing the risks associated with uncertainty is a key concept of the precautionary approach to fisheries management. An important tool is there Management Strategy Evaluation which is able to incorporate the main sources of uncertainty into the scientific advice. A simple harvest control rule incorporating both a target F and Biomass trigger was tested for the Atlantic yellowfin tuna population using an MSE framework. The operating model was based on the 2008 ADAPTVPA base case assessment model. The MSE framework included two scenarios related to stock dynamics (OMs), two levels of data quality (OEMs) and two harvest control rules (MPs). The model simulations indicated that the major impact on the model outputs was due to value uncertainty, i.e., choice of natural mortality (M). Relatively minor changes in assumed M resulted in stock collapse. This is a matter of concern given that M is poorly known in most assessments. The MSE evaluations also demonstrated that the use of a Btrigger resulted in better performances in all cases. This would indicate that good management can compensate for deficiencies in the stock assessment. In addition, the MSE showed that under a harvest control rule, variations in advice on fishing effort and TACs are likely to occur. Future HCR development should take this into account, possibly restricting inter-annual variability in TACs and fishing effort. Although this work is considered preliminary and much additional effort is needed, the benefit of the MSE process is clear. It must be noted however, that the process is usually an iterative one where certain sources of information/uncertainty can be shown to be less important than others, and thus excluded from further analysis, effectively streamlining the evaluations.

RÉSUMÉ

La gestion des risques associés à l'incertitude constitue un concept essentiel de l'approche de précaution vis-à-vis de la gestion des pêcheries. Un outil important à cet égard est l'évaluation des stratégies de gestion (MSE) qui est capable d'incorporer les principales sources d'incertitude dans l'avis scientifique. Une simple norme de contrôle de la ponction incorporant à la fois un F cible et un déclencheur de la biomasse a été testée pour la population d'albacore de l'Atlantique à l'aide d'un cadre MSE. Le modèle opérationnel était basé sur le cas de base du modèle d'évaluation ADAPT-VPA 2008. Le cadre MSE incluait deux scénarios portant sur la dynamique des stocks (OM), deux niveaux de qualité des données (OEM) et deux normes de contrôle de la ponction (MP). Les simulations du modèle ont indiqué que l'impact principal sur les résultats du modèle était dû à l'incertitude des valeurs, c'est-à-dire le choix de la mortalité naturelle (M). Des changements relativement mineurs dans M postulé ont entraîné l'effondrement des stocks. C'est un facteur d'inquiétude étant donné que M est peu connu dans la plupart des évaluations. Les MSE ont également montré que l'utilisation de Btrigger donnait lieu à des meilleures performances dans tous les cas. Ceci indiquerait que la bonne gestion peut compenser les insuffisances de l'évaluation des stocks. En outre, la MSE a fait apparaître qu'avec une norme de contrôle de la ponction, il risque de se produire des variations dans l'avis sur l'effort de pêche et les TAC. Le développement futur d'une norme de contrôle de la ponction devrait en tenir compte, en limitant éventuellement la variabilité interannuelle dans les TAC et l'effort de pêche. Même si ces travaux sont considérés comme préliminaires et que des efforts supplémentaires sont nécessaires, l'avantage du processus de l'évaluation des stratégies de gestion est indéniable. Il convient toutefois de noter que le processus est habituellement itératif en ce sens que certaines sources d'information/incertitude pourraient paraître moins

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importantes que d'autres, et pourraient donc être exclues d'une analyse ultérieure, ce qui simplifierait effectivement les évaluations.

RESUMEN

La gestión de riesgos asociados con la incertidumbre es un concepto clave del enfoque precautorio en la ordenación de pesquerías. Una herramienta importante es la evaluación de estrategias de ordenación, que permite incorporar las principales fuentes de incertidumbre en el asesoramiento científico. Se probó una norma sencilla de control de la captura que incorporaba tanto una F objetivo como un activador de biomasa para la población del rabil del Atlántico, utilizando un marco MSE. El modelo operativo se basó en el caso base del modelo de evaluación ADAPT-VPA de 2008. El marco MSE incluía dos escenarios relacionados con la dinámica del stock (OM), dos niveles de calidad de datos (OEM) y dos normas de control de la captura (MP). Las simulaciones del modelo indicaban que el principal impacto en los resultados del modelo se debía a la incertidumbre en los valores, por ejemplo, la elección de la mortalidad natural (M). Cambios relativamente pequeños en la M asumida daban lugar al colapso del stock. Es una cuestión preocupante, ya que en la mayoría de las evaluaciones se conoce poco M. Las MSE también demostraron que utilizar una Btrigger daba mejores resultados en todos los casos. Esto indicaría que una buena ordenación puede compensar las deficiencias de la evaluación de stock. Además, la MSE mostraba que con la norma de control de la captura es probable que se produzcan variaciones en el asesoramiento sobre esfuerzo pesquero y sobre los TAC. El desarrollo futuro de HCR debería tener esto en cuenta, posiblemente mediante la restricción de la variabilidad interanual en los TAC y en el esfuerzo pesquero. Aunque este trabajo se considera preliminar y se requieren muchos más esfuerzos en este sentido, sí han quedado claros los beneficios que implica el proceso MSE. Sin embargo, cabe señalar que el proceso es generalmente un proceso iterativo en el que algunas fuentes de información/ incertidumbre parecen menos importantes que otras y, por tanto, se excluyeron de análisis adicionales, racionalizando de un modo eficaz las evaluaciones.

KEYWORDS

Harvest Control Rule, FLR, Management Strategy Evaluation, VPA, yellowfin

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, which is commonly interpreted as using an analytical estimate of maximum sustainable yield (MSY) as a target, derived from either yield per recruit analysis combined with a stock recruitment relationship or directly or from a biomass dynamics model. However, Ricker's (Ricker, 1975) original definition is defined as the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. Even if you can calculate MSY based reference points from an assessment model does not mean that you can achieve that level of yield in practice due to uncertainty.

As well as target reference points the Precautionary Approach (Garcia, 1996) requires limit reference points and harvest control rules (HCRs). Where the HCR specifies in advance what actions should be taken when limits are reached. Although harvest control rules may include several precautionary elements, it does not necessarily follow that they will be precautionary in practice Kirkwood and Smith (1995). This is because many harvest control rules are not evaluated formally to determine the extent to which they achieve the goals for which they were designed, given the uncertainty inherent in the system being managed Punt [2008]. Therefore simulation, and Management Strategy Evaluation (MSE) in particular, has increasingly been used to evaluate the impact of the main sources of uncertainty inherent in the system being managed (Kirkwood and Smith 1995; Cooke 1999; McAllister et al. 1999; Kell et al. 2007).

MSE allows uncertainty beyond just the assessment process has to be considered; since under active management uncertainties about management decisions, their effects and their implementation also affect management outcomes. However, fisheries management advice has traditionally been based on a reductionist approach, where tasks are considered in a linear fashion e.g. collect the data, perform the assessment, compute reference points, then set the quota. However, just as in ecology where it is argued that inappropriate use of reductionism limits our understanding of complex systems, we need to understand how systems work and in particular how feedback loops influence those systems. Management Strategy Evaluation (MSE) has therefore become an important tool for evaluating management advice.

2. Material and methods

2.1 Management Strategy Evaluation Framework

An important aspect of the MSE approach is that the 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 (**Figure 1)**. 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].

The most rigorous use of MSE is when a Management Procedure (MP) is simulation tested prior to implementation. Where a Management procedure is the combination of pre-defined data, together with an algorithm to which such data are input to provide a value for a TAC or effort control measure. A flowchart describing the MP development process is given in **Figure 1**.

Operating Model (OM) that represents alternative plausible hypotheses about stock and fishery dynamics, allowing integration of a higher level of complexity and knowledge than is generally used within stock assessment models;

Management Procedure (MP) or management strategy which is the combination of the available pseudo-data, the stock assessment used to derive estimates of stock status and the management model or Harvest Control Rule (HCR) that generates the management outcomes, such as a target fishing mortality rate or Total Allowable Catch.

Observation-error Model (OEM), a part of the MO that describes how simulated fisheries data, or pseudo-data, are sampled from the Operating Model; and

All terminology is based upon that of Rademeyer et al. (2007).

Complex models are used primarily to test the robustness of simpler assessment management rules before implementation, by conducting computer-based experiments that embody how the whole system reacts to a variety of possible management actions (Hilborn, 2003). Population and fleet dynamics are deduced from a range of plausible hypotheses and available data sets, rather than being based on a singular set of assumptions, because the objective is to develop strategies that are robust to our uncertainty about the true dynamics and, hence, to meet the requirements of the precautionary approach. The challenge is no longer to build (and then justify) a single best model but to identify an appropriate of range of plausible models, parameterize and assigning weights to them (Punt, 2008). There is also a need to explore alternative model structures and ways of assigning weights or probabilities to them for example using Bayesian and meta-analytic techniques (Michielsens and McAllister, 2004).

All modeling was done using FLR (Kell et al. 2007) which was designed to be used to build simulation models representing alternative hypotheses about stock and fishery dynamics, thereby allowing a higher level of complexity and knowledge than used by stock assessment models and to explicitly include a greater range of uncertainty.

It is important to consider appropriate sources of uncertainty; traditional stock assessments mainly only consider uncertainty in observations and process (e.g. recruitment). However, uncertainty about the actual dynamics (i.e. model uncertainty) has a larger impact on achieving management objectives (Punt, 2008). Therefore when providing management advice it is important to consider appropriate sources of uncertainty. Rosenberg and Restrepo (1994) categorized uncertainties in fish stock assessment and management as being related to:

- Processes; caused by disregarding variability, temporal and spatial, in dynamic population and fisheries processes;
- Observations; sampling error and measurement error;

- Estimation; arising when estimating parameters of the models used in the assessment procedure;
- Models; related to the ability of the model structure to capture the core of the system dynamics;
- Implementation; where the effects of management actions may differ from those intended.
- Sources of uncertainty related to Models include
- Structural uncertainty; due to inadequate models, incomplete or competing conceptual frameworks, or where significant processes or relationships are wrongly specified or not considered. Such situations tend to be underestimated by experts (Morganand Henrion, 1990). and
- Value uncertainty; due to missing or inaccurate data or poorly known parameters.

2.2 Operating model

Setting up and conditioning Operating Models depends on the objectives of a particular study but if uncertainties in the resource assessment are large, the construction of a reference set of OMs is preferable to the use of a single reference case OM. In the last assessment 13 VPA-Adapt runs were considered; which explored different hypotheses about the data and the stock dynamics conditioned upon the VPA assumptions. However, in this study we constructed a single OM based on the base case from 2008 since we are mainly concerned in illustrating the utility of the approach; Varying some of the assumptions about the data and knowledge used in the stock assessment.

Biological parameters were taken from the last ICCAT assessment; however, these can easily be changed to consider other life-history traits.

- annual spawning (1 cohort per year),
- 50% maturity at age 4, 100% maturity at ages 5+ (i.e. immature before age 4),
- fecundity is linearly proportional to weight,
- growth following the von-Bertalanffy equation used in the ICCAT working group (with the following parameters: L = 318.85, k=0.093, tO=-0.97),
- length-weight relationship used in the ICCAT working group (W=2.95.10-5*L2.899),
- lifespan of 20 years.
- age-specific, but time-invariant, natural mortality based on tagging experiments on the southern bluefin tuna and used in the ICCAT working group (i.e., M=0.49 for age 1, M=0.24 for ages 2 to 5, M=0.2 for age 6, M=0.175 for age 7, M=0.15 for age 8, M=0.125 for age 9 and M=0.1 for ages 10 to 20).
- Recruitment given by Beverton and Holt stock recruitment relationship with a steepness of 0.75

Given the selection pattern (s) of a fishery, and the catchability (q) of a population for a given effort (E), the fishing mortality rate (Fa,y,j) for age a, year y, and population j is given by:

2.3 Management procedure

The Management Procedure is linked to the operating model by the data and assumed level of knowledge, this is modeled by the Observation Error Model (OEM) and the dynamics assumed in the Stock Assessment Procedure (SAP). Depending upon the perceived stock status and reference points the HCR then determines management action.

The SAP chosen was VPA which requires total catch-at-age and assumptions about natural mortality and CPUE as data inputs and estimates numbers and fishing mortality-at-age from which time series of stock trends and stock recruitment relationships and reference points can be estimated. Process and measurement error were modeled as a lognormal error with a CV of 30% on the CPUE. All other data were considered to be known exactly by the working group unless stated otherwise.

The Harvest Control Rule (**Figure 2**) was based on that described in the Report of the 2010 ICCAT Working Group on Stock Assessment Methods (Anon. 2011). HCR incorporates limit and target reference points into a rule that dictates the action to be taken in terms of defining fishing mortality rates depending on the estimated biomass level (x-axis) (**Figure 2**). The Btrigger causes F to be reduced if the stock falls below this level, otherwise fishing is at the target F level.

In this example, the target fishing mortality was 75% of F_{MSY} and the Btrigger 75% of B_{MSY}.

2.4 Scenarios

Three scenarios were considered i.e.:

1 No Bias, in that the data (other than the CPUE) used in the assessment were sampled without error from the OM.
2 As 1 but recruitment declined by 25% in the future
3 As 1 but M is assumed to be 25% greater in the MP than the OM

and compared to a stock projection.

Two harvest control rules were evaluated:

1 A constant F.
2 Constant F above a biomass limit below which F declines.

Figure 3 shows the results from a single scenario in the form of a worm plots for fishing mortality, recruitment, spawning stock biomass and yield. These show the annual medians and interquartiles (thick and thin blue lines) with two example trajectories (red and green). This shows that half the time a trajectory will be outside of the inter-quartile range and that the realised trajectories will be much more variable than that suggested by the median.

The MSE outcomes for constant F (orange) MP are compared with a projection in **Figure 4** (all quantities are relative to MSY benchmarks). The first column is for the projection with constant F where only recruitment varied (i.e., process error). The second column presents the results from an MSE where the assessment model was VPA (i.e., the same assumed dynamics as the OM) and all data and parameters used in the MP were known without error, i.e., as well as process error estimation and measure error were modeled. In the third column a regime shift (i.e., OM recruitment reduced by 75%) occurred, and the final column evaluates the outcomes when natural mortality was assumed to be greater than 25% in the MP than the OM, i.e. model error in the form of value uncertainty.

These show that even where the assumed assessment dynamics are identical to those used to simulate the stock in the OM, differences are seen between the projection and MSE (columns 1 & 2), mainly due to the variability of the MSE being greater due to the inclusion of measurement and estimation error in the MSE. A regime shift causes at first F to be greater than the target since the productivity of the stock is overestimated and so the TAC is set too high, however after 2020 the F is reduced as reference points take into account the reduced recruitment. The bias in M has the largest effect causing the stock to collapse.

Figure 5 presents the same scenarios for a HCR with a biomass limit, after which F is reduced. These show that the limit is effective in stabilizing fishing mortality and stock biomass. This is particularly important in the case of the mis-specification of M. Another feature of the HCR is that oscillations are seen due to lags, i.e. it takes a few years before the stock recovery is detected and F can increase.

Figures 6 to **10** show the same data in the form of a Kobe phase plot for five year intervals, clockwise from the top left panel.

The projection is noticeably less variable than the results from the MSE. Inspection of the MSE with no bias shows that in the 1st few years of operation of the HCR cycling is seen, i.e. a decline followed by a recovery, In the case of the constant F such fluctuations are not seen. In the case of the regime shift no cycling is seen although in the case of the constant F MP F increases above FMSY and stock declines, although the HCR maintains F at the target level and SSB just below BMSY and little yield id forgone. The most striking result is in the case of a bias in the assumed M; although this was relatively small if a Btrigger is not used in the HCR the stock collapses.

2.5 Discussion

This study is not intended to be a definitive MSE for yellowfin tuna. It is a simple demonstration of how an MSE models greater uncertainty than a traditional stock assessment and how reference points should be evaluated, e.g. as part of a HCRs.

Although this example was not intended to be a definitive analysis, it did incorporate a greater range of uncertainty than is normally considered within stock assessment. The simulations conducted in this study clearly demonstrate that considering more realistic sources of uncertainty is important when providing probabilistic management advice.

The main sources of uncertainty considered were process error (i.e. recruitment variability), uncertainty about the true dynamics of the stock being evaluated (e.g. M), measurement error (CPUE CV) and estimation error. As mentioned above, this is more uncertainty than considered with an ICCAT stock assessment.

The model simulations indicated that the major impact on the model outputs was due to value uncertainty, in that just a 25% mis-specification of M caused stock collapse, which is a very important result given that M is poor known in most assessments. However, using a Btrigger as part of a HCR resulted in much better performance in all cases, showing that good management is more important than stock assessment.

The so-called ”worm plots” clearly indicate that in reality, catches, harvest (and hence fishing effort) and stock trends will not follow the smooth trends suggested by the medians and logically 50% of the time will be outside of the range given by the inter-quartiles. This example showed that under a harvest control rule variation in advice on fishing effort and TACs is likely to occur. Therefore it will be important to consider other components when designing HCRs, e.g. to reduce inter-annual variability in TACs and fishing effort.

5. Future work

As with all work in progress, it is important to map out future directions and opportunities for building on the methods detailed in this document. Although this was a preliminary example and the sources of uncertainties considered were meant to be illustrative rather than realistic, it did show the importance of considering a broader range of uncertainty when designing HCRs than is traditionally considered with performing stock assessments. The MSE process is an inclusive process that is amplified by incorporating all stakeholders. This is also however a time consuming process. In the short term, the scientific aspects of the process can be addressed fairly quickly. It is important that before management advice can be provided based on such an MSE as described above, the main sources of uncertainty as well as realistic plausible values for this uncertainty must be considered, discussed and agreed upon. The most convenient forum to achieve this is in the relevant Working Parties, where a range of experts are available. The use of MSE is also likely to be an iterative process where, through simulation testing, certain sources of information/uncertainty can be shown to be less important than others and so excluded from further analysis, stream-lining future work.

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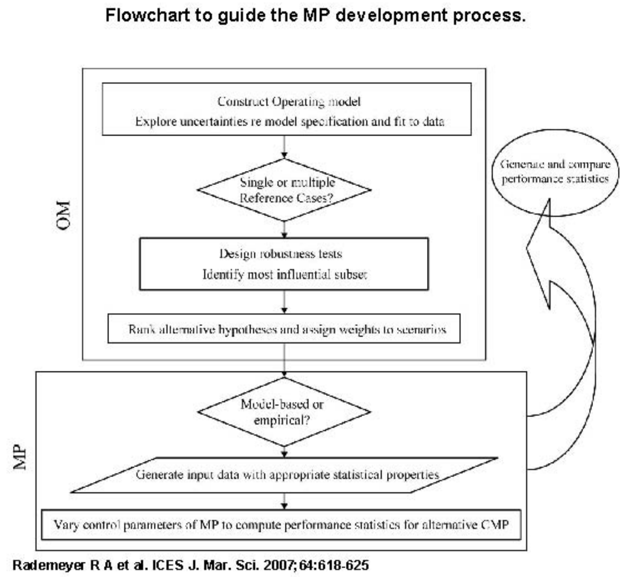

Figure 1. Conceptual framework for Management Strategy Evaluation.

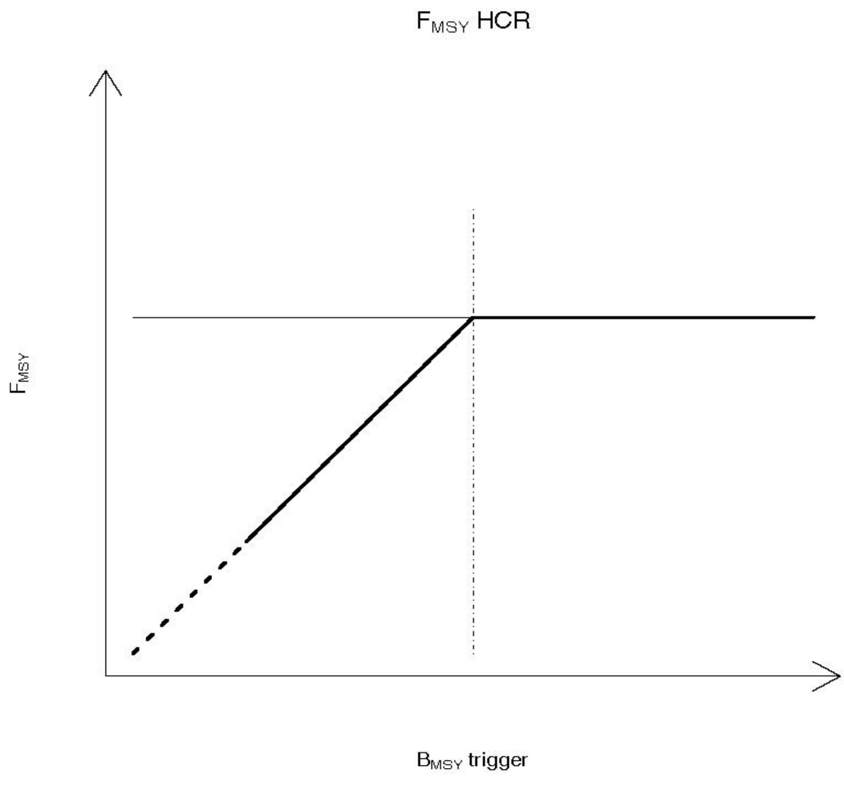

Figure 2. An example of a harvest control rule.

Figure 3. Worm plots for MSE with a constant F target showing 2 possible trajectories (red and green) for fishing mortality, recruitment, spawning stock biomass and yield, annual medians and interquartiles (thick and thin blue lines) are also indicated.

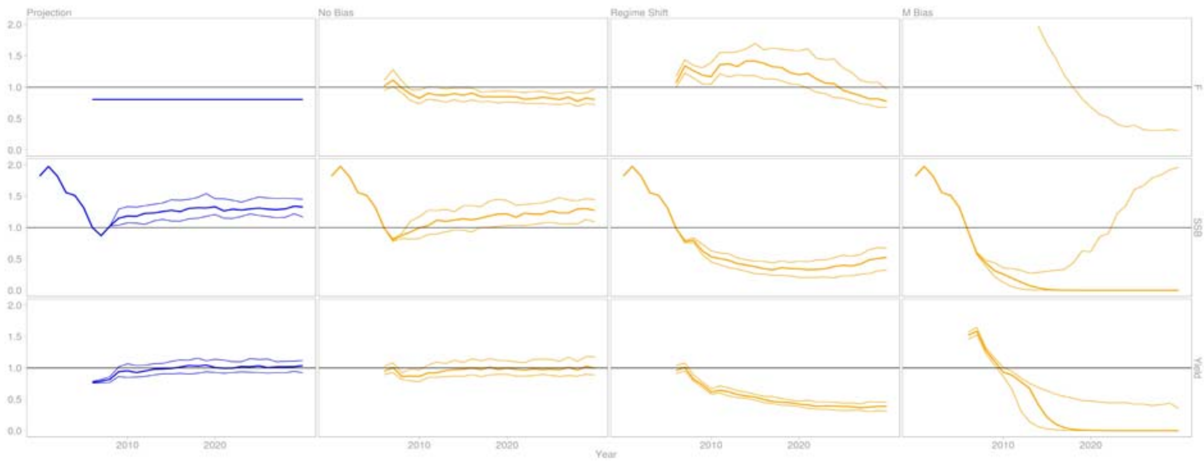

Figure 4. Results from the MSE; interquartile and median plots for fishing mortality, spawning stock biomass and yield, annual medians and interquartiles are indicated; results are presented for a constant F MSE (orange) and for a stock projection (blue).

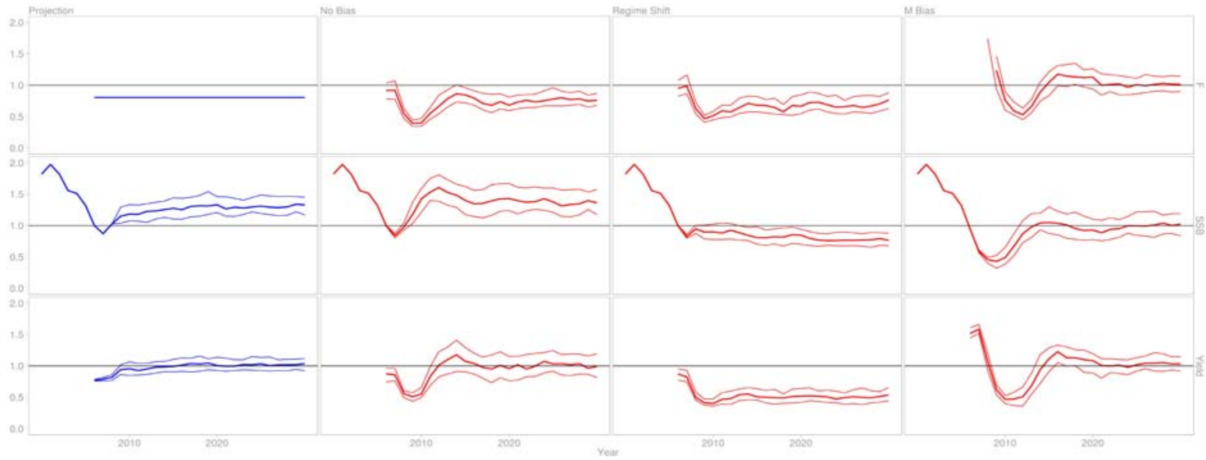

Figure 5. Results from the MSE; interquartile and median plots for fishing mortality, spawning stock biomass and yield, annual medians and interquartiles are indicated; results are presented for a HCR with a B£T rigger (red)and a stock projection (blue).

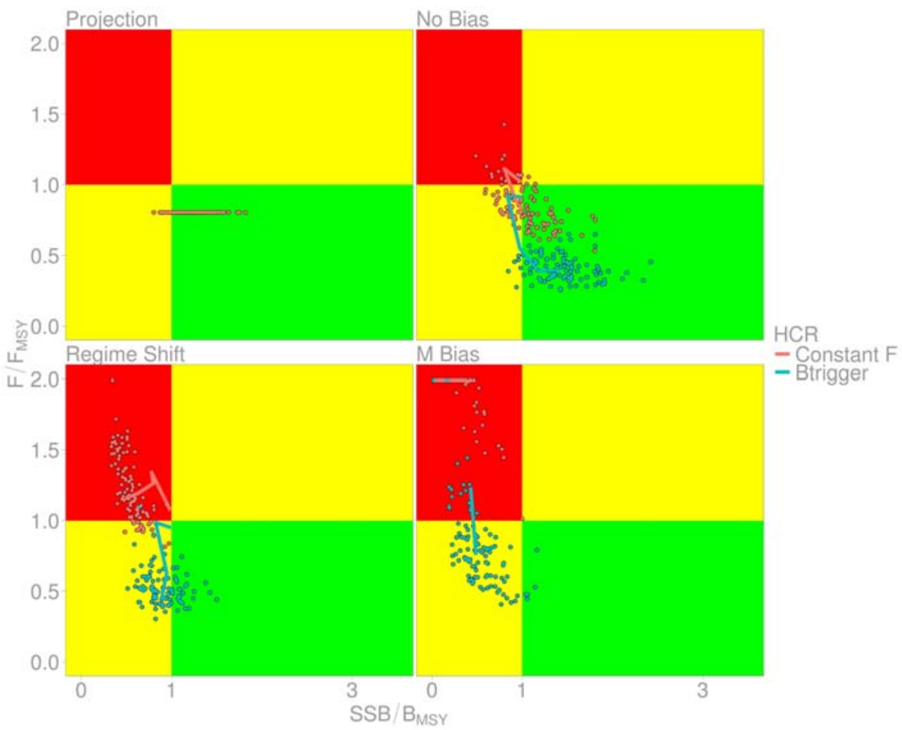

Figure 6. Kobe Strategy Matrices for stock evolution in 2010 by scenario for constant F and HCR with BTrigger (pink and blue, respectively).

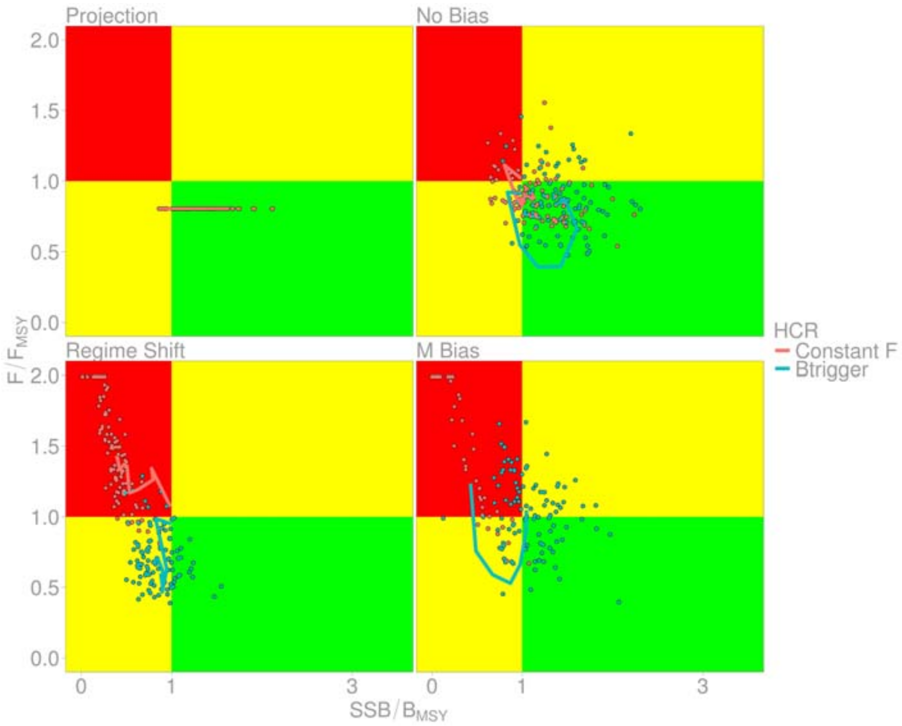

Figure 7. Kobe Strategy Matrices for stock evolution in 2015 by scenario for constant F and HCR with BTrigger (pink and blue, respectively).

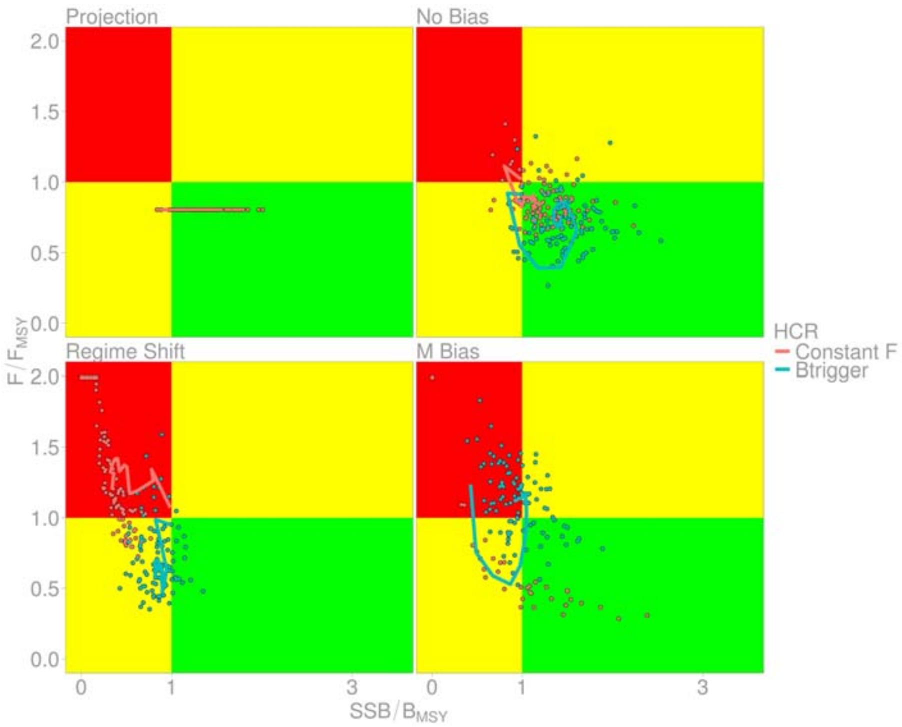

Figure 8. Kobe Strategy Matrices for stock evolution in 2020 by scenario for constant F and HCR with BTrigger (pink and blue, respectively).

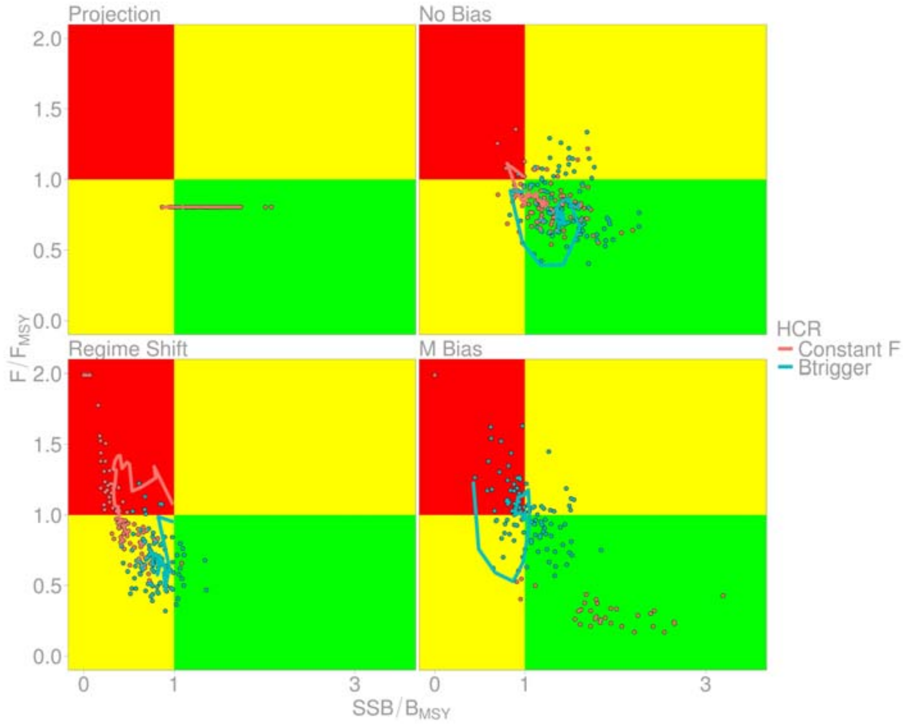

Figure 9. Kobe Strategy Matrices for stock evolution in 2025 by scenario for constant F and HCR with BTrigger (pink and blue, respectively).

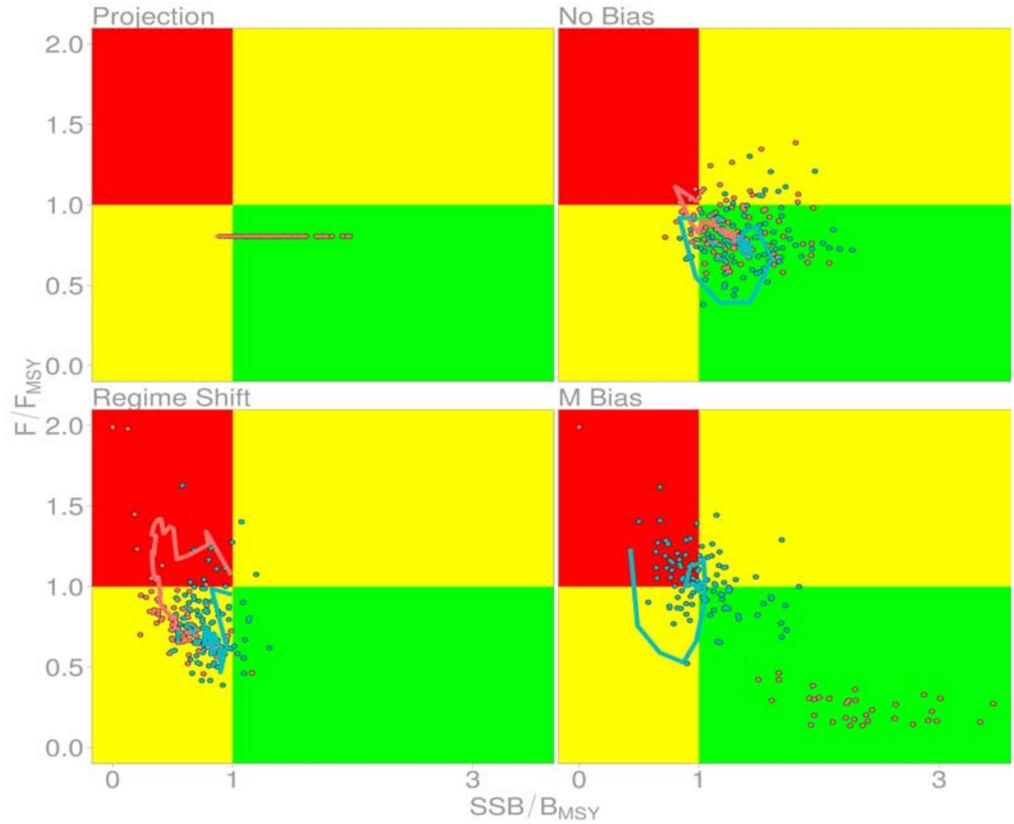

Figure 10. Kobe Strategy Matrices for stock evolution in 2030 by scenario for constant F and HCR with BTrigger (pink and blue, respectively).