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BUILDING A MANAGEMENT STRATEGY EVALUATION FOR NORTHERN SWORDFISH: PART 1

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SUMMARY

An initial management strategy evaluation (MSE) procedure was constructed to assess potential outcomes of four different management procedures. The procedures consisted of a combination of two assessment models (the Shafer and Fox production models, implemented with ASPIC) and two different management targets (one less conservative, $B_{MSY} = B_{MSY} * 1.0$ and $F_{MSY} = F_{MSY} * 1.0$, and one more conservative, $B_{MSY} = B_{MSY} * 1.20$ and $F_{MSY} = F_{MSY} * 0.80$). The performance measures used to measure the success of the four management procedures where absolute and variation in landings, the average fishing mortality over F_{MSY} by year, the average spawning stock biomass over B_{MSY} each year, and the probability of the stock being overfished and experiencing overfishing each year. Based on the eight performance measures considered, the Shafer production model coupled with the more conservative benchmark outperformed the other three management procedures. This combination of assessment model and management targets resulted in the lowest probability of overfishing with no sacrifice in landings. This work is intended to be continued to be built upon to broaden its usefulness and conclusions.

RÉSUMÉ

Une procédure initiale d'évaluation de la stratégie de gestion (MSE) a été formulée dans le but d'évaluer les résultats potentiels de quatre procédures de gestion différentes. Les procédures ont consisté en une combinaison de deux modèles d'évaluation (les modèles de production de Schafer et de Fox, mis en œuvre avec ASPIC) et de deux objectifs de gestion différents (un moins conservateur, $B_{PME} = B_{PME} * 1,0$ et $F_{PME} = F_{PME} * 1,0$ et un plus conservateur, $B_{PME} = B_{PME} * 1,20$ et $F_{PME} = F_{PME} * 0,80$). Les mesures des performances utilisées pour juger du succès des quatre procédures de gestion étaient : une mesure absolue et une variation dans les débarquements, la mortalité par pêche moyenne supérieure à F_{PME} par année, la biomasse moyenne du stock reproducteur supérieure à B_{PME} tous les ans, et la probabilité que le stock soit surexploité et fasse l'objet d'une surexploitation tous les ans. Sur la base des huit mesures des performances considérées, le modèle de production de Schaefer conjugué au paramètre le plus conservateur a donné de meilleurs résultats que les autres trois procédures de gestion. Cette association du modèle d'évaluation et d'objectifs de gestion a entraîné la plus faible probabilité de surpêche sans aucune répercussion sur les débarquements. Ces travaux doivent être poursuivis afin d'être consolidés et d'élargir leur utilité et leurs conclusions

RESUMEN

Se elaboró un procedimiento inicial de evaluación de estrategias de ordenación (MSE) para evaluar los potenciales resultados de cuatro procesos diferentes de ordenación. Los procedimientos consistían en una combinación de dos modelos de evaluación (los modelos de producción Schaefer y Fox, implementados con ASPIC) y dos objetivos de ordenación diferentes (uno menos conservador $B_{RMS} = B_{RMS} * 1,0$ y $F_{RMS}= F_{RMS} * 1,0$, y uno más conservador $B_{RMS} = B_{RMS} * 1,20$ y $F_{RMS}= F_{RMS} * 0,80$). Las medidas del rendimiento utilizadas para medir el éxito de los cuatro procedimientos de ordenación fueron: medidas absolutas y variación en los desembarques, mortalidad por pesca media por encima de F_{RMS} por año, biomasa del stock reproductor media por encima de B_{RMS} cada año y la probabilidad de que el stock estuviera sobrepescado y experimentando sobrepesca cada año. Basándose en las ocho medidas del rendimiento consideradas, el modelo de producción de Schaefer unido al elemento de referencia más conservador superó a los otros tres procedimientos de ordenación. Esta combinación de modelo de evaluación y objetivos de ordenación tuvo como resultado una probabilidad más baja de sobrepesca sin ninguna repercusión en los desembarques. Está previsto continuar este trabajo para ampliar su utilidad y sus conclusiones.

KEYWORDS

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Management Strategy Evaluation, harvest control rule, swordfish

1. Introduction

A harvest strategy is a plan stating how the catch taken from the stock will be adjusted from year-to-year depending upon the size of the stock, the economic or social conditions of the fishery, conditions of other stocks, and perhaps the state of uncertainty regarding biological knowledge of the stock (Hilborn and Walters, 1992, pg. 453). A harvest strategy is not a set of annual regulations. At the time of this writing ICCAT does not use a specific harvest strategy to manage the suite of species under their purview. Rather, the annual quota for each species is negotiated independently. However, one of the goals/objectives of the ICCAT strategic plan is to apply harvest strategies for several key species (working with the commission) in an effort to develop a robust harvest strategy.

Management strategy evaluation (MSE), also sometime referred to as the management procedure (MP), is an approach for evaluating and implementing fishery management strategies. The MSE approach is designed to identify and operationalize strategies for managing fisheries that are robust to several types of uncertainty and capable of balancing multiple economic, social and biological objectives (Holland 2011). MSE is a general framework aimed at designing and testing MPs, which specify pre-agreed decision rules (heuristics), assessment methods and data used for setting and adjusting TACs or effort levels to achieve a set of fishery management objectives (Holland 2011). Note that an MP is not simply a harvest control rule (HCR) which might be simply a policy to set the TAC to achieve a constant specific exploitation rate; an MP must also specify the data and assessment methods for determining how the TAC is calculated. While the use of HCRs in fisheries is relatively common, the use of MP is not (Holland 2011). Key challenges for effective us of MSE therefore include characterizing and uncertainty (Punt *et al*. 2014).

In this study we take information from the most recent stock assessment of northern swordfish (completed in 2013 using data up to 2011) and apply two stock assessment models and two harvest control rules (for a total of four management procedures) and use an MSE approach to determine which of the four management procedures best meets a set of basic, generic performance measures. As ICCAT has no significant role to play in the production of CPUE data or the implementation of its regulations, variations in these two steps were left out of this MSE study (**Figure 1**). The absence of these two factors also aids in the clarity of the comparison between the assessment models and the harvest control rules; two things that ICCAT has a great deal of decision power over. It needs to be kept in mind that this work is not designed to determine if we are *assessing* the stock properly, but rather are we *managing* the stock properly, despite the fact that our assessments have inherent uncertainties.

2. Material and methods

An MSE requires at least two coupled modeling platforms: an operating model, used to simulate and dictate the dynamics of the population, and an estimation model, used to estimate and assess the dynamics of the population based on data drawn from the operating model. For this study I used the MSE software available from the National Marine Fisheries Service (NMFS) Toolbox. This software uses the simulator POPSIM (also available in the NMFS Toolbox) as its operating model and, in the case of this study, ASPIC (Prager 1995) as the estimation model (also available in the NMFS Toolbox).

The operating model. The first task of the study was to create a simulated, age structured swordfish model that was a reasonable representation of the current knowledge and status of the northern stock. This was accomplished by referring to the most recent swordfish assessment conducted with the Stock Synthesis model (SS), an age-based fully integrated modeling framework, which utilized multiple sexes, fleets, and surveys. The fully integrated SS model was reduced down to a one sex, one fleet, and one survey model (SS_MSE). This was done so that the resulting structure could be directly transferred into the simpler MSE model. The age-based, logistic, selectivity for the SS_MSE model was arrived at by averaging the selectivity for all surveys and fleets from the SS model. These were held constant in the SS_MSE model. The estimated steepness from the SS model was used in the SS_MSE model and held constant (h = 0.83). This resulted in an SS_MSE model that estimated initial recruitment ($R0$) and annual recruitment deviations. This model was fit to the single overall CPUE time series developed during the 2013 swordfish assessment meeting, the same one used in the ASPIC model that provided the management advice. The resulting model structure (initial numbers at age, weight at age, stock recruitment parameters, annual selectivity and fishing mortality) was used in the MSE model for further analysis. Note that it was not necessary for the MSE simulated population to match the population as assess in 2013 exactly, however the results were such that the two management benchmarks of F/F_{MSY} and B/B_{MSY} were very close to those now believed to be true.

The estimation model. When an estimation model was used, ASPIC version 5.34 was employed. The ASPIC platform was used because this is the default model used in the latest northern swordfish assessment. There are several important difference between the structures of the operating model and the estimation model that need to be kept in mind: (1) the operating model is age-based, the estimation model is not; (2) the estimation model uses age specific fecundity and maturity, while the estimation model assumes all fish are fully fecund and mature; (3) the operating model uses an increasing, asymptotic selectivity while the estimation model assumes full selectivity for all ages; and (4) the operating model uses a Beverton-Holt stock-recruitment function, which has an inherently different B_{MSY} and virgin biomass assumption than does ASPIC.

Harvest Control Rule. The following is the generic harvest control rule (HCR) used in the MSE:

IF ($B < B_{MSY}$) THEN
    $F_{Target} = F_{MSY} * (B / B_{MSY})$
ELSE
    $F_{Target} = F_{MSY}$
END IF

where B is the spawning stock biomass. Because the values of F_{MSY} and B_{MSY} are not internally calculated within the MSE model, these terms can be substituted with any desired MSY proxy wishing to be considered for a management benchmark (F0.1, F at SPR 30%, B at SPR 30%, etc.). Note that the values for F_{MSY} and B_{MSY} used for the HCR are the known values from the operating model and not those estimated by the assessment models.

Three build-up models were constructed to ensure proper calibration between all models and reference points. No estimation model was used for the build-up process to stochastic error was applied to SSB, F, and landings from population simulation. These models were only used establish a sound working base for the subsequent models.

Model	*Observation Error*	*Error in Fmsy and Bmsy*	*Estimation Model*	*Fishing mortality*	*Harvest Control Rule*
Model_0	No	No	None	Constant	$B_{MSY}= B_{MSY}*1;F_{MSY} = F_{MSY}*1$
Model_1	No	No	None	SWO time series	$B_{MSY}= B_{MSY}*1;F_{MSY} = F_{MSY}*1$
Model_2	Yes	No	None	SWO time series	$B_{MSY}= B_{MSY}*1;F_{MSY} = F_{MSY}*1$
Model_3	Yes	Yes	None	SWO time series	$B_{MSY}= B_{MSY}*1;F_{MSY} = F_{MSY}*1$

MSE calculations. The procedure makes an attempt to mimic how we typically operate: using last year's data in an assessment and an estimate of this year's catch to predict the catch that should be taken next year. Thus, if the last year in the assessment is 2014, then a value for the 2015 catch is provided in the two year projection, and an F applied in 2016 to determine what the catch in 2016 should be. However, in this study the stock is assessed every year. The following is a sequential list of the MSE procedure:

All procedures begin with last base year (Year N). The sequence of calculations for the build-up models and the ASPIC estimation models are as follows:

Generic Mode - No Estimation Model

1. Apply log-normal error and bias from management specification to SSB (year N-1) to get SSB-Estimated
2. Apply Harvest Control Rule to get Target-F
3. Apply log-normal error and bias from management specification to Target-F to get Full-F in year N+1
4. If constraint applies use to constrain Full-F in year N+1
5. Increment N and Perform population calculations using Full-F from step above

ASPIC-ASPIC Projection

1. Target catch is Landings+Discards in Year N
2. Draw random Catch & Survey Samples for N Years
3. Run ASPIC in Bootstrap mode and retrieve biomass from ASPIC in Year N
4. Apply Management Rule Equation to get Target-F
5. Apply log-normal error & bias as defined in ASPIC template to Target Catch
6. Run Two-Year ASPIC_P run with specs as catch from step above in year 1 and Target-F in year 2
7. Get Yield in 2nd year from ASPIC-P Results (Catch-Save)
8. If N = base year then Projected-Catch = Total Landings+Discards in Year N
9. If N > base year then Projected-Catch = Catch-Save in year N-1
10. Estimated-Catch is obtained by applying log-normal error & bias to Projected-Catch
11. If constraint applies use to constrain Estimated Catch in Year N+1
12. Increment N and Perform population calculations using Estimated catch from step above as harvest spec

Management Procedures. Four different management procedures were constructed for evaluation. The two assessment models used were ones typically used for swordfish, the Shafer production model and the Fox production model, each implemented with ASPIC. The two harvest control rules used where $B_{MSY} = B_{MSY}$ *1 and $F_{MSY} = F_{MSY}$ *1, and, $B_{MSY} = B_{MSY}$ *1.20, and $F_{MSY} = F_{MSY}$ *0.80. It should be noted that even though Model_5 is the most similar to the manner in which the swordfish stock is currently being managed, ICCAT still does not employ a harvest control rule.

Management Procedure	*Estimation Model*	*Harvest Control Rule*
Model_4	ASPIC with Shafer	$B_{MSY} = B_{MSY}$ *1; $F_{MSY} = F_{MSY}$ *1
Model_5	ASPIC with Shafer	$B_{MSY} = B_{MSY}$ *1.20; $F_{MSY} = F_{MSY}$ *0.80
Model_6	ASPIC with Fox	$B_{MSY} = B_{MSY}$ *1; $F_{MSY} = F_{MSY}$ *1
Model_7	ASPIC with Fox	$B_{MSY} = B_{MSY}$ *1.20; $F_{MSY} = F_{MSY}$ *0.80

***Performance measures*.** The selection of performance measures were based on three simple premises: (1) the amount of long term harvest of the stock and the annual variation of harvest; (2) how often the stock is estimated to be overfished and that overfishing is occurring during the entire management period as well as the annual variation in these estimates; and (3) the probability that the stock will be overfished or experiencing overfishing in the last year of the management period. To this end, the following is a list of the performance measures considered:

- Landings
- Landings (CV)
- F/F_{MSY}
- F/F_{MSY} (CV)
- B/B_{MSY}
- B/B_{MSY} (CV)
- Probability of overfishing
- Probability of overfished

3. Results

The results from the build-up models (Models_0 to Model_3) did not indicate any inconsistencies in any of the model configurations. With no estimation model considered each of the management procedures converged on to the level of MSY used within the HCR (**Figure 3**). Values of F/F_{MSY} were consistently maintained slightly below the reference point of 1.0 and values B/B_{MSY} was consistently maintained slightly above the reference point of 1.0. Consequently, with assessment results with normally distributed observations error and no bias in the observation data or the estimates of F/F_{MSY} and B/B_{MSY} the models and harvest control rule worked as expected.

Models_4 and _6 resulted in the most landings at the beginning of the management period (**Figure 4**, top). This is due to the more aggressive HCR that allowed the stock to be fished closer to MSY. However all model converged on the same catch by the end of the management period. By the end of the management period Model_5 resulted in slightly higher landings (**Figure 4**, bottom).

Of the four management procedures examined only one, Model_5, consistently resulted in values of F/F_{MSY} of less than the reference point of 1.0. On average, across all iterations, Model_5, _6, and _7 all resulted in estimates of F/F_{MSY} of between 1.0 and 1.20 (**Figure 5**, top). Likewise, in the final management year only Model_5 resulted in a mean value of F/F_{MSY} below 1.0 (**Figure 5**, bottom).

Of the four management procedures examined on one, Model_5, consistently resulted in values of B/B_{MSY} at the desired reference point of 1.20 times B_{MSY} (**Figure 6**, top). This was also the case for the last year of the management period (**Figure 6**, bottom).

Based on the eight performance measures considered, the Shafer production model coupled with the more conservative harvest control rule outperformed the other three management procedures (**Figure 7**). This management procedure resulted in the lowest probability of overfishing while doing so with no sacrifice in landings.

4. Discussion

The study represents the beginning of what will be an ongoing effort to arrive at a management procedure that can be used for northern swordfish. As this work progresses it aims to expand this analysis in an effort to arrive at a more universal management procedure, one that will incorporate other species under the purview of ICCAT.

The results of this study suggest that the use of the proper management procedures can reduce management risk without reducing landings. However, while this may be the case for swordfish in its current state, further work will need to be done that incorporates such things as biases in the assessment models and CPUE data, under reporting of landings, and the use of shortened CPUE time series, just to name a few.

This paper did not address either sampling or implementation issues. The case was made that since ICCAT cannot control these factors that they could be set aside for now. However, in retrospect, the very fact that ICCAT cannot control these two factors is exactly why they should be included in the MSE. Managers need to be certain that any management procedure that is chosen is robust to the factors that they have no control over.

The final performance measures and objectives used to evaluate the relative effectiveness of each management procedure were quite generic. In reality, these objectives need to be a product of dialogue between scientists, managers, and ideally stakeholders. Only by these various groups working together can the full suite of management objectives be agreed upon in which future MSE work can be conducted. Consequently, this paper recommends that a list of measureable criteria be arrived upon in which identified management objectives can be developed. The ICCAT meetings held by the Working Group on dialogue between fisheries scientists and managers (SWGSM) are the ideal place for these conversations to be held.

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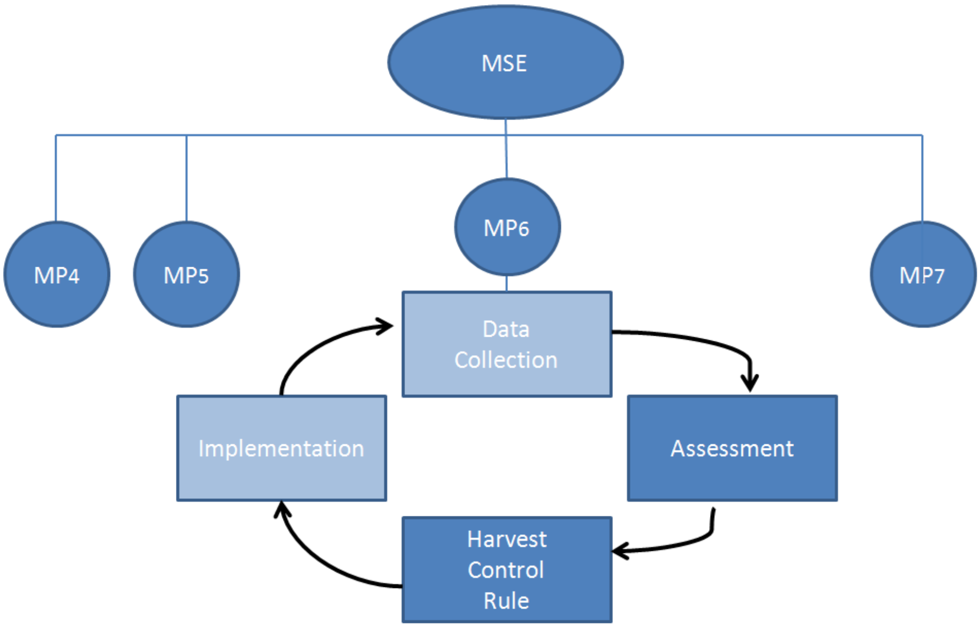


Figure 1. Basic flow chart for the management strategy evaluation undertaken in this study. Note that data collection and implementation is not considered, but assessment models and harvest control rules are.

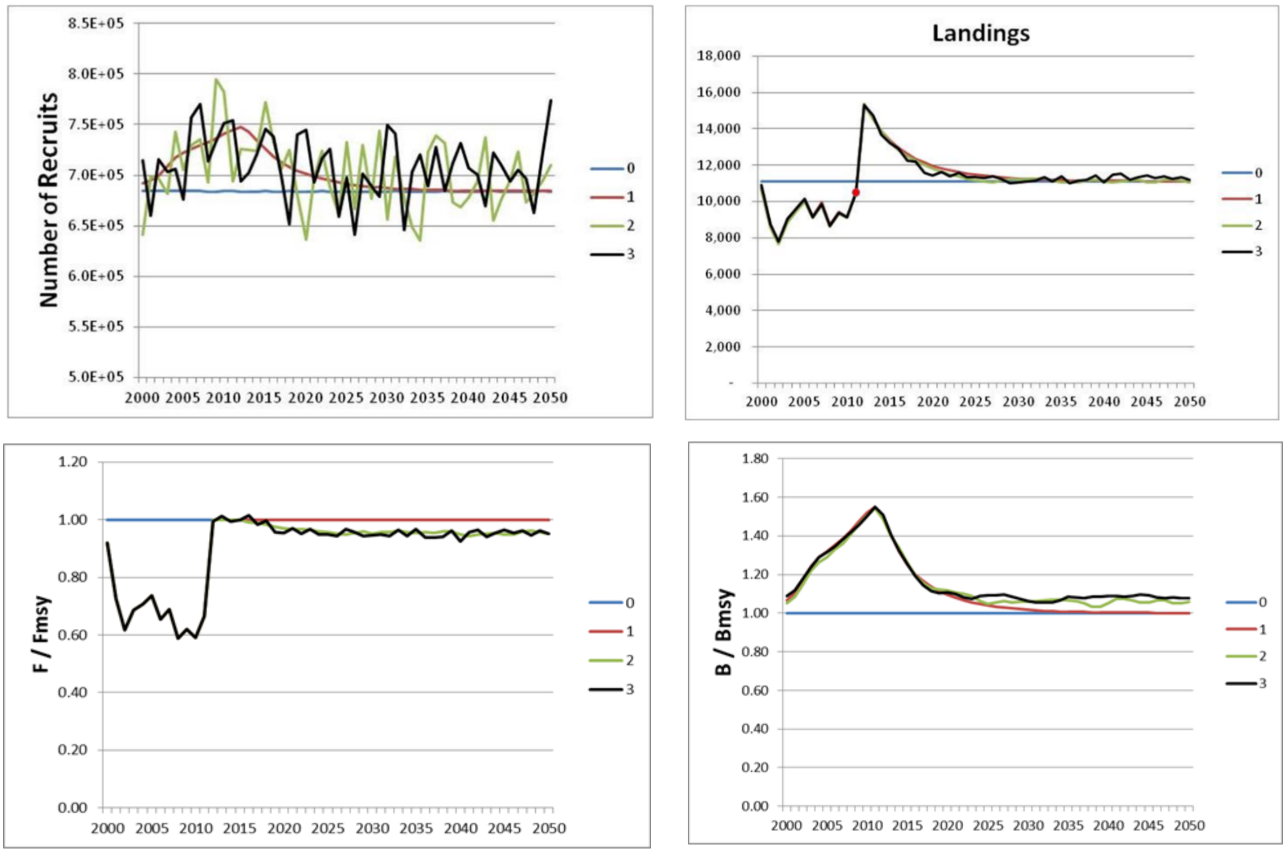
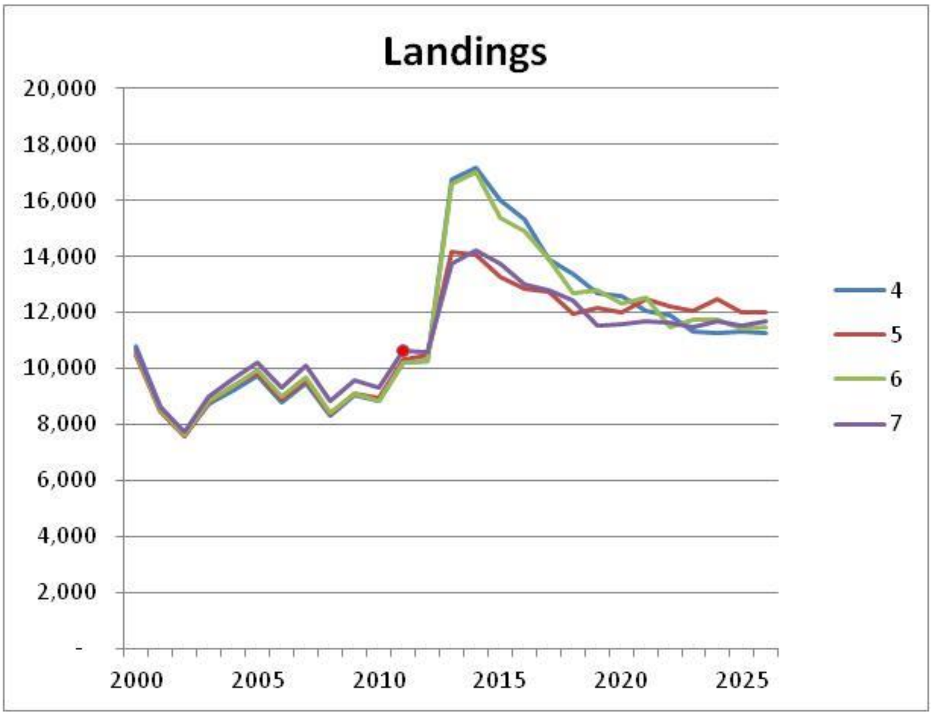


Figure 2. Time series of recruits (upper left), landings (upper right), F/F_{MSY} (lower left) and B/B_{MSY} (lower right) for build-up models.



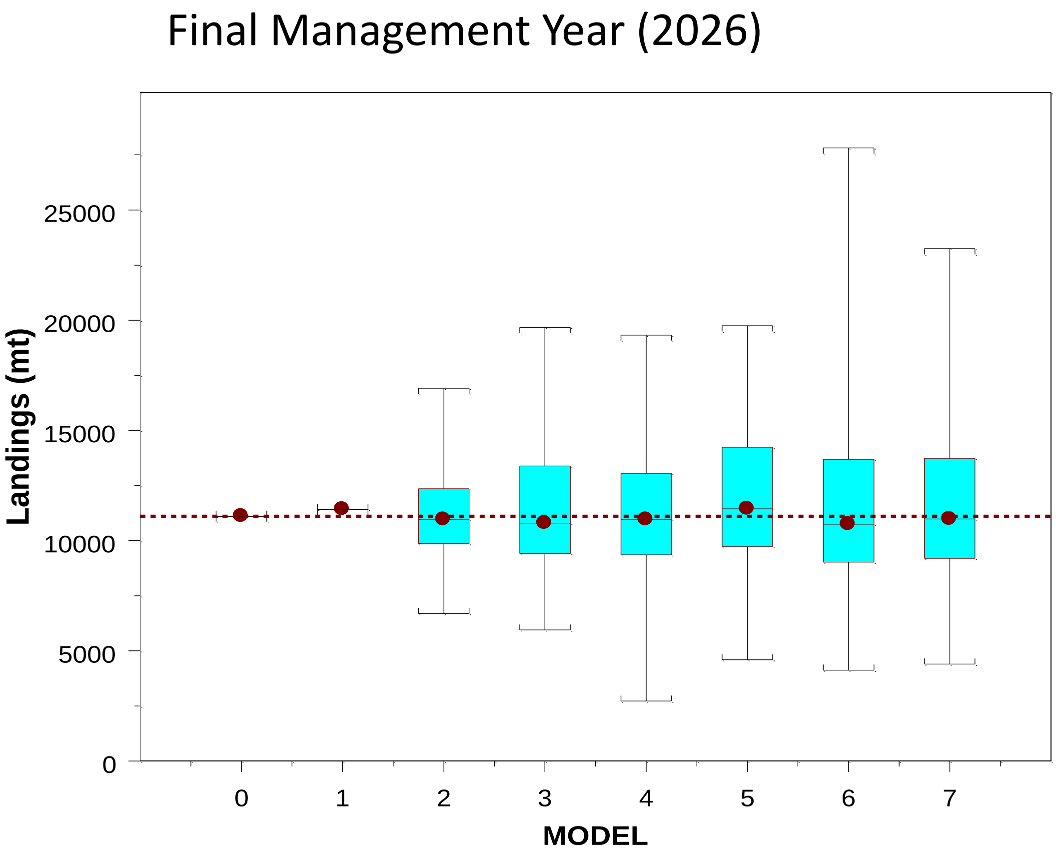
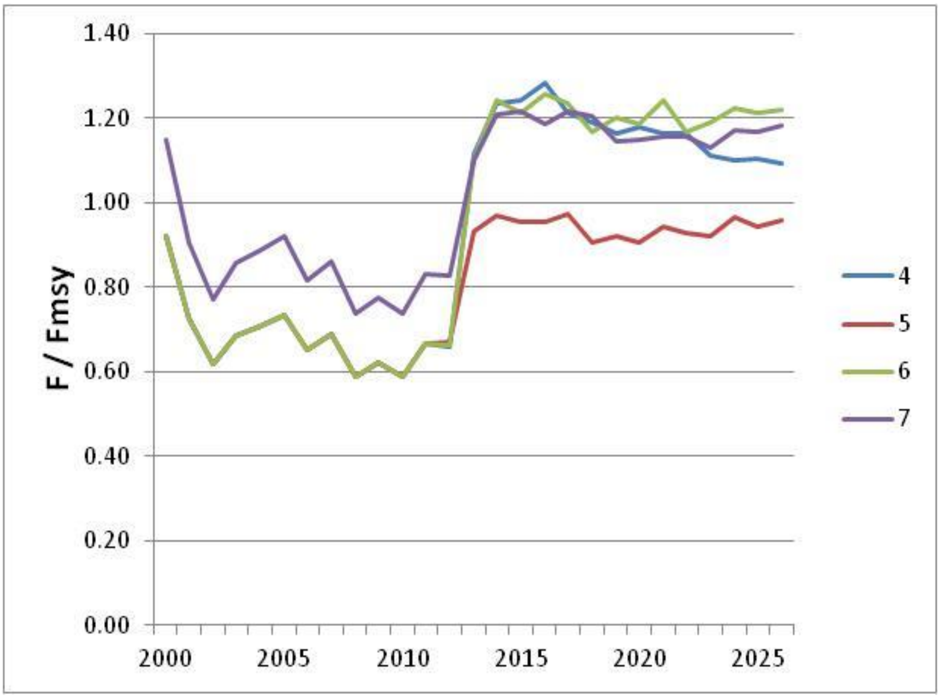


Figure 3. Landings in weight by management procedure (model number) and year averaged across all interations (top); landings for the final year of the management period for the build-up models and all four management procedures (bottom).



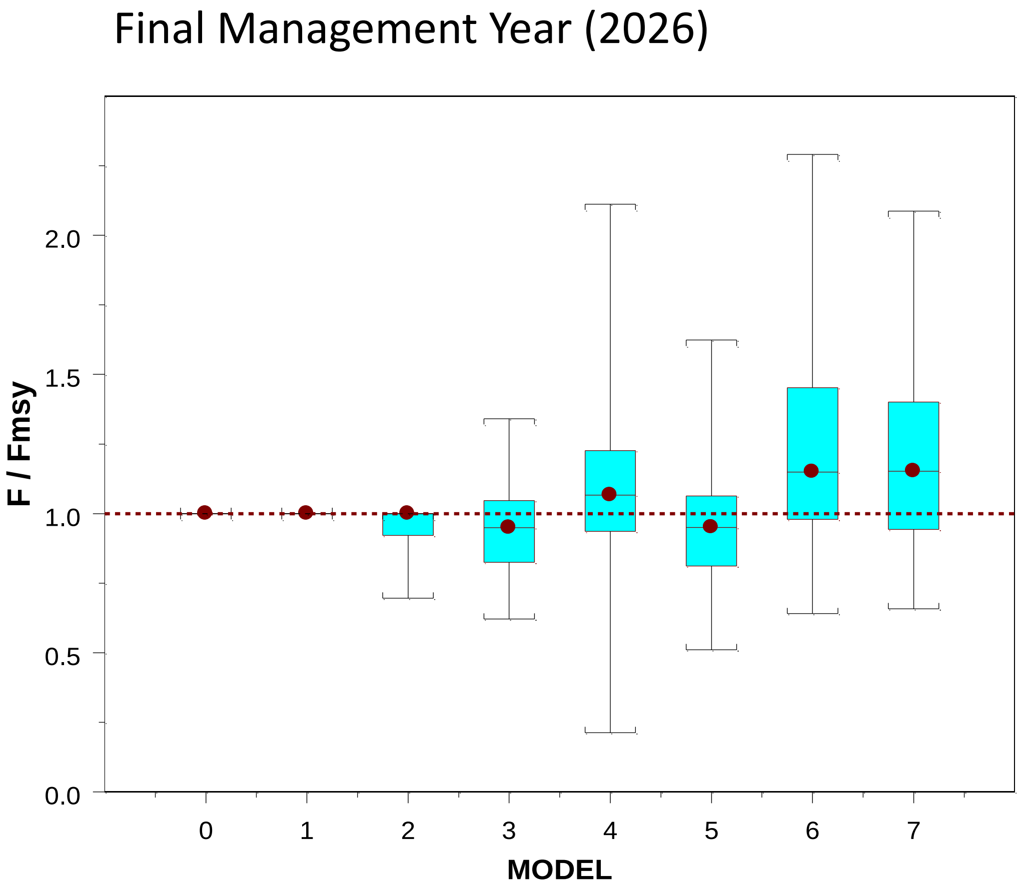


Figure 4. F/F_{MSY} by management procedure (model number) and year averaged across all interations (top); F/F_{MSY} for the final year of the management period for the build-up models and all four management procedures (bottom).

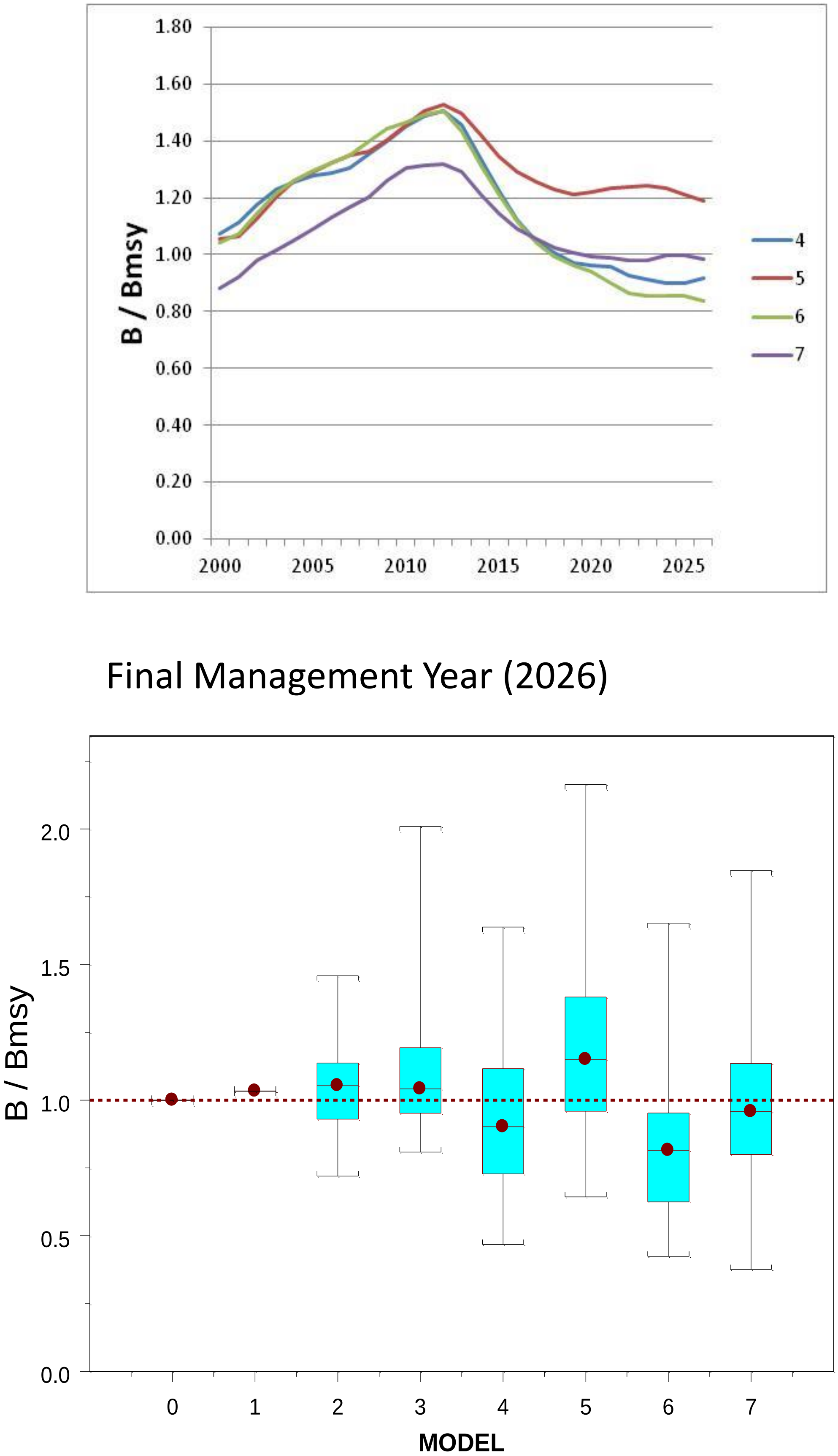
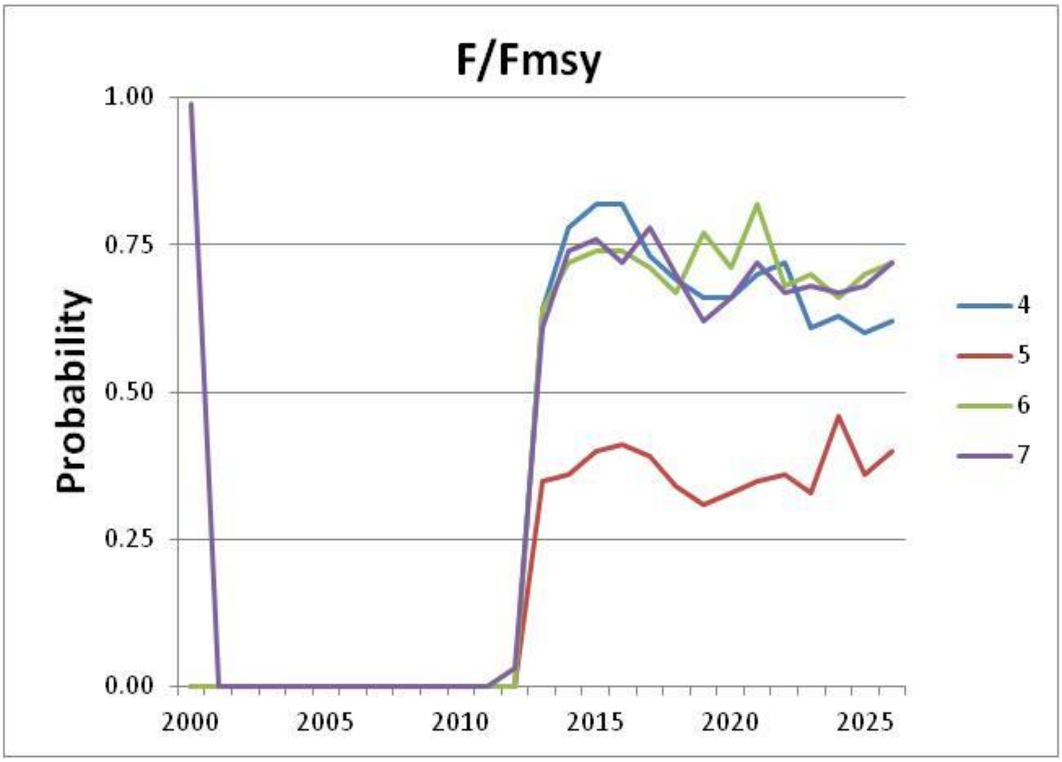


Figure 5. B/Bmsy by management procedure (model number) and year averaged across all interations (top); B/Bmsy for the final year of the management period for the build-up models and all four management procedures (bottom).



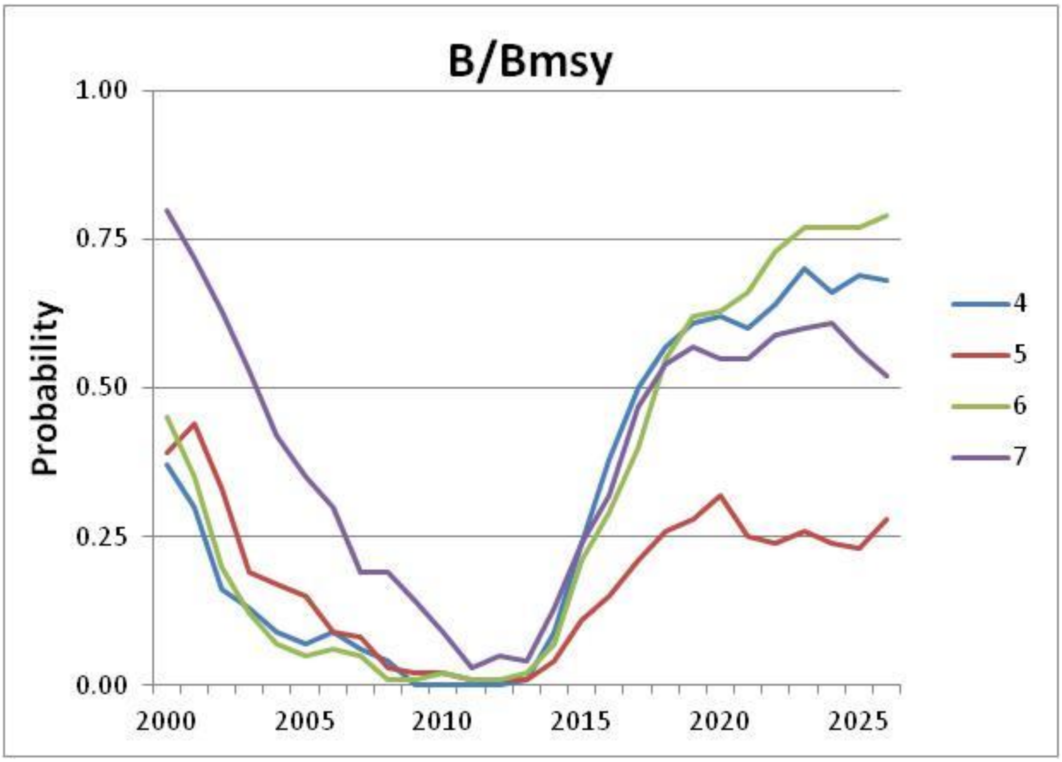


Figure 6. Probability of fishing mortality being greater than fishing mortality that produces MSY by year and management procedure (top); probability of biomass being greater than the biomass that produces MSY by year and management procedure (bottom).

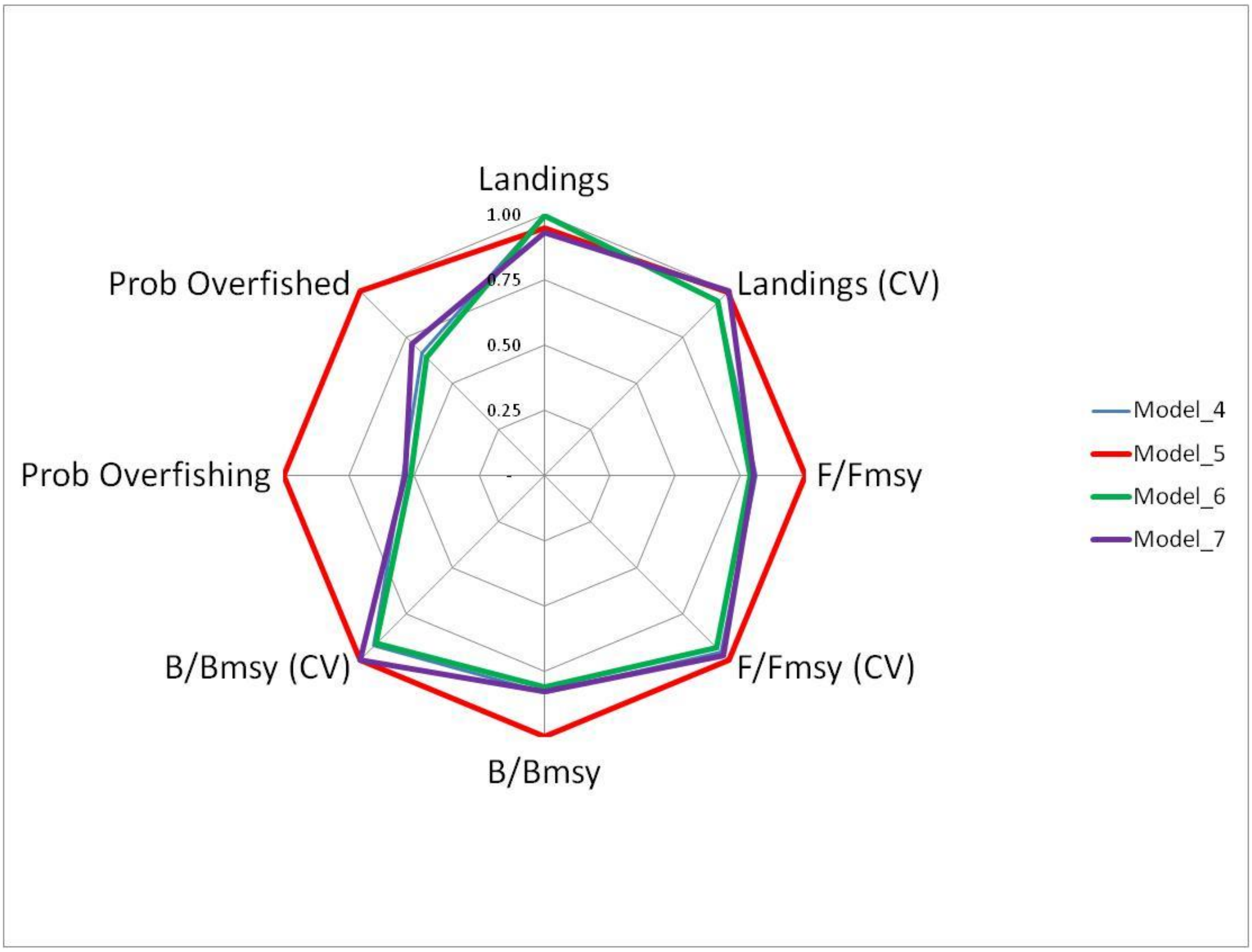


Figure 7. Radial graph depicting the scores of each of the four management procedures (models) for each performance measure. Scores were calculated for the average of the entire management period and standardized to either their maximum or minimum values for each performance measure.