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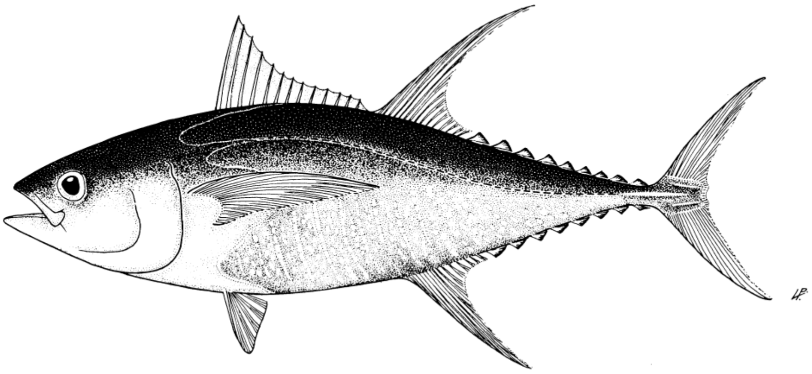
SCTB16 Working Paper

MWG–5

Application of SCALIA and Production Models (Fox, Schaefer, and Age-Structured) to the SCTB MWG 2003 Simulated Tuna Fishery Data



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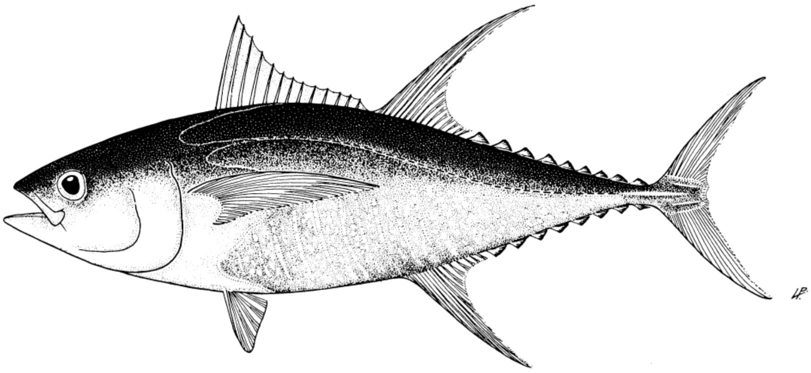

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Abstract

This working paper provides a brief overview of the application and inferences obtained from fitting several stock assessment models to simulated fisheries data generated by an operating model with biological characteristics resembling western and central Pacific Ocean yellowfin tuna (5 different fishery scenarios, developed by the Secretariat of the Pacific Community Oceanic Fisheries Program). The assessment models presented here consist of a spatially-aggregated integrated analysis model (SCALIA) and 4 production models (Fox, Schaefer, age-structured with deterministic recruitment, and age-structured with annual recruitment deviations). SCALIA used all of the available data dis-aggregated by fishery (but not region): catch-length, tag release/recovery, effort, catch-mass and catch-numbers; the production models used only total catch, and CPUE from the (largest catch) longline fishery as a relative abundance index.

A preliminary comparison of the results to some known operating model values suggests that the simpler production models generally provided inferences that were similar to, or better than, the age-structured production models, while SCALIA most often provided the worst inferences (for absolute biomass estimates, MSY and F_MSY). At least one version of SCALIA generally estimated depletion (B(T)/B(0)) as well as, or better than, the production models, but all models estimated depletion rather poorly in 2 out of 5 operating model scenarios. In all cases, SCALIA produced reasonably good correspondence between model predictions and observations, but the estimated stock dynamics and productivity characteristics were rather sensitive to assumptions (and depending on one's prior beliefs, might be considered unrealistic in many cases). We discuss these results in relation to a similar simulation study and the methodological problems inherent in both.

A more detailed comparison of these assessment model results with other assessments and a broader range of performance indicators should be an outcome of the SCTB-16 MWG.

Introduction

The Secretariat of the Pacific Community Oceanic Fisheries Program (SPC-OFP) is developing a model to simulate fish and fishery dynamics that resemble the WCPO yellowfin tuna system (eg Labelle 2002), with a primary objective of testing the inferential performance of MULTIFAN-CL (eg Hampton and Fournier, 2001) as a stock assessment tool. An initial round of testing was undertaken in 2002, co-ordinated by the Standing Committee on Tuna and Billfish Methods Working Group (MWG), in which several assessment models were tested and compared to different degrees (Anon. 2002). Results were mixed, but generally encouraging, and the MWG proposed further simulation testing in 2003. The new scenarios were intended to have higher overall exploitation (F~M) and increased levels of process and observation error. It was hoped that this round of simulations might help to distinguish the appropriateness of spatial structure in the WCPO tuna assessment models. As a result, 5 different simulation scenarios were devised, and 40 stochastic state and data realizations were generated from each. All scenarios involved similar biological characteristics; they varied primarily in the fishery characteristics and data aggregation units (the simplest scenario produced data from one fishery in one large region; the most complicated had 16 fisheries distributed across 7 smaller regions).

This paper briefly describes the application of 5 spatially-aggregated assessment models (2 age-aggregated production models, 2 age-structured production models and a Statistical Catch-at-Age/Length Integrated Analysis (SCALIA)). A few key assessment model inferences are compared with known values from the operating model, but we expect more detailed results to be an outcome of SCTB-15. Finally, we provide some comments about the problems encountered in this exercise and a similar project being undertaken at CSIRO (Simulation-Estimation Stock Assessment Model Evaluation – SESAME).

The Operating Models

The yellowfin tuna simulator (extended from Labelle 2002) operates on a monthly time step with migration dynamics and spawning characteristics linked to temporally variable and relatively fine spatial scale (5 x 5 degree) environmental data fields (SST) covering a large part of the WCPO. Spawning was continuous and independent within each sub-region and dependent on SST. Each of these recruitment events formed a homogenous sub-population that remained together as a migrating unit. The simulated data consisted of 148 quarterly observations of total catch (numbers or mass depending on the fishery), catch length frequency distributions and effort by fishery, plus tag releases by area (including release lengths) and recaptures by fishery (and length at release). Relative areas and spatial relationships between the fishery regions were provided. Additional biological information was provided on length-at-age, mass-at-length, maturity-at-age and maximum longevity. The 5 scenarios consisted of 1 fishery in 1 region (1F x 1R), 2 fisheries in 1 regions (2F x 1R), 4 fisheries in 2 regions (4F x 2R), 7 fisheries in 7 regions (7F x 7R) and 16 fisheries in 7 regions (16F x 7R). We are not entirely clear about all of the simulated fishery and fish population characteristics at this time; it was suggested that some scenarios may have included some rather perverse (realistic) dynamics including temporally variable selectivity and catchability, and variable fish growth rates.

The Assessment Models

Production Models

The production models included fairly standard implementations of Fox, Schaefer and two versions of age-structured production models (ASPM). ASPM_det included recruitment as a deterministic function of an estimated Beverton-Holt stock recruitment relationship as applied in 2002 (Ricard and Kolody 2002), and ASPM_sto, which includes estimation of quarterly recruitment deviations from an estimated stock recruitment relationship (log scale CV of 0.8). Major changes from SCTB-15 (and other important details) include:

- production models only used CPUE from the longline fishery with the largest catch
- temporal trends in catchability were not estimated (we assume this to be the biggest difference from the rather poor performance observed in 2002)
- ASPM fishery selectivity was derived directly from the data, using a simple analysis comparing catch-at-length in the first few timesteps, relative to the equilibrium age structure (assuming F = M). The length-based selectivity was converted to age-based by cohort slicing. Within each scenario, the procedure was conducted on only one realization and subsequently used for all realizations within the scenario. In contrast, the 2002 analysis used rather arbitrary selectivity vectors, not derived from the data.
- Natural mortality was assumed constant with age (quarterly M = 0.15; ~1.5% of a cohort survives 28 quarters)

Comprehensive documentation will be forthcoming in relation to the CSIRO SESAME project. Due to time constraints, ASPMs were not applied to the 16F x 7R scenarios; and Fox and Schaefer results for 7F x 7R and 16F x 7R are described here, but were not submitted to the MWG.

SCALIA

SCALIA is an evolving assessment framework, with most features adopted from MULTIFAN-CL (including multiple fisheries, catch-at-length prediction, tag dynamics; but no spatial dis-aggregation at present); comprehensive documentation will be produced over the next few months as part of the SESAME project. SCALIA was originally developed for the assessment of Southern Bluefin Tuna. Extensions and application differences since SCTB 15-MWG (Kolody 2002) include:

- total catch in mass data can be used directly (in addition to catch in numbers)
- stock recruitment relationship steepness is estimated with no prior constraints

- MSY and related reference point calculations are implemented, assuming either constant fishing mortality ratios among fisheries, or constant catch ratios. The latter is less convenient to implement, but is becoming the standard in SBT, where international agreements are based on catch mass.
- A bug in the tag dynamics has been fixed (which affected the 2F x 1R results in the 2002 MWG study)
- an alternative implementation for ageing tagged fish from lengths was implemented to remove likelihood discontinuities caused by cohort-slicing when length-at-age is estimated
- effective sample sizes for CL prediction vary over time as a user-defined fraction of the input sample size (plus a user-defined upper limit)

A couple different assumptions were tested for the simpler scenarios, but given the time constraints, only one or two were applied to all realizations, using default specifications similar to MWG 2002, and the SESAME-SBT simulation project (Appendix 1 provides a description of key specifications/assumptions). In a real assessment situation, we would have explored several formulations, examined goodness-of-fit diagnostics and attempted to express the uncertainty across models in some manner. As it is, the scenarios presented do not represent “best assessments”, but rather are identified as plausible specifications that have qualitatively reasonable agreement between predictions and observed data. If more than one SCALIA specification was run, results were selected for submission to the MWG on the basis of prior perceptions about the stock productivity (preference given to no trends in biomass that would have occurred in the absence of fishing); SCALIA 3 models were run after submission for curiosity. Due to time constraints, the late arriving 16F x 7R results were based on only 20 realizations, and not submitted to MWG.

Results

In all cases examined, the assessment models provided “reasonably” good fits between the data and predictions (a qualitative description based on experience fitting real data to models). The age-aggregated production models often showed some strong auto-correlated residuals in the fit to CPUE, sometimes including conflicting trends in terminal biomass and CPUE in the most recent years. Not surprisingly, the ASPMs generally had a better fit to the CPUE then the age-aggregated models (particularly ASPM_sto). SCALIA predictions and observations generally corresponded well, and it seemed as though the largest discrepancies were consistent with attempting to fit a spatially-aggregated model to a spatially heterogenous system. These problems included some auto-correlated effort deviations with consistent trends (noted only in some fisheries, particularly in the more complicated scenarios). There were some dubious fits to the length frequency data, and (aside from small sample size cases and the very small length classes), these were generally a few consecutive quarters, and not obviously related across fisheries. The gross features of the tag recoveries were usually well described, although older tags were often noticeable under-estimated.

Summary results were provided to the SCTB-16 MWG in electronic format (including time series of recruitment, (exploitable) B, SSB, C/B, plus B and SSB that would have occurred in the absence of fishing; and point estimates of quarterly MSY, C(MSY)/B(MSY), SSB(MSY)). We provide a few summary statistics compared with the actual operating model means (across realizations within scenario as provided by Marc Labelle , SPC-OFP, June 2003). The following indices describe absolute biomass, relative depletion, and sustainable catches:

B(T) = mean exploitable biomass (last 3 quarters)

B(T)/B(0) = mean exploitable biomass (last 3 quarters) / B(0)

MSY = Maximum Sustainable Yield (assuming constant catch-mass ratios across fisheries according to the mean of the final 12 quarters for the assessment models or final 3 quarters for the simulator)

F_MSY = C(MSY)/B(MSY) catch-mass over exploitable biomass at MSY

1F x 1R Operating Model Scenario

Based on the 4 evaluation criteria (fig. 1), it appears as though the Schaefer model was probably the best overall performer followed by Fox and ASPM_det. SCALIA is clearly worse than the production models in terms of F_MSY and B(T), but at least one SCALIA specification is similar or better than the production models in terms of B(T)/B(0) and MSY. ASPM_sto demonstrated serious problems except in MSY estimates.

2F x 1R Operating Model Scenario

The Schaefer model was probably the best all around model for this scenario, with the other production models (excpet ASPM_sto) exhibiting similar performance (fig. 2). The SCALIA models demonstrate a broad range of performance, with some reasonable inferences, but none of the 3 specifications are consistently better than the simple production models. ASPM_sto demonstrated serious problems except in MSY estimates.

4F x 2R Operating Model Scenario

It is not clear which model performed the best in this case (fig. 3). All models substantially exaggerated the state of depletion (under-estimated B(T)/B(0)), but all produced reasonable MSY estimates. SCALIA and ASPM_sto provided reasonable estimates of B(T); ASPM_sto provided the best average performance on F_MSY, though with many outliers.

7F x 7R Operating Model Scenario

The production models performed reasonably well, except for the F_MSY estimates, and were clearly better than SCALIA in all categories except for the depletion estimates B(T)/B(0), which were similar (fig. 4). The contrast in the two SCALIA specifications illustrate the sensitivity to assumptions.

16F x 7R Operating Model Scenario

The results in fig. 5 only represent about 20 realizations (due to computational time constraints), but are sufficient to reasonably demonstrate mean performance. All assessment models performed poorly in the estimation of B(T)/B(0). The age aggregated models were not too bad for MSY and B(T); while SCALIA was pretty poor in all estimates.

DISCUSSION

Based solely on the preliminary results illustrated in figs. 1-5, it would be difficult to conclude that the complicated SCALIA models are particularly useful, when very simple production models tend to make more accurate and precise inferences. We might be tempted to consider this a classic case of fitting a model that is more complicated than the data quality/quantity can justify (eg Ludwig and Walters 1985), but there are a number of points that need further consideration when drawing conclusions:

1) There are a number of situations that we would expect to contribute to the failure of production models, including transient age-structure effects and spatial heterogeneity. If the age-structure is sufficiently variable over time, it can impact the spawning biomass – productivity relationship or cause poor agreement between stock biomass and CPUE due to fishery selectivity (more of a concern for age-aggregated models than ASPMs). However, a long time series relative to the fish longevity, and fishery selectivity/intensity that does not produce a strong temporal trend in the age structure would probably allow this effect to average out. Spatial heterogeneity in age-structure and abundance could also deteriorate the quality of CPUE as a relative abundance index. However, fortuitous choice of a fishery representative of average characteristics (perhaps due to localized mixing characteristics) could make this effect negligible. In contrast to the production models SCALIA has mechanisms for explicitly accommodating some of these effects, but it is certainly not clear that they are very effective. If the operating model dynamics were not sufficiently challenging these limitations, we would not be surprised to see the production models perform well.

2) These four performance indicators do not necessarily describe the most important stock assessment inferences (eg accuracy of absolute biomass estimates are probably very sensitive to estimates of juvenile mortality, and less meaningful than other inferences like relative trends in spawning biomass). Similarly, if a model provides a very poor estimate of a key system attribute (eg current depletion), can we consider a corresponding estimate of another property (eg MSY), to be useful (even if it is good in the simulations)? We expect the MWG synthesis to provide more information related to this.

3) None of these models seemed to perform very well in some scenarios (4F x 2R and 16F x 7 R) – we would like to figure out if we can identify models that do make appropriate inferences in these cases. More importantly, we would like to be able to identify goodness-of-fit diagnostics to guide the improvements to the assessments in a real situation. It may not be possible, but there is rather limited scope for even attempting this with production models.

4) These simulation studies need to deal appropriately with prior knowledge to actually compare model performance rather than analyst guesswork. e.g. If two models differ only in their treatment of natural mortality, a lucky guess will presumably outperform estimation with uninformative data. Similarly, as long as the operating model is parameterized in such a way that implicit assumptions in simple models correctly approximate the dynamics, then they will be expected to perform well. We found that SCALIA estimates of M and the stock recruitment relationship (and hence B(T), MSY and F_MSY) were rather sensitive to assumptions in this exercise, but found it difficult to justify imposing priors into the assessments beyond the limited information distributed with the data. The ratio B_MSY/B(0) of the Fox (0.37) and Schaefer (0.5) models are rather close to the mean values in the operating models (0.39 – 0.44), so presumably (when coupled with an informative CPUE series) this explains the reliability of the age-aggregated MSY estimates. Presumably they would not have performed so well if the simulations were designed to test estimation performance over a range of stock-recruitment relationships. However, this argument is partly a rationalization on the part of the frustrated SCALIA proponent, as we note that the ASPM_det generally yielded better MSY estimates than SCALIA, despite also estimating a stock recruitment relationship (and the imposition of steepness 1 to SCALIA 3, did not necessarily improve the MSY estimates).

5) When employing a SCALIA-type assessment to real data, we have found it essential to explore a range of assumptions and attempt to express the resulting uncertainty across specifications. This is computationally demanding, but allows one to explore conflicting trends supported by different data to different degrees. The range of performance indicators among the limited range of SCALIA versions tested clearly indicates the model sensitivity. There is limited scope for doing this with production models. And unless we attempt uncertainty quantification in simulations, we will not know how well we can actually express uncertainty with the more complicated models either. We would argue that this should be a focus in future MWG work.

6) If migration dynamics and spatial heterogeneity in fisheries really do change the nature of local populations over time, and this has important implications for management, then there may be no alternative to running assessments with some sort of spatial structure (eg MULTIFAN-CL). In which case none of the models examined here may be appropriate (even if global inferences are reasonable).

We assume that the actual biological characteristics and data quality (though not quantity) of the simulated fish populations were similar in each scenario, so presumably the variable performance of the assessment models across scenarios is largely determined by the different exploitation patterns of the fisheries in time and space (ie coupled with migration dynamics). This spatio-temporal heterogeneity is a large part of the impetus driving the development of MULTIFAN-CL, and it will be interesting to see if appropriate spatial structure can be defined and parameterized to be informative.

We are also curious whether SCALIA can approximate the effects of this spatial heterogeneity by using temporally variable catchability and selectivity (this feature was not tested in the SCTB context to date). In some scenarios, some of the fisheries demonstrated strong trends in the effort deviations, which could result from differential depletions between regions. ie If local catchability remained constant over time and a particular region has an increasing proportion of the global population, there will be an estimated increasing trend in the catchability of that fishery because it is parameterized for the global population in SCALIA. Particularly in the complicated scenarios, it was sometimes evident that predicted and observed CL fits were not so good in individual fisheries for a number of consecutive time periods. Assuming a true constant local selectivity, this is presumably due to the changes in local population age structure relative to the global population. If the changes are due to consistent migration patterns, presumably appropriate spatial dis-aggregation as used in MULTIFAN-CL could describe the effect. However, if stochastic (environmental) variation in the migration (and recruitment) dynamics dominate, it is not clear that spatial dis-aggregation would be better than allowing temporal variability in selectivity, or even aggregating data over coarser space/time resolution. Given more time, we would have liked to explore the ability of SCALIA to accomodate spatial dynamics using temporal variability in catchability and selectivity, and may continue to do so in the months ahead. We also have not really considered some of the obvious adjustments that one could make to SCALIA (effort deviation variances and effective sample sizes) to consider things like the relative size and proportion of the fish sub-population in each fishery. It is also unclear whether the inclusion of spatially-aggregtated tags is actually helpful. Given the general flavour of the results observed here, we should also be considering alternative treatment of the production models (particularly the selection of CPUE series when multiple fisheries exist). However, it is a concern that, knowing the “correct” answer, one can always justify a model that yields the best inference in hindsight. It might be a misguided effort to attempt to force a model that is substantially structurally incorrect, as the best performing formulation might result from chance rather than reproducible insight.

The assessment models referred to here are undergoing separate simulation testing (similar methodology to the SCTB-MWG), but in the context of a Southern Bluefin Tuna (SBT) operating model. To date, the results have been much more encouraging than the SCTB results (Kolody 2003 describes some SCALIA results primarily aimed at the estimation of stock-recruitment characteristics). We would assume that the performance difference is mostly attributable to the following differences in the SBT study:

1. The SBT (4 fishery) simulator has only been run in a spatially-aggregated mode to date. The initial justification for this approach has been the large scale directed annual migrations that concentrate (possibly homogenize) the stock (adult spawning and juvenile inshore migrations), combined with the distribution of the main fleets, which are each assumed to cover a substantial portion of the global (target-age) SBT range when each fishery is active. These are strong simplifying assumptions, but likely more appropriate for SBT than the tropical tunas. The MWG exercise has suggested that spatial dynamics requires more serious consideration, particularly if SCALIA is going to be applied to tropical tunas or other weakly-mixing stocks.

2. Additional prior knowledge has been provided about the dynamics and data in the SBT case. Some of this has been intentional (eg variance-related parameters) to avoid the problem of evaluating an assessment model on the basis of a careless guess. Different functional implementations between SCALIA and the operating model, plus differing temporal resolution ensure that these values are not known perfectly. But even so, intentional mis-specifications have not generally resulted in the magnitude of errors observed here. Of perhaps more concern, there is presumably an additional unintentional biasing effect in these studies due to the circularity of conditioning based on assessment results to some degree (if other analysts were willing to participate in this study, it might help indicate where unintentional biasing is occurring). We have not reached a satisfactory solution about the appropriate handling of prior information.

3. The SBT simulator (and actual fishery) generates some direct ageing data (from otoliths) from a single fishery in a few recent years, and this appears to be highly informative about the spawning stock age composition (length composition data is not very informative for these age classes).

4. The initial phases of the SESAME project have focused on simulations in which the data are unrealistically good. The data quality and consistency with SCALIA assumptions is being iteratively reduced in further rounds of testing (eg selectivity temporal variability is linked to the age structure, truly size-selective mortality, catchability trends, sample sizes shrinking, etc)

5. The SBT simulated scenarios (and presumably actual fishery) generally reached a higher state of exploitation than the YFT scenarios, offering more informative contrast (particularly for stock and recruitment estimation). While this seems to allow one to distinquish between low, medium and high productivity (on average) in the simulations, the issue remains unresolved in the actual SBT assessment.

As with the SCTB-MWG, it often appears that production model results are no worse than SCALIA results. We expect that this will remain the case in cases where CPUE is highly informative. However, we have also observed the expected breakdown in the age-aggregated production models in some cases – particularly when comparing model inferences across a range of stock recruitment relationships.

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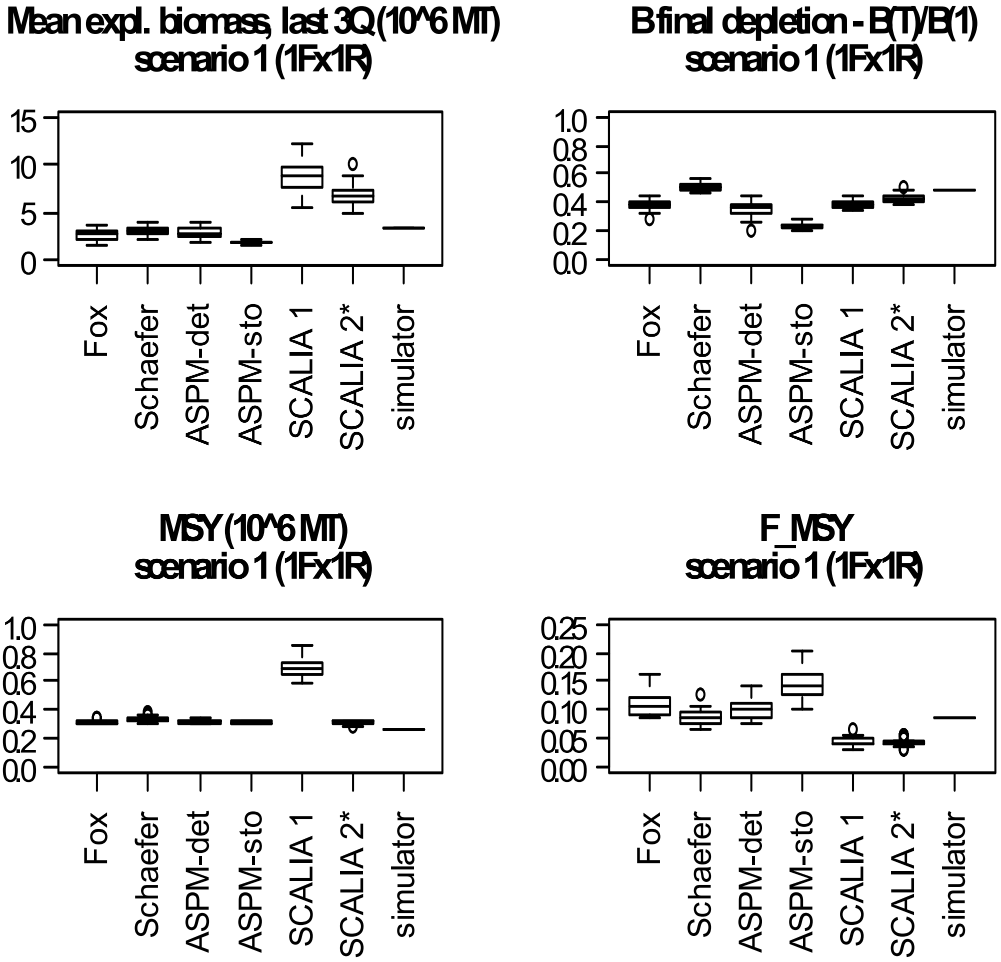

fig. 1. 1 Fishery x 1 Region assessment model results compared with the mean value from the yellowfin simulator. Each boxplot represents the distribution of the Maximum Likelihood or Maximum Posterior Density from assessment model fittings to 40 stochastic data realizations. (*) indicates the SCALIA results that were submitted to the SCTB-16 MWG in electronic format.

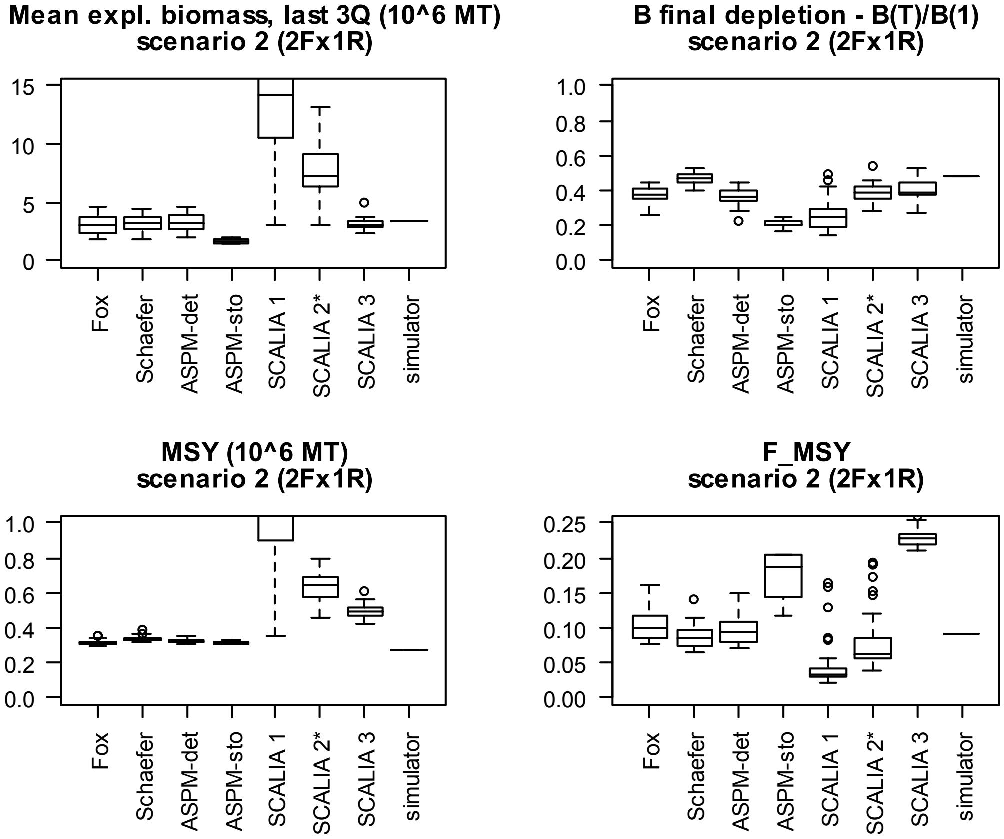

fig. 2. 2 Fishery x 1 Region assessment model results compared with the mean value from the yellowfin simulator. Each boxplot represents the distribution of the Maximum Likelihood or Maximum Posterior Density from assessment model fittings to 40 stochastic data realizations. (*) indicates the SCALIA results that were submitted to the SCTB-16 MWG in electronic format.

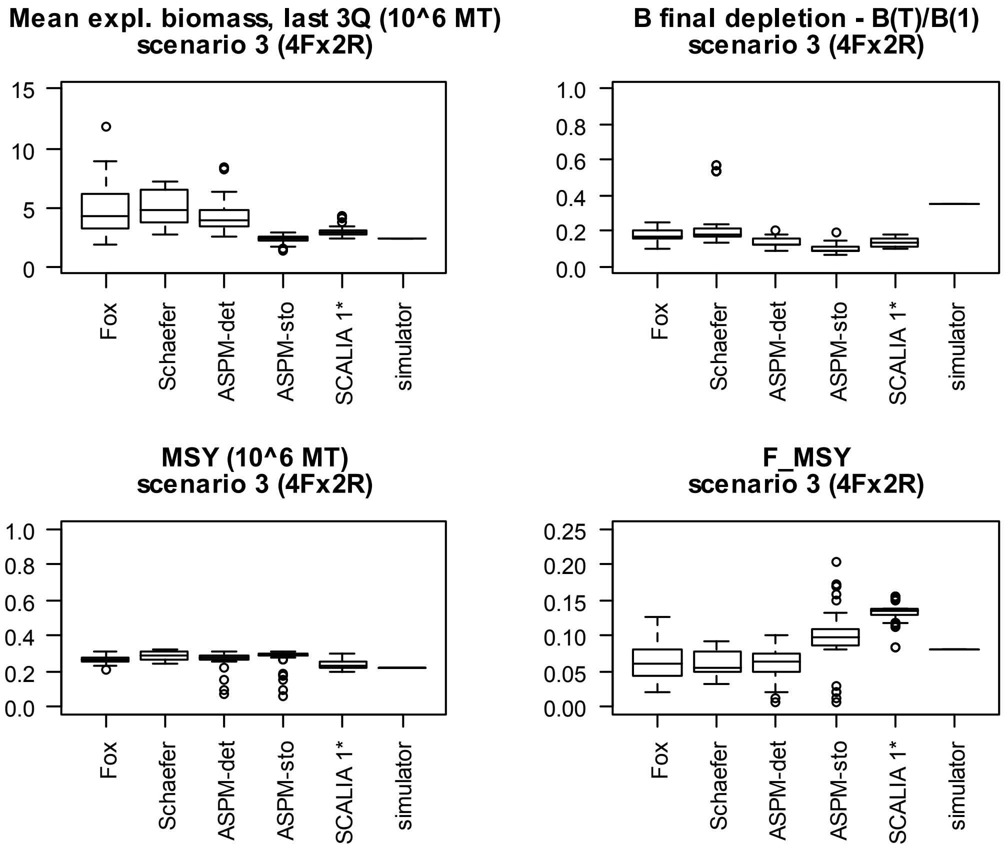

fig. 3. 4 Fishery x 2 Region assessment model results compared with the mean value from the yellowfin simulator. Each boxplot represents the distribution of the Maximum Likelihood or Maximum Posterior density from assessment model fittings to 40 stochastic data realizations. (*) indicates the SCALIA results that were submitted to the SCTB-16 MWG in electronic format.

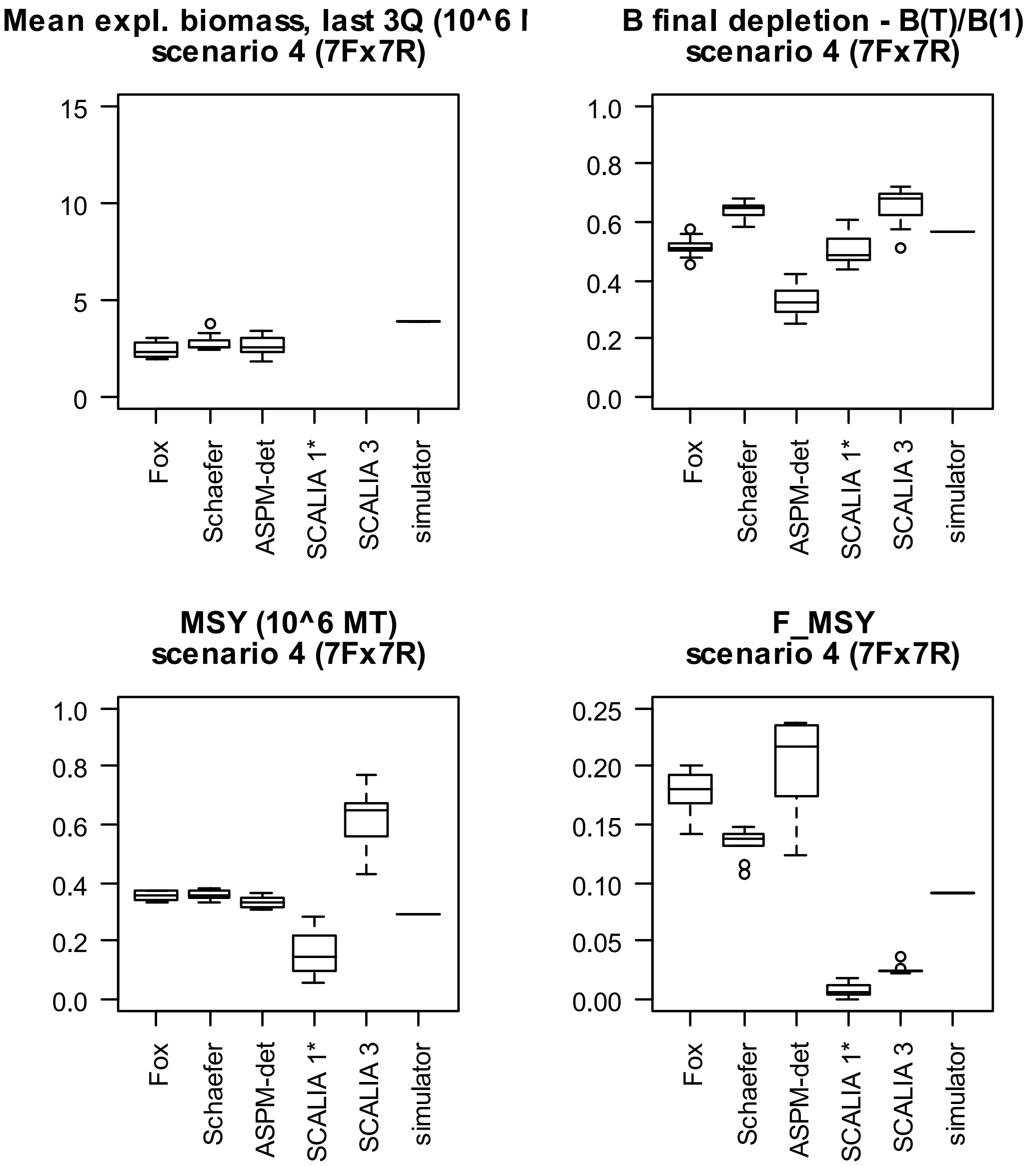

fig. 4. 7 Fishery x 7 Region assessment model results compared with the mean value from the yellowfin simulator. Each boxplot represents the distribution of the Maximum Likelihood or Maximum Posterior density from assessment model fittings to 10 stochastic data realizations (40 realizations were fit for SCALIA 1 and the production models, but only 10 for SCALIA 3; the additional 30 results do not change the general picture illustrated here). The SCALIA absolute biomass estimates are off the scale. (*) indicates the SCALIA results that were submitted to the SCTB-16 MWG in electronic format (none of the 7F x 7R production model results were submitted).

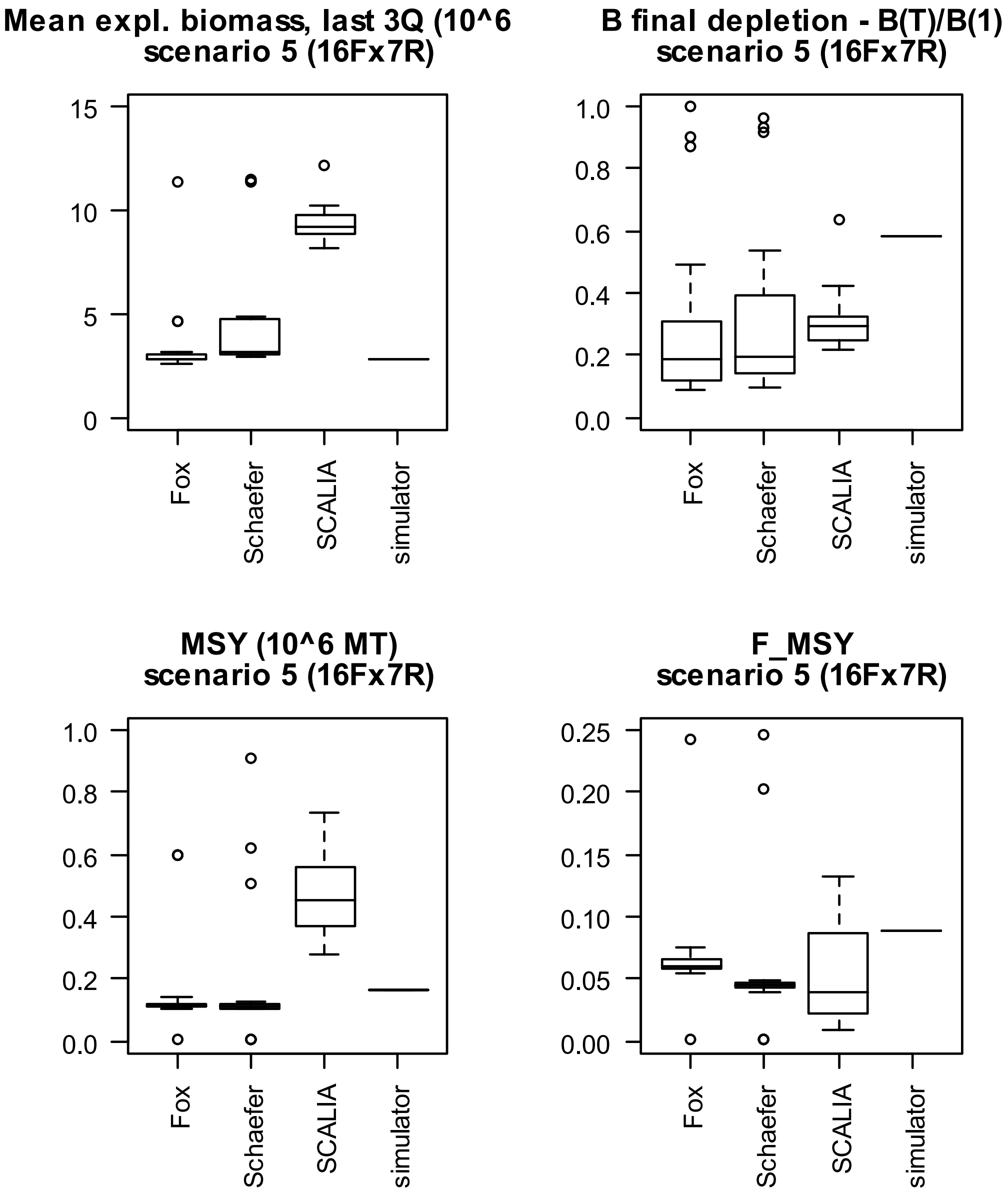

fig. 5. 16 Fishery x 7 Region assessment model results compared with the mean value from the yellowfin simulator. Each boxplot represents the distribution of the Maximum Likelihood or Maximum Posterior density from assessment model fittings to 20 stochastic data realizations. None of these results were submitted to the SCTB-16 MWG in electronic format.

Appendix 1. SCALIA specifications for the analysis of the 2003 SCTB-MWG simulated yellowfin fishery data sets

The SCALIA assessments were all derived from a baseline specification that has been reasonable in a range of other simulation testing scenarios. Deviations from the baseline involved variance-related parameters and the number of parameters estimated (restricted in the more complicated scenarios for minimization speed). All fisheries data were treated with equal reliability (despite obvious differences in effort, sample sizes and location relative to the bulk of the population). Specific assumptions included the following (definitions explained in Kolody 2002):

Description	Value
total catch observation error app. CV	0.01
stock-recruitment relationship log-scale CV ($t < -5$; $-4 <= t <= 148$)	0.01; 0.8
stock-recruitment auto-correlation	0
catch-at-length effective sample size (fraction of observed)	0.1
catch-at-length maximum effective sample size	1000
effective tag release co-efficient	0.1
maximum effective effort deviation app. CV	0.2
effort deviation prior scaling exponent	1
temporal change in catchability app. CV	na
selectivity curvature penalty (pseudo-length-based parameterization used)	2.0
mortality-at-age curvature penalty and CV on deviations from mean	0.05
app. CV for priors on mortality-at-age deviations from mean mortality	0.2
Beverton-Holt Stock Recruitment relationship steepness	estimated
number of quarters that catchability is assumed constant between changes	na
number of quarters that selectivity is assumed constant between changes	na
tag reporting rates (all fisheries)	1.0

In all cases, the mean length-at-age was adopted from the prior information (Marc Labelle, SPC, pers comm); variances on length-at-age were estimated for the simple cases (<7 fisheries) but not the complicated cases (7+ fisheries).

A haphazard testing of alternative specifications included:

maximum CL effective sample size =	200
effective tag release multiplier =	1.0, 0.01
maximum effective effort deviation app. CV =	0.1, 0.4
effort deviation prior scaling exponent =	0
mortality-at-age curvature penalty =	0.2
recruitment deviation CV =	0.4

The distinction between SCALIA 1 and SCALIA 2 in the text and figures does not indicate an exact specification for a given scenario. However, SCALIA 3, indicates stock recruitment relationship steepness fixed at 0.999, and M estimated, but constant for all ages.