INTER-AMERICAN TROPICAL TUNA COMMISSION

# EXTERNAL REVIEW OF IATTC YELLOWFIN TUNA ASSESSMENT

La Jolla, California (USA)

October 15-19, 2012

## FINAL REPORT

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## BACKGROUND

The assessment of yellowfin tuna (*Thunnus albacares*; YFT) in the eastern Pacific Ocean (EPO), defined for the purposes of this review as the area east of 150°W between 40°N and 40°S, is based on fitting an age-structured population dynamics model to data on catches, catch rates, length-frequency data, and data on length-at-age. Sixteen separate fisheries based on geographical locations and fishing methods were defined for this assessment. They are defined on the basis of gear type (purse seine (PS), pole and line (LP), and longline (LL)), purse-seine set type (associated with floating objects (OBJ), unassociated (NOA), and dolphin-associated (DEL)), and IATTC length-frequency (LF) sampling area or latitude (Northern and Southern regions) (Figure A and Table A). The assessment uses the Stock Synthesis (SS) software (Methot 2009). The IATTC staff identified a set of assumptions, which are reflected in the base-case model (Aires-da-Silva and Maunder 2011). There is uncertainty about recent and future levels of recruitment and biomass. It is hypothesized that there have been two, or possibly three, different productivity regimes that affect overall population scaling and reference points based on maximum sustainable yield (MSY). Assuming the base-case model is the most parsimonious, recent fishing mortality rates (F) were estimated to be lower than those corresponding to $F_{MSY}$, and current estimates of spawning biomass (SB) are at $SB_{MSY}$. Uncertainty is most likely to have been under-estimated and model results are highly sensitive to assumed values of the steepness parameter (h) in the Beverton-Holt stock-recruitment

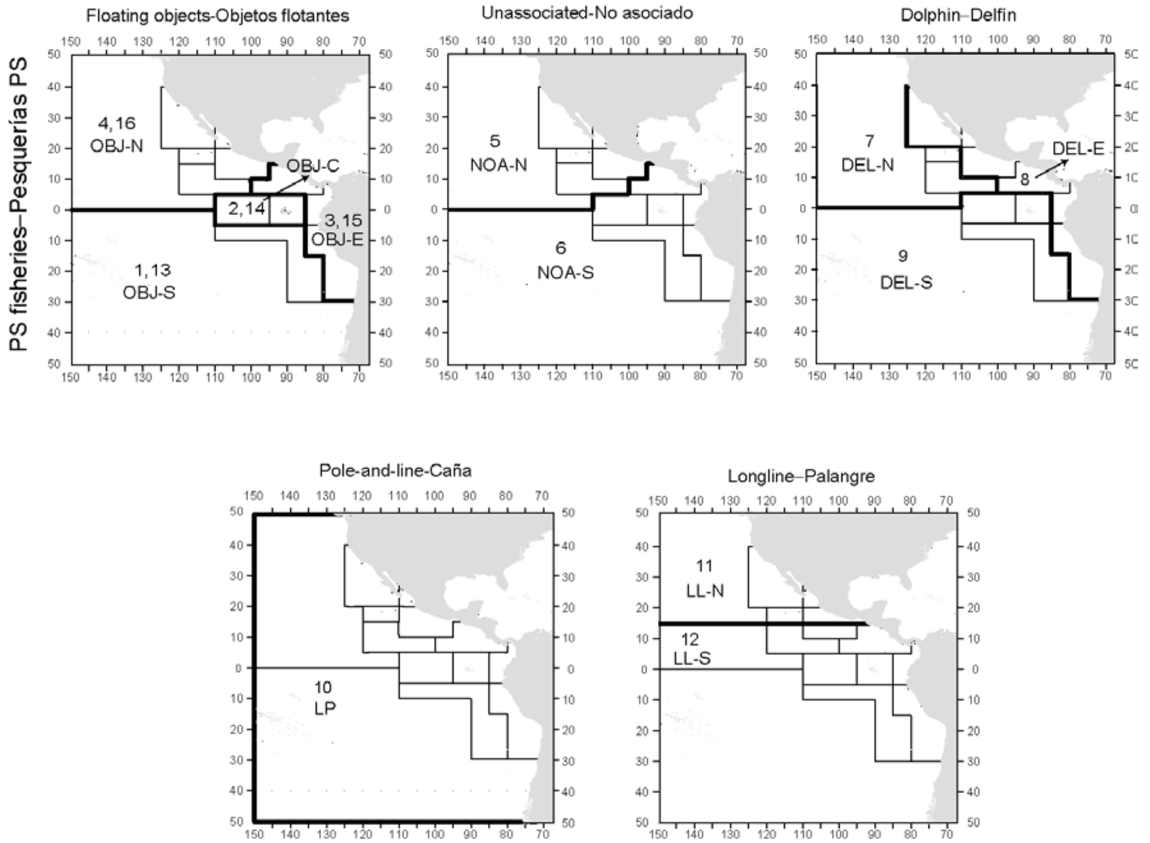

**FIGURE A.** Fisheries defined by the IATTC staff for the stock assessment of yellowfin, skipjack, and bigeye tunas in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the numbers the fisheries to which the latter boundaries apply. Fisheries 13-16 are 'discard' fisheries. The fisheries are described in Table A.

**TABLE A.** Fisheries defined for the stock assessment of yellowfin tuna in the EPO. PS = purse seine; LP = pole and line; LL = longline; OBJ = floating objects; NOA = unassociated fish; DEL = dolphin. The sampling areas are shown in Figure A.

| Fishery | Gear type | Set type | Region | Sampling areas |
|---|---|---|---|---|
| 1 | PS | OBJ | South | 11-12 |
| 2 | PS | OBJ | Central | 7, 9 |
| 3 | PS | OBJ | Inshore | 5-6, 13 |
| 4 | PS | OBJ | North | 1-4, 8, 10 |
| 5 | PS | NOA | North | 1-4, 8, 10 |
| 6 | PS | NOA | South | 5-7, 9, 11-13 |
| 7 | PS | DEL | North | 2-3, 10 |
| 8 | PS | DEL | Inshore | 1, 4-6, 8, 13 |
| 9 | PS | DEL | South | 7, 9, 11-12 |
| 10 | LP | | All | 1-13 |
| 11 | LL | | North | N of 15°N |
| 12 | LL | | South | S of 15°N |
| Discard fisheries | | | | |
| 13 | PS | OBJ | South | 11-12 |
| 14 | PS | OBJ | Central | 7, 9 |
| 15 | PS | OBJ | Inshore | 5-6, 13 |
| 16 | PS | OBJ | North | 1-4, 8, 10 |

relationship, the average length of the oldest fish ($L_2$) in the Richards growth function, and the assumed value of natural mortality (M). The results are more pessimistic if a stock-recruitment relationship is assumed with a steepness value of 0.75, or if yellowfin tunas are assumed to grow to a larger asymptotic size, or lower natural mortality rates are assumed for adult yellowfin tuna. The assessment includes three sensitivity runs, which explore the impacts of model assumptions on the overall fits to the data and the potential impacts on management advice. Other sensitivities were explored as part of earlier assessments.

The IATTC staff requested that the Review Panel consider the following general questions related to the assessment of yellowfin tuna stocks in the EPO:

1. What is an appropriate stock structure for assessment of yellowfin tuna in the EPO?
2. What is an appropriate fishery structure for assessment of yellowfin tuna in the EPO?
3. What approach should be used to deal with the uncertainty in the length of old individuals and the impact it has on the stock assessment results?
4. What is the appropriate stock-recruitment relationship?
5. How should the CPUE (catch per unit of effort) indices of abundance be used in the stock assessment?
6. What selectivity curves should be used?
7. Age and sex specific natural mortality?

Staff members provided the Panel (participants listed in Appendix A) with several documents (Appendix B) prior to the meeting and introduced each agenda item with a series of presentations. The staff identified several key undesirable features of the current base-case model:

1. Uncertainty in key biological parameters – steepness, growth (particularly the value of $L_2$ in the Richards growth function) and natural mortality.
2. Strong retrospective pattern in the most recent estimates of recruitments.
3. Selectivity issues – time-varying and apparent numerical and convergence issues related to selectivity.
4. Data weighting – apparent contradictions between the CPUE series from the Southern longline and Northern dolphin fisheries. The assessment model also wants to place more

weight on the size-composition information based on the effective sample size calculations from the multinomial likelihood.

5. Environmental regime shifts and consequent periods of low, high, and intermediate stock productivity. Productivity regime assumptions influence the overall estimates of stock status and management advice.

The Panel identified a series of issues, divided into general topics based on background material and documents provided before the meeting, and the results of the requested model runs. This report reflects the Panel's view on the work of the staff. Progress with regard to improving the assessment will require additional modeling and data. The Panel has summarized its key findings and makes specific recommendations to the staff on each issue.

Based on the results of alternative model runs it requested, the Panel concludes that there is considerable uncertainty regarding the absolute abundance of yellowfin tuna in the EPO using a stock assessment which treats all yellowfin as a single homogeneous population. Specifically:

1. There are contradictory trends in the CPUE for two key fleets used for fitting the assessment model. Sensitivity runs which effectively simulated separate Northern and Southern stocks appeared to improve model fits to the CPUE series for the simulated region, particularly in the Northern model.
2. The base-case model appeared to be driven by the information from the Southern region, which is potentially problematic bearing in mind the majority of catch is landed in the Northern region. The spatially-separated Northern model showed recruitment trends that differed significantly from the base-case model, whereas the Southern model displayed similar recruitment trends to the base case.

In light of these apparent contradictions and model-free information based on the analysis of fisheries catch statistics only, the Panel concludes that it may be necessary to consider splitting this stock up into two distinct Northern and Southern populations or splitting the data up into Northern and Southern components and fitting two separate assessment models to these data streams.

Following is a list of specific recommendations made by the Panel that should be taken into consideration for the next assessment of yellowfin tuna in the EPO for 2013. Following the recommendations is a more detailed review of the assessment methods, descriptions of the additional model runs, and results, that were requested during the four-day review workshop.

## RECOMMENDATIONS

Based on discussions, presentations and alternative model runs conducted during the review, the following recommendations are suggested for the upcoming 2013 yellowfin tuna assessment. It is assumed that the next assessment for yellowfin tuna will be conducted using the Stock Synthesis platform.

1) Stock Structure:
   a) Break this assessment into Northern and Southern regions (using 5°N as a dividing line). This can be done using either two regions in Stock Synthesis (if you are able to have independent recruitment deviates and movement coefficients), or develop two independent SS models.
   b) It will be necessary to develop a CPUE standardization protocol for the Northern dolphin fishery as this index will be the basis with which to fit the northern model.
   c) Partition the Inshore dolphin fishery (DEL-I; fishery 8) at 5°N. This fishery, as it is currently defined, spans the Northern and Southern regions.

    d) For the time being, assume that growth in the Southern and Northern regions is the same (see recommendation 3d below).

2) Fisheries Structure:

    a) Where possible with regard to a two-area model, use the recommendations based on Cleridy Lennert-Cody's (YFT-01-02) analysis of the fishery data to partition the datasets by area.

3) Uncertainty in Growth:

    a) Short-term: Use results from the integrated growth (LEP, Laslett, 2002[1]) model to parameterize the standard deviation in length-at-age as a function of length inside the SS model.

    b) Short-term: Use parameters from the integrated growth (LEP) model if the fits to the size composition data are improved over the base-case model (which uses parameter estimates from a previous assessment conducted using A-SCALA).

    c) Long-term: Incorporate the new integrated growth model (LEP, using the penalized likelihood option) into Stock Synthesis; explore the use of a multinomial distribution based on the age structure in the predicted population for estimating the ages in mark-recapture data. Note that this will require adding the year dimension to the otolith data collected in the Wild (1986) study.

    d) Long-term: collect growth information (growth increment from tagging and otolith data) from the South and use area-specific growth models in the multi-area assessment.

    e) Short-term: Fix the mean length-at-age growth curve based on the integrated model and internally estimate the standard deviation in length-at-age (or coefficient of variation as a linear function of length in the model) while assuming a reasonable prior.

4) Stock-recruitment relationship:

    a) Continue to provide steepness options (h=1, h=0.75) and provide likelihood profiles over steepness.

    b) Explore the use of an informative prior for steepness if convergence problems continue using Stock Synthesis.

    c) Provide summary plots of the ln(R/S) versus spawners (connect lines, or use heat colors for points), and a time series of ln(R/S) as a visual diagnostic tool for evidence of changes in productivity (juvenile survival rates and carrying capacity).

5) CPUE standardization and data weighting:

    a) Obtain operational parameters for the Japanese longline fleet and use these for standardization of their CPUE series.

    b) Develop a CPUE standardization protocol for the Northern dolphin fishery. Examine literature on standardizing purse-seine fishery data and consider technological factors affecting catchability.

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[1] Laslett, G., Eveson, J., and Polacheck, T. (2002). A flexible maximum likelihood approach for fitting growth curves to tag recapture data. Canadian Journal of Fisheries and Aquatic Sciences, 59(6):976–986.

   c) In both the assessment document and the presentation of model results, present residual plots of the relative abundance indices being fitted to better show the serial autocorrelation and fits to the data (log(observed CPUE)-log(predicted CPUE).
   d) As with 5c, present a table of assumed/estimated CVs, along with root mean square error for both relative abundance indices and the recruitment deviates (*i.e.*, expand Table 4.3).
   e) Report parameter correlations for key quantities that define population scaling and productivity.
   f) Report parameter estimates, standard deviations, and bounds in a single table such that reviewers can be sure parameters are not sitting on or near bounds.

6) Selectivity curves:
   a) Explore the use of age-specific coefficients (constant, or random walk over time) for the floating-object fisheries.
   b) Plot a time series of fishery-specific observed median lengths; best if this is overlaid onto of bubble plots of the raw size composition data.
   c) Continue to explore the use of time-varying selectivity and aggregating the data from the floating-object fisheries into a single fishery for each of the Northern and Southern regions (*i.e.,* continue the work presented in YFT-01-06).

7) Natural mortality:
   a) Estimate male and female natural mortality rates based on sex-specific age-composition data (outside the model).
   b) Examine sex ratio data from other fleets (it appears the original M work was done on very little information).
   c) If growth is estimated internally, then a re-examination of length-based natural mortality and maturity is necessary within the model; *i.e*. to take account of the new estimates of mean length-at-age.

8) Uncertainty:
   a) Explore structural uncertainty on a grid of all the equally plausible options for the assumptions made.
   b) Present information to managers in a decision table framework that attempts to integrate over the structural uncertainty.

9) Shorten the time series:
   a) Starting the model in the year 2000 should be considered if natural mortality and growth are assumed fixed in the model and allowing for time-varying selectivity. The advantages are large reductions in computational time, and very likely, similar policy advice. It may also be possible to do Markov chain Monte Carlo analysis.
   b) It may be necessary to re-introduce the historical time-series data for stock status calculations (Kobe plots) to ensure the mean recruitment value reflects all of the productivity regimes.

# ASSESSMENT METHODS

## INPUT DATA

Input data for the assessment model consisted of catch and discard data, relative abundance indices in the form of standardized and nominal CPUE information, age-length data from 196 fish sampled in the late 1970s, and size composition data from the commercial fisheries. Five major fishing fleets (OBJ, NOA, DEL, LP and LL) were defined in the model and these five fleets were broken down into 16 different fisheries, each of which has its own length-frequency sampling data that is used in fitting the model (Figure A and Table A).

## MODEL PLATFORMS

The general stock assessment was conducted using Stock Synthesis (version 3.23b).

Growth information for the Stock Synthesis model was based on estimated growth parameters from an earlier assessment of yellowfin tuna using A-SCALA.

In addition to growth estimates from A-SCALA, an integrated otolith and tag-recapture growth increment model was also developed to examine growth data for both bigeye tuna and yellowfin tuna. The integrated growth model is based upon the statistical methodology described in Laslett *et al*. (2002)[2], and Eveson *et al*. (2004)[3] and referred to by the IATTC staff (and below in this report) as the Laslett-Eveson-Polacheck (LEP) method.

## BASE-MODEL SPECIFICATION

A total of 212 parameters were estimated by fitting the model to the CPUE and size-composition data. Estimated model parameters include: selectivity parameters for all fisheries (except discards), initial fishing mortality rate for the DEL-N fishery, unfished age-0 recruits ($R_0$), offset for initial recruitment relative to $R_0$, initial recruitment deviates, annual recruitment deviates, catchability coefficients for each CPUE index (where the same coefficient was assumed for the DEL-S and LL-S fisheries), and the coefficients of variation for each CPUE index (except the LL-S CPUE where the CV is fixed at 0.2). Note that estimates of catchability coefficients are based on the conditional maximum likelihood estimates and were not treated as estimated parameters in Stock Synthesis. Also, these are not part of the 212 estimated parameters defined above. Annual instantaneous fishing mortality rates are conditional on the input catch data and the model assumes no measurement error in the catch.

The base-case model scenario assumes the same length-at-age for males and females and does not vary over time. Selectivity for each fishery is assumed to be time-invariant and asymptotic for the LL-S, NOA-S, and DEL-S fisheries. Natural mortality was estimated external to the model, is sex- and age-specific, and time-invariant, and similarly for female maturity. Steepness of the Beverton-Holt stock recruitment relationship was fixed at 1 or 0.75 as an alternative model run. Under these assumptions (fixed growth, asymptotic selectivity, fixed natural mortality rates, and catch measured without error), the size composition data provides information on population scaling via size-based estimates of total mortality rate (*i.e.*, catch-curve analysis).

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[2] Laslett, G. M., Eveson, P. and Polacheck, T. 2002. A flexible maximum likelihood approach for fitting growth curves to tag-recapture data. Can. J. Fish. Aquat. Sci. 59: 997-986.

[3] Eveson, J. P, Laslett, G. M. and Polacheck, T. 2004. An integrated model for growth incorporating tag-recapture, length-frequency, and direct aging data. Can. J. Fish. Aquat. Sci. 61: 292-306.

The model was fitted to all of the size composition data with the exception of the Southern dolphin fishery (DEL-S) and to the nominal relative abundance indices from the unassociated fisheries (NOA-N, NOA-S), the nominal CPUE from the dolphin fisheries (DEL-N, DEL-I), and the standardized Southern longline CPUE (LL-S).

Alternatives to the base-case model included an additional run with the steepness fixed at 0.75, two alternative values for the asymptotic length ($L_2$=170 and $L_2$=190), and a model run where the CV for the CPUE in the DEL-N fishery was fixed at 0.2). Among the initial alternative model runs, the data favors a lower value of steepness, and a lower value for the asymptotic length. These two alternatives result in pessimistic and optimistic estimates of stock status, respectively. These alternative models were new, and other structural assumptions (not listed here) have been explored in the past.

# FOCAL AREAS

During the course of this review, the Review Panel took into consideration seven general areas of focus. Its findings in each of the focal areas are summarized below. More detailed findings with respect to model runs requested by the Panel are summarized in tabular format in Appendix C.

## WHAT IS THE MOST APPROPRIATE STOCK STRUCTURE FOR THE YELLOWFIN TUNA STOCK ASSESSMENT?

### Single EPO stock

Facts:

The EPO yellowfin tuna population is distributed in a large geographical realm (40°N-30°S and 72°-150°W), extending to the north and south of the equator and experiencing large environmental gradients and variability, both in space and time. Fisheries data shows spatial and temporal heterogeneity and structure, especially with north/south and east/west components (YFT-01-02 and Martin Hall, pers. com.). The stock assessment model for the EPO yellowfin tuna assumes one single well-mixed stock across the entire geographical area. Spatial heterogeneity is accounted for by incorporating fishery-specific selectivity patterns. Concerns have been raised with respect to the current model configuration and its flexibility to account for this spatial structure.

Findings of the model runs requested:

In order to incorporate spatial heterogeneity into the current assessment model, three special model runs were requested to "approximate spatial separation" between the Northern and Southern regions (runs **Tue_9** to **Tue_11**, Appendix C). Results show differences in recruitment patterns and management quantities. Despite large differences in relative recruitment variability, similar underlying long-term patterns are evident in the datasets from the Northern and Southern regions.

The Panel's recommendations are to spatially disaggregate the assessment model into Northern and Southern regions. Further work needs to be done to explore the fishery data on a fine temporal-spatial scale for evidence of complex demographic patterns that may have been ignored under the assumptions made in the current assessment model.

## WHAT IS THE MOST APPROPRIATE FISHERY STRUCTURE FOR THE YELLOWFIN TUNA STOCK ASSESSMENT?

Facts:

The assessment model divides the fishery into 16 components (4 floating object, 2 unassociated, 3 dolphin, 1 pole-and-line, 2 longline and 4 discard fisheries) allocated over 13 statistical areas across the EPO (Figure A and Table A). The division of the current fisheries sampling areas was originally proposed in the 1970s to optimize the sampling of the catch data. The work by Lennert-Cody (YFT-01-02) is a novel attempt to revise this partition, identifying important spatial patterns in the catch. Their results from tree analysis show the importance of maintaining North-South and East-West divisions.

Findings of the model runs requested:

Estimates of selectivity for the PS-OBJ fishery and model management quantities were not affected substantially when this fishery was aggregated into a single unit over the entire model spatial domain (run **Wed_2** Appendix C).

Recommendations are made to:

- Aggregate the 4 PS-OBJ fisheries into a single fishery, or if the North and South regional structure is applied, aggregate into single fisheries for each of the regions.
- Take account of the findings by Lennert-Cody (YFT-01-02) in defining the model fishery structure.

## WHAT APPROACH SHOULD BE USED TO DEAL WITH THE UNCERTAINTY IN THE LENGTH OF OLD INDIVIDUALS AND THE IMPACT IT HAS ON THE STOCK ASSESSMENT RESULTS?

Facts:

This statistical age-structured model Stock Synthesis uses length and CPUE data to obtain demographic information about this stock. Growth must be explicitly modeled to convert numbers-at-age into numbers-at-length and there is a high impact of underlying growth assumptions on model results (parameter uncertainty mostly associated with the asymptotic length, $L_2$). The base-case model considers an externally parameterized Richards growth model, and borrows parameter values from previous assessments (A-SCALA model), which included length-at-age information for younger fish. During this review, staff members presented a new integrated growth estimation model based on the statistical model described by Laslett *et. al.* (2002)[4] that uses both the available length-at-age and historical mark-recapture data. Several model runs were requested to assess the sensitivity of the model and the conflict of this piece of information with the rest of the inputs.

Findings of the model runs requested:

Tagging data are too few for larger sizes of yellowfin to reliably inform the estimates of asymptotic length. At this stage not enough information is available for yellowfin to take advantage of the new integrated approach for estimating growth. Generally, most of the model runs requested that investigated growth estimation within Stock Synthesis produced implausibly low estimates of the mean length of fish at the maximum age (runs **Tue_1**, **Tue_2**, **Tue_3**, **Tue_16**, Appendix C), and a plausible estimate was only obtained when natural mortality was estimated simultaneously (run **Wed_5**, Appendix C). While an improved model fit was achieved, management quantities were insensitive to reducing the assumed level of individual growth variability (run **Mon_4**, Appendix C).

Recommendations are made to:

- Express individual growth variability as a function of length and estimate this internally within the population model;

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[4] Laslett, G. M., Eveson, P. and Polacheck, T. 2002. A flexible maximum likelihood approach for fitting growth curves to tag-recapture data. Can. J. Fish. Aquat. Sci. 59: 997-986.

- Include the integrated analysis for growth (penalized likelihood) within Stock Synthesis; this may reduce the uncertainty in growth estimates.

## WHAT IS THE APPROPRIATE STOCK-RECRUITMENT RELATIONSHIP?

Facts:

The results of this assessment were heavily influenced by the assumed value of the steepness parameter. The base-case model uses a steepness value of 1 and the likelihood profile on this parameter indicates a value around 0.7 (YFT-01-05). Attempts have been made to estimate the recruitment variance, but the available data were found to be not informative. Current recruitment estimates from 1975-2011 would appear to indicate three periods of low (1975-1983), high (1984-2004) and intermediate (2005-2011) recruitment, which have been interpreted as three different regimes. During this review additional model runs were requested to address parameter uncertainty on steepness (run **Mon_2**, Appendix C).

Findings of the model runs requested:

The Panel examined summary plots of the ln(R/S) versus spawners and a time series of ln(R/S) as a visual diagnostic tool for evidence of changes in productivity (juvenile survival rates and carrying capacity). No temporal change in the maximum (R/S) was visible as evidenced by the y-intercept of the ln(R/S) versus spawners plots, implying that the slope of the stock-recruitment relationship appears stable, which implies that the estimate of $F_{MSY}$ is also likely to be stable. This diagnostic, however, implies that survivorship from egg to recruit has not visibly changed. In other words, the density-dependent survival rate of juvenile tuna (as measured by ln[R/S]) appears not to have been affected by "regime" changes.

Several attempts were made to estimate steepness within the model, however difficulties were encountered and only a single run having an informative normal prior was successful, which achieved an estimate, of 0.775 (run **Mon_2**, Appendix C).

Recommendations are made to continue to examine model sensitivity to steepness assumptions, to provide steepness likelihood profiles, and to further explore the use of an informative prior for estimating steepness.

## HOW SHOULD THE CPUE INDICES OF ABUNDANCE BE USED IN THE STOCK ASSESSMENT?

Facts:

Indices of abundance are generally an important piece of information for most stock assessments. The yellowfin model uses five CPUE indices, from the two unassociated fisheries (NOA-N and NOA-S), the two dolphin fisheries (DEL-N and DEL-S), and the southern longline fishery (LL-S). The base-case model considers the standardized longline CPUE as the most reliable index of abundance in the assessment (coefficient of variation is fixed at 0.2). It has been standardized using three explanatory variables (latitude, longitude, and hooks per basket). All other CPUE indices are based on nominal catch rates, despite the fact that some important operational changes have occurred in some surface fisheries (*e.g.*, technological advances in the NOA and DEL fisheries).

Findings of the model runs requested:

Changing the relative weight of the CPUE data in the model fit resulted in no change to the overall absolute abundance, most likely because the CPUE index only informs the model of relative changes (given the short-lived nature of yellowfin) and because of the absence of large catch fluctuations that produce contrast in the productivity signals (run **Mon_5**, Appendix C). However, higher relative weight produced a decrease in the estimate of average recruitment relative to the base case, and also a decrease in recent absolute biomass (a greater decline in recent years) resulting in more pessimistic management quantities (run **Mon_5.b**, Appendix C).

Recommendations are made to improve the standardization methods for CPUE indices of the Japanese longline and PS-DEL fisheries, and to provide more extensive diagnostics of the model fit to these indices.

## WHAT SELECTIVITY CURVES SHOULD BE USED?

Facts:

The EPO yellowfin stock assessment defines 16 fisheries (Figure A) to model age-specific changes in fishing mortality rates. Several parametric selectivity functions are being used (4 assumed for the discard fisheries; 11 estimated selectivity curves: 4 PS-OBJ, 2 PS-NOA, 1 PS-DEL (DEL-S was fixed equal to LL-S), 2 LL, and 1 LP). Model fit diagnostics of the base-case scenario show important residual patterns for younger and older individuals in the length-composition data of several fisheries. Additionally the recruitment time series shows an important retrospective pattern in the uncertainty of recent recruitments. During the review several runs were requested to address these two issues by investigating different selectivity configurations.

Findings of the model runs requested:

Runs were presented in which time-varying selectivities were estimated for the PS-OBJ fishery. These runs increased the uncertainty in recent recruitments, however the retrospective pattern diminishes owing to the additional process being modeled. This approach, and the run in which non-parametric selectivities-at-age were estimated (run **Wed_2**, Appendix C), improved the retrospective patterns. Additional runs that attempted to modify the data (aggregate over fisheries/sizes, or omit data from larger sizes) for dealing with the infrequent appearance of large individuals in this fishery were largely unsuccessful (Appendix C).

Recommendations are made to continue to develop time-varying selectivity and non-parametric age-based selectivity coefficients for the PS-OBJ fishery, which influences the estimated trends in recent recruitment estimates.

## AGE- AND SEX-SPECIFIC NATURAL MORTALITY

Facts:

Natural mortality is an influential parameter in any stock assessment model, but unfortunately very difficult to estimate. Yellowfin tunas of the Pacific Ocean experience high levels of natural mortality (Hampton 2000) and natural mortality is generally modeled as a function of age. The base-case model of this assessment uses an externally parameterized sex- and age-specific natural mortality function, showing high levels at recruitment (0.7 quarters$^{-1}$), a rapid decline towards age-8 quarters, and a conspicuous sex-specific difference for older fish (0.2 quarters$^{-1}$ for males, 0.45 quarters$^{-1}$ for females). The sex-specific contrast of the natural mortality function relies heavily on an analysis of sex ratio data for yellowfin from the Southern longline fishery external of the model, which shows a much higher proportion of males. During this review a paper was presented that evaluated the feasibility of estimating age- and sex-specific M (YFT-01-07) within the stock assessment model, and several additional runs were requested to address parametric uncertainty.

Findings of the model runs requested:

Estimating female natural mortality for the old age classes while assuming the offset value for males, and assuming fixed growth parameters resulted in slightly higher M relative to the base case, and higher parametric uncertainty (run **Tue_12**, Appendix C). Estimating M and growth simultaneously produced an improved fit to the CPUE data and plausible growth rates, but the estimate of M may be implausibly high compared to that of the base case assumption (run **Wed_5**, Appendix C).

Recommendations are made for further work to estimate natural mortality externally to the model using age-specific sex ratio data from a wide range of the EPO fleets (*e.g.* PS-DEL fishery). A new development of Stock Synthesis was suggested to express natural mortality as a function of fish length, and in the instances where growth is estimated internally within the population model an informative prior on the natural mortality rate be specified to reduce potential confounding. This feature should also be developed/examined for female maturity-at-length when growth is estimated.

## OTHER RECOMMENDATIONS

### Model calculation period

Assumptions are made in the base-case model for the years preceding 1993 and 2000 regarding discarded fish and species composition in catches, respectively. Some benefits may be gained in avoiding these assumptions by reducing the model calculation period by starting the model in either of these years. Additionally, the reduced computation time gained by using a shorter calculation period is an advantage in making model developments and in estimating parametric and structural uncertainty. Consequently, two alternative periods for the model calculation period were evaluated, having starting years of 1993 and 2000 (runs **Tue_7**, **Tue_18**, **Wed_4.a**, **Wed_4.b** Appendix C). Only minor differences in the absolute abundance estimates occurred when using the reduced data sets; however, estimates of average recruitment were affected.

### Findings of the model runs requested:

The recruitment trends were similar to the base case over the corresponding years (post-1993 and -2000); however, in some runs, average recruitments were higher, presumably because the period over which recruitments were estimated includes mostly high recruitments. This has implications for the recruitment assumptions made in model projections and assessment of current stock status relative to that when unfished. Computation times for obtaining a model solution were reduced considerably (from ~2+ hours to less than 30 minutes).

A recommendation is made to start the model in 2000 with natural mortality and growth being assumed, while time-varying selectivity for the PS-OBJ fishery is estimated.

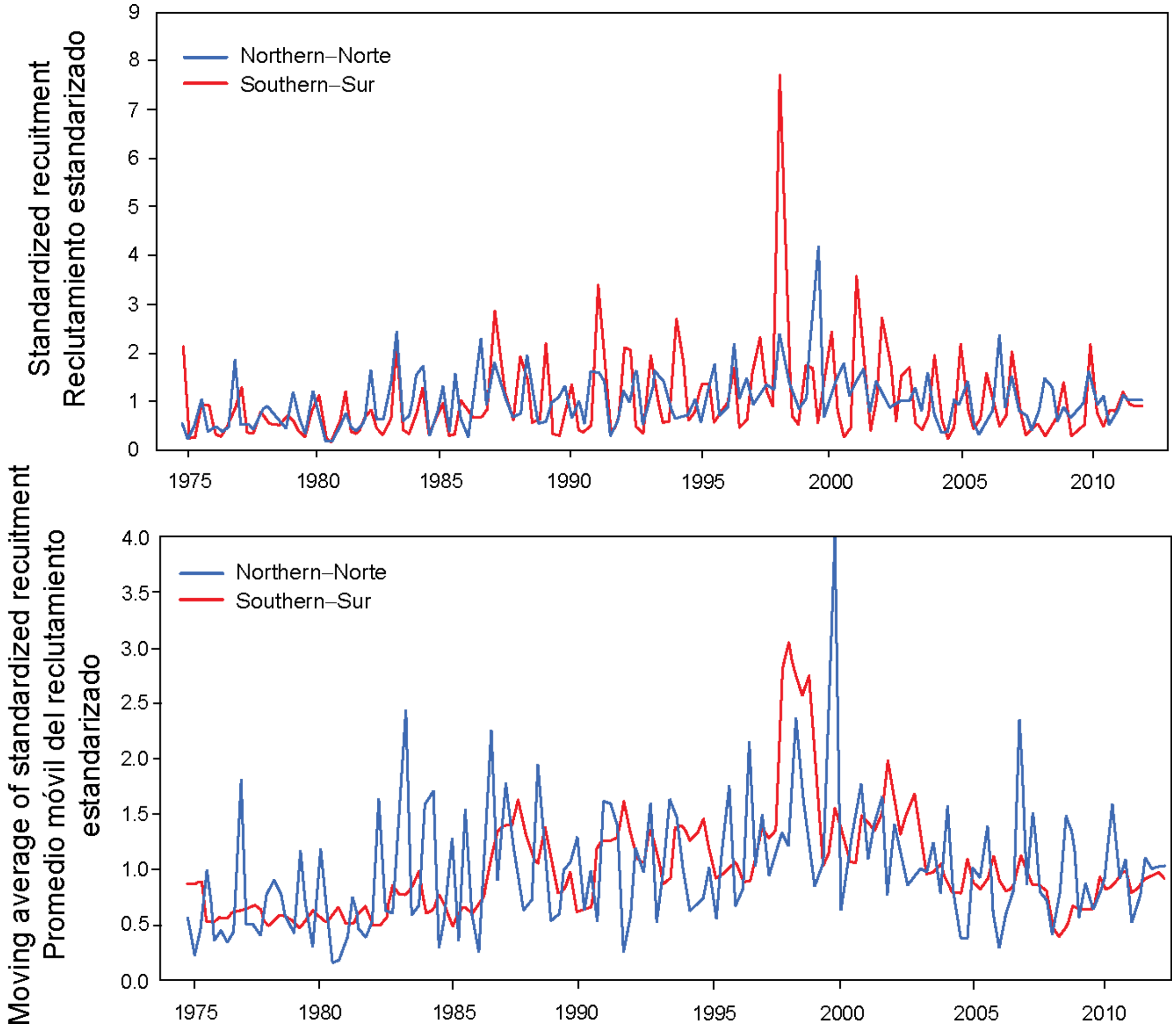


**FIGURE 1:** Estimated recruitments from the model run requested by the Panel that simulates disaggregation of the yellowfin EPO stock into Northern and Southern regions. Quarterly recruitments were standardized (top panel) and expressed as a moving average (bottom panel).

## MODEL RUNS

The following is a list of alternative model configurations that were requested during the review.

### Model runs for Monday evening

1. Relax assumption on steepness prior (use a Beta prior with a mean of 0.9) (a) CV 0.1 and (b) CV 0.2.
2. Reduce sample size on length-composition data by 10% to see the impact on the root mean squared error on the LL-S CPUE data.
3. Reduce CV in length-at-age using the current growth model. Reduce the CV by 50% for large fish.
4. Drop fitting to all CPUE data except the LL-S CPUE data.
5. Increase lambda to 10 for the LL-S CPUE and examine the fits to the length-composition data to determine which size-composition data set(s) is in conflict with the LL-S CPUE.

### Model runs for Tuesday evening

1. Fit to the conditional length-age otolith data (Wild) internally in Stock Synthesis. Use std as a linear function of length.
2. Use a normal prior on $L_2$ based on mean and variance from the external integrated growth analysis, and fit to the otolith data.
3. Use normal priors for all growth parameters, including variance, based on the external integrated growth analysis and do not fit to the otolith data.
4. Relax assumption about selectivity being equal to zero at the smallest size class.
5. Delete the data for the large (> 70 cm) fish for the PS-OBJ fisheries in which large individuals are captured only periodically .
6. Delete the data for the large (> 70 cm) fish for the PS-NOA and PS-OBJ fisheries in which large individuals are captured only periodically.
7. Model run starting in 1993 (when the discard data start); omit all of the early data as the historical estimates of recruitment appear to be relatively invariant to changes in the PS-OBJ fisheries.
8. Apply the windowed time-varying selectivities to the PS-NOA fisheries as well, unweight the CPUE indices, and do PS-OBJ at the same time. (5-year time-varying selectivity).
9. Put 0 lambdas on data from the Southern region, fix selectivities from the par file and fit to data from the Northern fisheries (OBJ-N, DEL-N, NOA-N, LL-N, and DEL-I), and compare estimates of recruitment relative to the base-case model. The idea here is to see if the data from the Northern (Southern) region explain the lag in the CPUE data between the two regions.
10. Put 0 lambdas on data from the Southern region, fix selectivities from the par file and fit to data from the Northern fisheries (OBJ-N, NOA-N, DEL-N, and LL-N; ignore DEL-I), and compare estimates of recruitment relative to the base-case model. The idea here is to see if the data from the Northern (Southern) region explain the lag in the CPUE data between the two regions.
11. Southern assessment with the OBJ-S, OBJ-E, NOA-S, DEL-S, and LL-S fisheries, and use fixed selectivities from par file in the Northern fisheries.
12. A run with estimates of natural mortality with new growth curve. Estimating mature female natural mortality with the new growth. Specifically, look at parametric uncertainty, Hessian, recruitment estimates with the base case.

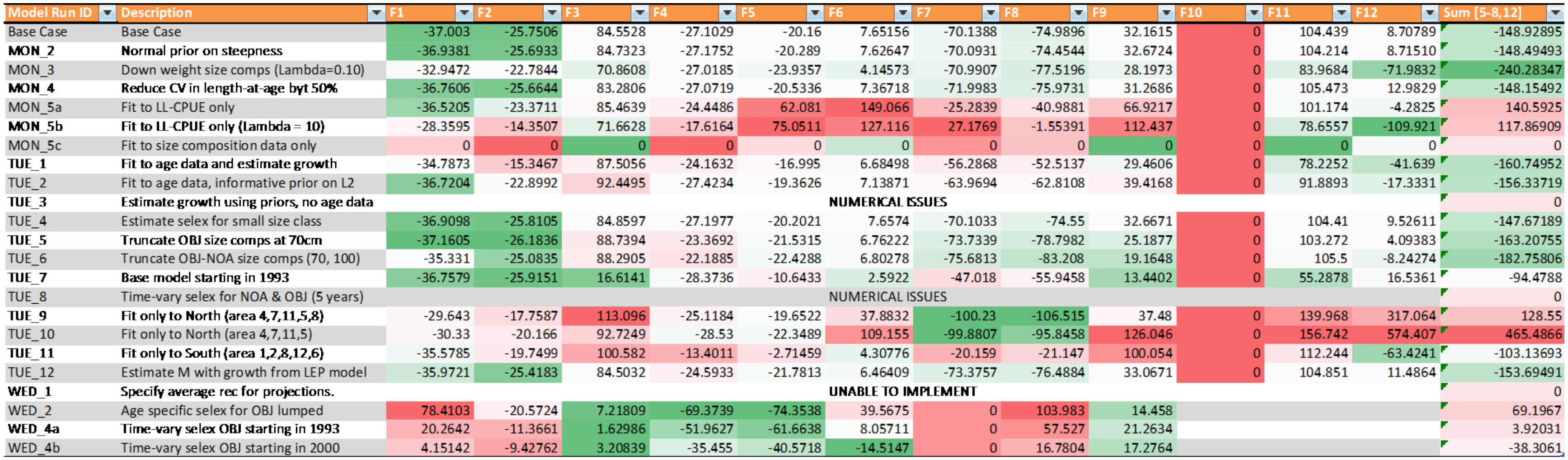
### Model runs for Wednesday evening

1. Explore the potential for specifying average recruitment used for projections.
2. Estimate point-estimate selectivities-at-age for the PS-OBJ fishery using the model which aggregates this fishery into a single unit.
3. Estimate steepness with normal priors.
4. Run the truncated models (1993 and 2000 start year) with 5-year time-variant selectivities for the PS-OBJ fishery.

## ACKNOWLEDGMENTS

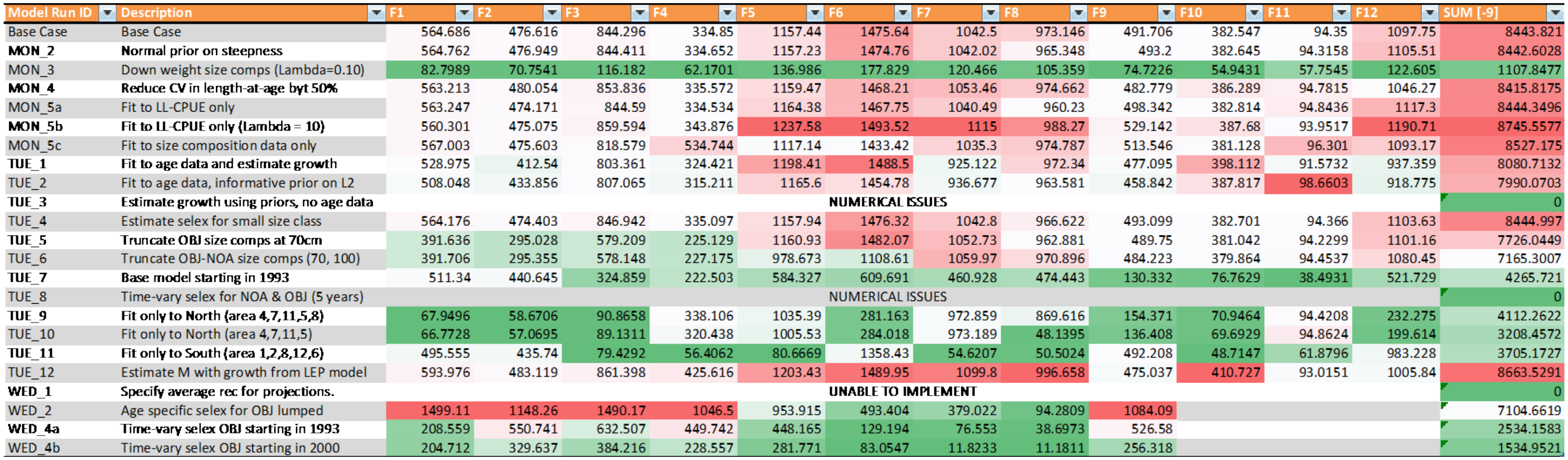
The Panel thanks the staff of the IATTC, in particular Mark Maunder and Alexandre Aires-da-Silva, for their hard work and willingness to respond to Panel requests, for their exceptional support, provisions, and general hospitality during the review.

**TABLE 1.** Negative log-likelihood components for the fits to the CPUE series. Note that the Stock Synthesis model was only fitted to data from Fisheries 5-8 and 12 (NOA, DEL, and LL-S). In each column, the relative goodness of fit is indicated by color, with dark green best and dark red worst.



| Model Run ID | Description | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | Sum [5-8,12] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Case | Base Case | -37.003 | -25.7506 | 84.5528 | -27.1029 | -20.16 | 7.65156 | -70.1388 | -74.9896 | 32.1615 | 0 | 104.439 | 8.70789 | -148.92895 |
| **MON_2** | **Normal prior on steepness** | -36.9381 | -25.6933 | 84.7323 | -27.1752 | -20.289 | 7.62647 | -70.0931 | -74.4544 | 32.6724 | 0 | 104.214 | 8.71510 | -148.49493 |
| MON_3 | Down weight size comps (Lambda=0.10) | -32.9472 | -22.7844 | 70.8608 | -27.0185 | -23.9357 | 4.14573 | -70.9907 | -77.5196 | 28.1973 | 0 | 83.9684 | -71.9832 | -240.28347 |
| **MON_4** | **Reduce CV in length-at-age byt 50%** | -36.7606 | -25.6644 | 83.2806 | -27.0719 | -20.5336 | 7.36718 | -71.9983 | -75.9731 | 31.2686 | 0 | 105.473 | 12.9829 | -148.15492 |
| MON_5a | Fit to LL-CPUE only | -36.5205 | -23.3711 | 85.4639 | -24.4486 | 62.081 | 149.066 | -25.2839 | -40.9881 | 66.9217 | 0 | 101.174 | -4.2825 | 140.5925 |
| **MON_5b** | **Fit to LL-CPUE only (Lambda = 10)** | -28.3595 | -14.3507 | 71.6628 | -17.6164 | 75.0511 | 127.116 | 27.1769 | -1.55391 | 112.437 | 0 | 78.6557 | -109.921 | 117.86909 |
| MON_5c | Fit to size composition data only | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TUE_1** | **Fit to age data and estimate growth** | -34.7873 | -15.3467 | 87.5056 | -24.1632 | -16.995 | 6.68498 | -56.2868 | -52.5137 | 29.4606 | 0 | 78.2252 | -41.639 | -160.74952 |
| TUE_2 | Fit to age data, informative prior on L2 | -36.7204 | -22.8992 | 92.4495 | -27.4234 | -19.3626 | 7.13871 | -63.9694 | -62.8108 | 39.4168 | 0 | 91.8893 | -17.3331 | -156.33719 |
| **TUE_3** | **Estimate growth using priors, no age data** | | | | | | **NUMERICAL ISSUES** | | | | | | | 0 |
| TUE_4 | Estimate selex for small size class | -36.9098 | -25.8105 | 84.8597 | -27.1977 | -20.2021 | 7.6574 | -70.1033 | -74.55 | 32.6671 | 0 | 104.41 | 9.52611 | -147.67189 |
| **TUE_5** | **Truncate OBJ size comps at 70cm** | -37.1605 | -26.1836 | 88.7394 | -23.3692 | -21.5315 | 6.76222 | -73.7339 | -78.7982 | 25.1877 | 0 | 103.272 | 4.09383 | -163.20755 |
| TUE_6 | Truncate OBJ-NOA size comps (70, 100) | -35.331 | -25.0835 | 88.2905 | -22.1885 | -22.4288 | 6.80278 | -75.6813 | -83.208 | 19.1648 | 0 | 105.5 | -8.24274 | -182.75806 |
| **TUE_7** | **Base model starting in 1993** | -36.7579 | -25.9151 | 16.6141 | -28.3736 | -10.6433 | 2.5922 | -47.018 | -55.9458 | 13.4402 | 0 | 55.2878 | 16.5361 | -94.4788 |
| TUE_8 | Time-vary selex for NOA & OBJ (5 years) | | | | | | NUMERICAL ISSUES | | | | | | | 0 |
| **TUE_9** | **Fit only to North (area 4,7,11,5,8)** | -29.643 | -17.7587 | 113.096 | -25.1184 | -19.6522 | 37.8832 | -100.23 | -106.515 | 37.48 | 0 | 139.968 | 317.064 | 128.55 |
| TUE_10 | Fit only to North (area 4,7,11,5) | -30.33 | -20.166 | 92.7249 | -28.53 | -22.3489 | 109.155 | -99.8807 | -95.8458 | 126.046 | 0 | 156.742 | 574.407 | 465.4866 |
| **TUE_11** | **Fit only to South (area 1,2,8,12,6)** | -35.5785 | -19.7499 | 100.582 | -13.4011 | -2.71459 | 4.30776 | -20.159 | -21.147 | 100.054 | 0 | 112.244 | -63.4241 | -103.13693 |
| TUE_12 | Estimate M with growth from LEP model | -35.9721 | -25.4183 | 84.5032 | -24.5933 | -21.7813 | 6.46409 | -73.3757 | -76.4884 | 33.0671 | 0 | 104.851 | 11.4864 | -153.69491 |
| **WED_1** | **Specify average rec for projections.** | | | | | | **UNABLE TO IMPLEMENT** | | | | | | | 0 |
| WED_2 | Age specific selex for OBJ lumped | 78.4103 | -20.5724 | 7.21809 | -69.3739 | -74.3538 | 39.5675 | 0 | 103.983 | 14.458 | | | | 69.1967 |
| **WED_4a** | **Time-vary selex OBJ starting in 1993** | 20.2642 | -11.3661 | 1.62986 | -51.9627 | -61.6638 | 8.05711 | 0 | 57.527 | 21.2634 | | | | 3.92031 |
| WED_4b | Time-vary selex OBJ starting in 2000 | 4.15142 | -9.42762 | 3.20839 | -35.455 | -40.5718 | -14.5147 | 0 | 16.7804 | 17.2764 | | | | -38.3061 |

**TABLE 2.** Multinomial likelihood components for fits to the size composition data for the base-case model and alternative model runs conducted during the review. In each column, the relative goodness of fit is indicated by color, with dark green best and dark red worst. The summation omits size-composition data from Fishery 9 (DEL-S).



| Model Run ID | Description | F1 | F2 | F3 | F4 | F5 | F6 | F7 | F8 | F9 | F10 | F11 | F12 | SUM [-9] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Base Case | Base Case | 564.686 | 476.616 | 844.296 | 334.85 | 1157.44 | 1475.64 | 1042.5 | 973.146 | 491.706 | 382.547 | 94.35 | 1097.75 | 8443.821 |
| **MON_2** | **Normal prior on steepness** | 564.762 | 476.949 | 844.411 | 334.652 | 1157.23 | 1474.76 | 1042.02 | 965.348 | 493.2 | 382.645 | 94.3158 | 1105.51 | 8442.6028 |
| MON_3 | Down weight size comps (Lambda=0.10) | 82.7989 | 70.7541 | 116.182 | 62.1701 | 136.986 | 177.829 | 120.466 | 105.359 | 74.7226 | 54.9431 | 57.7545 | 122.605 | 1107.8477 |
| **MON_4** | **Reduce CV in length-at-age byt 50%** | 563.213 | 480.054 | 853.836 | 335.572 | 1159.47 | 1468.21 | 1053.46 | 974.662 | 482.779 | 386.289 | 94.7815 | 1046.27 | 8415.8175 |
| MON_5a | Fit to LL-CPUE only | 563.247 | 474.171 | 844.59 | 334.534 | 1164.38 | 1467.75 | 1040.49 | 960.23 | 498.342 | 382.814 | 94.8436 | 1117.3 | 8444.3496 |
| **MON_5b** | **Fit to LL-CPUE only (Lambda = 10)** | 560.301 | 475.075 | 859.594 | 343.876 | 1237.58 | 1493.52 | 1115 | 988.27 | 529.142 | 387.68 | 93.9517 | 1190.71 | 8745.5577 |
| MON_5c | Fit to size composition data only | 567.003 | 475.603 | 818.579 | 534.744 | 1117.14 | 1433.42 | 1035.3 | 974.787 | 513.546 | 381.128 | 96.301 | 1093.17 | 8527.175 |
| **TUE_1** | **Fit to age data and estimate growth** | 528.975 | 412.54 | 803.361 | 324.421 | 1198.41 | 1488.5 | 925.122 | 972.34 | 477.095 | 398.112 | 91.5732 | 937.359 | 8080.7132 |
| TUE_2 | Fit to age data, informative prior on L2 | 508.048 | 433.856 | 807.065 | 315.211 | 1165.6 | 1454.78 | 936.677 | 963.581 | 458.842 | 387.817 | 98.6603 | 918.775 | 7990.0703 |
| **TUE_3** | **Estimate growth using priors, no age data** | | | | | | **NUMERICAL ISSUES** | | | | | | | 0 |
| TUE_4 | Estimate selex for small size class | 564.176 | 474.403 | 846.942 | 335.097 | 1157.94 | 1476.32 | 1042.8 | 966.622 | 493.099 | 382.701 | 94.366 | 1103.63 | 8444.997 |
| **TUE_5** | **Truncate OBJ size comps at 70cm** | 391.636 | 295.028 | 579.209 | 225.129 | 1160.93 | 1482.07 | 1052.73 | 962.881 | 489.75 | 381.042 | 94.2299 | 1101.16 | 7726.0449 |
| TUE_6 | Truncate OBJ-NOA size comps (70, 100) | 391.706 | 295.355 | 578.148 | 227.175 | 978.673 | 1108.61 | 1059.97 | 970.896 | 484.223 | 379.864 | 94.4537 | 1080.45 | 7165.3007 |
| **TUE_7** | **Base model starting in 1993** | 511.34 | 440.645 | 324.859 | 222.503 | 584.327 | 609.691 | 460.928 | 474.443 | 130.332 | 76.7629 | 38.4931 | 521.729 | 4265.721 |
| TUE_8 | Time-vary selex for NOA & OBJ (5 years) | | | | | | NUMERICAL ISSUES | | | | | | | 0 |
| **TUE_9** | **Fit only to North (area 4,7,11,5,8)** | 67.9496 | 58.6706 | 90.8658 | 338.106 | 1035.39 | 281.163 | 972.859 | 869.616 | 154.371 | 70.9464 | 94.4208 | 232.275 | 4112.2622 |
| TUE_10 | Fit only to North (area 4,7,11,5) | 66.7728 | 57.0695 | 89.1311 | 320.438 | 1005.53 | 284.018 | 973.189 | 48.1395 | 136.408 | 69.6929 | 94.8624 | 199.614 | 3208.4572 |
| **TUE_11** | **Fit only to South (area 1,2,8,12,6)** | 495.555 | 435.74 | 79.4292 | 56.4062 | 80.6669 | 1358.43 | 54.6207 | 50.5024 | 492.208 | 48.7147 | 61.8796 | 983.228 | 3705.1727 |
| TUE_12 | Estimate M with growth from LEP model | 593.976 | 483.119 | 861.398 | 425.616 | 1203.43 | 1489.95 | 1099.8 | 996.658 | 475.037 | 410.727 | 93.0151 | 1005.84 | 8663.5291 |
| **WED_1** | **Specify average rec for projections.** | | | | | | **UNABLE TO IMPLEMENT** | | | | | | | 0 |
| WED_2 | Age specific selex for OBJ lumped | 1499.11 | 1148.26 | 1490.17 | 1046.5 | 953.915 | 493.404 | 379.022 | 94.2809 | 1084.09 | | | | 7104.6619 |
| **WED_4a** | **Time-vary selex OBJ starting in 1993** | 208.559 | 550.741 | 632.507 | 449.742 | 448.165 | 129.194 | 76.553 | 38.6973 | 526.58 | | | | 2534.1583 |
| WED_4b | Time-vary selex OBJ starting in 2000 | 204.712 | 329.637 | 384.216 | 228.557 | 281.771 | 83.0547 | 11.8233 | 11.1811 | 256.318 | | | | 1534.9521 |

**TABLE 3.** MSY-based reference points, stock status and fishing rate multiplier for base-case model and alternative model runs explored during the review.

| Model run ID | Quant | MSY | $B_{MSY}$ | $S_{MSY}$ | $B_{MSY}/B_0$ | $S_{MSY}/S_0$ | $C_{Recent}/MSY$ | $B_{Recent}/B_{MSY}$ | $S_{Recent}/S_{MSY}$ | Fmultiplier |
|---|---|---|---|---|---|---|---|---|---|---|
|  | **BASE CASE** | **262642** | **356682** | **3334** | **0.31** | **0.26** | **0.79** | **1** | **1** | **1.15** |
| Mon_1 | Estimate steepness - beta prior |  |  |  | UNABLE TO IMPLEMENT |  |  |  |  |  |
| **Mon_2** | **Normal prior on steepness** | **282170** | **524829** | **5548** | **0.36** | **0.34** | **0.73** | **0.68** | **0.61** | **0.77** |
| Mon_3 | Down weight size comps (Lambda=0.10) | 285463 | 381090 | 3515 | 0.31 | 0.25 | 0.72 | 0.96 | 1.03 | 1.15 |
| **Mon_4** | **Reduce CV in length-at-age byt 50%** | **267142** | **369573** | **3513** | **0.32** | **0.27** | **0.77** | **1** | **1** | **1.17** |
| Mon_5a | Fit to LL-CPUE only | 259238 | 346024 | 3172 | 0.31 | 0.25 | 0.8 | 0.8 | 0.75 | 1.06 |
| **Mon_5b** | **Fit to LL-CPUE only (Lambda = 10)** | **257222** | **340166** | **3060** | **0.3** | **0.24** | **0.8** | **0.53** | **0.45** | **0.91** |
| Mon_5c | Fit to size composition data only | 270464 | 363103 | 3329 | 0.3 | 0.25 | 0.76 | 1.94 | 2.25 | 2.12 |
| **Tue_1** | **Fit to age data and estimate growth** | **709140** | **606799** | **1957** | **0.22** | **0.075** | **0.29** | **2.76** | **6.87** | **9.4** |
| Tue_2 | Fit to age data, informative prior on L2 | 312454 | 422781 | 3865 | 0.31 | 0.22 | 0.66 | 1.36 | 1.63 | 2.06 |
| **Tue_3** | Estimate growth using priors, no age data |  |  |  | NUMERICAL ISSUES |  |  |  |  |  |
| Tue_4 | Estimate selex for small size class | 262700 | 352659 | 3262 | 0.31 | 0.25 | 0.79 | 1.02 | 1.03 | 1.17 |
| Tue_5 | Truncate OBJ size comps at 70cm | 256741 | 370351 | 3603 | 0.31 | 0.27 | 0.8 | 0.87 | 0.86 | 0.97 |
| Tue_6 | Truncate OBJ-NOA size comps (70, 100) | 265455 | 384918 | 3773 | 0.32 | 0.28 | 0.78 | 0.74 | 0.69 | 0.8 |
| Tue_7 | Base model starting in 1993 | 313186 | 415951 | 3794 | 0.31 | 0.25 | 0.66 | 1.13 | 1.16 | 1.43 |
| Tue_8 | Time-vary selex for NOA & OBJ (5 years) |  |  |  | NUMERICAL ISSUES |  |  |  |  |  |
| Tue_9 | Fit only to North (area 4,7,11,5,8) | 169555 | 208352 | 1786 | 0.3 | 0.23 | 0.91 | 1.14 | 1.27 | 1.44 |
| Tue_10 | Fit only to North (area 4,7,11,5) | 94873 | 125101 | 1196 | 0.33 | 0.28 | 0.88 | 0.94 | 0.87 | 1.24 |
| Tue_11 | Fit only to South (area 1,2,8,12,6) | 65961 | 102969 | 1066 | 0.33 | 0.31 | 0.55 | 0.86 | 0.7 | 0.83 |
| Tue_12 | Estimate M with growth from LEP model | 280728 | 415507 | 3567 | 0.31 | 0.25 | 0.73 | 0.92 | 0.88 | 1.11 |
| Tue_13 | Use plus groups |  |  |  | NUMERICAL ISSUES |  |  |  |  |  |
| Tue_16 | North excl. South catches with growth estimates (fit to otolith data) |  |  |  |  |  |  |  |  |  |
| Tue_17 | Lambda = 100 assigned to otolith base case assumptions |  |  |  |  |  |  |  |  |  |
| Tue_18 | Base model starting in 2000 |  |  |  |  |  |  |  |  |  |
| Wed_1 | Specify average rec for projections. |  |  |  | UNABLE TO IMPLEMENT |  |  |  |  |  |
| Wed_2 | Age specific selex for OBJ lumped | 263044 | 356487 | 3380 | 0.32 | 0.27 | 0.78 | 0.9 | 0.96 | 1.15 |
| Wed_4a | Time-vary selex OBJ starting in 1993 | 298138 | 404857 | 3750 | 0.31 | 0.25 | 0.69 | 0.94 | 0.95 | 1.19 |
| Wed_4b | Time-vary selex OBJ starting in 2000 | 265030 | 361010 | 3312 | 0.3 | 0.24 | 0.78 | 1.17 | 1.22 | 1.34 |
| Wed_5 | Combined estimation of M and growth |  |  |  |  |  |  |  |  |  |

## APPENDIX A: PANEL MEMBERS AND PARTICIPANTS

Steven Martell (Chair)

Paul de Bruyn

Billy Ernst

Nick Davies

Rick Deriso

Cleridy Lennert-Cody

Mark Maunder

Alexandre Aires-Da-Silva

Carolina Minte Vera

Michael Hinton

**List of attendees**

Kevin Piner

Martin Hall

Michel Dreyfus

Bill Fox

Javier Ariz

## APPENDIX B: DOCUMENTS PRESENTED TO PANEL

Aires-da-Silva, A. 2012. Integrating Otolith and Tag Growth Increment Data to Estimate Growth for EPO Yellowfin Tuna and the Implications for Stock Assessment and Management. Document YFT-01-04 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Aires-da-Silva, A., and M. N. Maunder. 2012. An Exploration of Alternative Methods to Deal with Time-Varying Selectivity in the Stock Assessment of Yellowfin Tuna in the Eastern Pacific Ocean. Document YFT-01-06 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Anon. 2012. Introduction to the Review of the Assessment of Yellowfin Tuna in the Eastern Pacific Ocean, 2012. Document YFT-01-01 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Eveson, J. P, Laslett, G. M. and Polacheck, T. 2004. An integrated model for growth incorporating tag-recapture, length-frequency, and direct aging data. Can. J. Fish. Aquat. Sci. 61: 292-306.

Laslett, G. M., Eveson, P. and Polacheck, T. 2002. A flexible maximum likelihood approach for fitting growth curves to tag-recapture data. Can. J. Fish. Aquat. Sci. 59: 997-986.

Lennert-Cody, C. E., M. N. Maunder, A. Aires-da-Silva, A. Pérez and J. Marrow. 2012. Poststratification of Purse-Seine Port-Sampling Data from Dolphin Sets. Document YFT-01-03 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Lennert-Cody, C. E., M. N. Maunder, and A. Aires-da-Silva. 2012. Exploring Large-Scale Patterns in Yellowfin Tuna Data from Dolphin Sets in the Eastern Pacific Ocean Purse seine Fishery. Document YFT-01-02 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Maunder, M. N., and A. Aires-da-Silva. 2012. A Review and Evaluation of Recruitment and the Stock Recruitment Relationship for the Assessment and Management of Yellowfin Tuna in the Eastern Pacific Ocean. Document YFT-01-05 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Maunder, M. N., and A. Aires-da-Silva. 2012. A Review and Evaluation of Natural Mortality for the Assessment and Management of Yellowfin Tuna in the Eastern Pacific Ocean. Document YFT-01-07 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

Maunder, M. N., and A. Aires-da-Silva. 2012. A Review of Historical EPO YFT Stock Assessment Sensitivity Analyses. Document YFT-01-08 (draft). External review of the IATTC yellowfin tuna assessment. La Jolla, California (USA), 15-19 October 2012.

# APPENDIX C: REQUESTED MODEL RUNS AND RESULTS CATEGORISED BY AREAS OF FOCUS/TOPIC EXAMINED

## RECRUITMENT AND STEEPNESS

| Name | Run description | Results |
|---|---|---|
| **Mon_1** | Estimate steepness with a beta prior - relax assumption on steepness prior (beta prior with a mean 0.9 and CV = 0.1). | Run **Mon_1** could not minimise due to a calculation problem. |
| **Mon_2** | Estimate steepness with a normal prior - relax assumption on steepness prior (normal prior with a mean 0.9):<br>(a) CV = 0.1, and (b) CV = 0.2. | Run **Mon_2(a)** took 8 hrs to fit, and estimated a mean steepness of 0.775. The estimated recruitment trend was similar to that of the base-case model, but with an improvement in the recruitment likelihood term. Shifts in the derived MSY quantities are as expected with the lower steepness (higher MSY and more pessimistic outcome).<br>Run **Mon_2(b)** (with prior CV = 0.2) was not completed. |
| **Wed_1** | Explore the potential for specifying average recruitment used for projections. | Run **Wed_1** was not completed. |

## STOCK STRUCTURE

| Name | Run description | Results |
|---|---|---|
| **Tue_9** | Put lambda = 0 on all observations from the southern fisheries and exclude their catches; fix the selectivities of these fisheries at the values from the base case par file; and fit to data from Northern fisheries: OBJ-N, NOA-N, DEL-N, DEL-I, LL-N. Compare the estimates of recruitment relative to the base-case model, to illustrate if differences in the Northern and Southern data, explain the apparent phase shifts in the CPUE peaks in fisheries in the two regions. | A substantially better fit was obtained to all the northern data, with an exceptionally good fit to the PS-DEL fishery CPUE. A very different recruitment pattern was obtained compared to the base-case model. It was noted that an asymptotic selectivity for the DEL-N fishery must be assumed in order to constrain the model. Poor correspondence was obtained between the observed and predicted southern LF data. |
| **Tue_10** | As for run **Tue_9** in respect of the Northern fisheries (OBJ-N, NOA-N, DEL-N, LL-N) but in this case ignore the DEL-I fishery. | The only difference between this run and run **Tue_9** was to ignore the DEL-I fishery as in the base-case model. There was no large effect caused by including this fishery, and overall similar results were obtained to run **Tue_9.** |
| **Tue_11** | Put lambda = 0 on all observations from the Northern fisheries and exclude their catches; fix the selectivities of these fisheries at the values from the base case par file; and, fit to data from Southern fisheries: OBJ-S, OBJ-C, NOA-S, DEL-S, LL-S. Include DEL-I fishery, as in the base case. | There was no significant change from the base-case model management quantities, but an exceptionally good fit to the CPUE for the LL-S fishery was obtained, and with very different recruitment estimates. Surprisingly, moderate fits to Northern LF data were obtained. This result suggests that for the base-case model, Southern data appears to be driving the estimated recruitments and subsequently the biomass estimates, despite the fact that the northern fisheries account for most of the catch. |

## GROWTH

| Name | Run description | Results |
|---|---|---|
| **Mon_4** | Reduce the CV on the base-case model assumed mean length-at-age by 50% for large fish. | An improved fit to most LF data was obtained but without much change to the management quantities. |
| **Tue_1** | Include in the SS model fit the estimates of length-at-age from the otolith samples (Wild 1986) and estimate a sd(mean length-at-age) as a linear function of length. | The fit to the otolith observations failed for the mean length-at-age observations for ages > 13 qtrs, and an implausibly low $L_2$ value of 135 cm. However, a large improvement in fit to size data was gained, especially for the LL-S fishery, but also for the PS-OBJ fishery. |
| **Tue_2** | Use a normal prior on $L_2$ based on mean and variance from the external integrated growth analysis, and include the otolith observations in the model fit. | Similar results to **Tue_1**, but with an even better fit to the LL-S fishery LF data. |
| **Tue_3** | Use normal priors for the estimation of all growth parameters, including the sd(mean length-at-age), with the priors specified according to the external integrated growth analysis, and exclude the otolith data and PS-OBJ LF data from the model fit. | Growth estimates were obtained, but compared very poorly to the otolith data, with an implausibly low $L_2$ estimate. However, a more plausible estimate of sd(mean length-at-age) was obtained. |
| **Tue_13** | Aggregate age and size strata into "plus" groups for > 20 quarters and > 170 cm. This run investigates whether the uncertainties in growth estimates for large and old fish can be avoided. | Insurmountable difficulties were experienced in fitting this model, with implausibly high biomass estimates, most probably because it now lacks any signal on total mortality. |
| **Tue_16** | Repeat the "Northern" model run **Tue_10** that excludes Southern fishery observations and catches, while estimating growth and includes otolith data in the model fit. This run investigates if the fit to the otolith data is improved by just using Northern observations (since all the otolith observations were collected from that region). | This run failed to address the difficulties in estimating growth, with an implausible estimate of $L_2$ obtained. The LF residual pattern for the DEL-N fishery was somewhat improved. |
| **Tue_17** | Assume a high lambda (100) assigned to otolith likelihood term. | A closer correspondence was obtained to the growth estimates derived from the otolith data, but the estimated $L_2$ was still implausibly low. |

## SELECTIVITY

| Name | Run description | Results |
|---|---|---|
| **Tue_4** | Relax the assumption about selectivity being equal to zero at the smallest size class for the PS-OBJ fisheries. | Selectivity of the left-hand limb still went to a value close to zero, and it was noted that the selectivity of the OBJ-C fishery was sensitive to this assumption, with a difference in the right-hand limb that descended to zero at smaller sizes relative to the base case estimate. This sensitivity may indicate the convergence issues due to local minima associated with the selectivity estimates. |
| **Tue_5** | Truncate the LF data for large fish (> 70 cm) from the PS-OBJ fishery in which large individuals are captured only periodically. | Many of the selectivity functions became "narrower" and improvements were gained in the patterns of the LF residuals. Only slight differences were noted in recruitment estimates but recent absolute biomass estimates were lower which resulted in more pessimistic management quantities. |
| **Tue_6** | Truncate the LF data for large fish (> 100 cm and > 70 cm) from the PS-NOA and PS-OBJ fisheries (respectively) in which large individuals are captured only periodically. | Implausibly steep truncations of the selectivity functions for the PS-NOA fishery were obtained at the point of the truncation. |
| **Tue_8** | Apply the windowed time-varying selectivities (5-year window), to both the PS-OBJ and PS-NOA fisheries, while down-weighting the CPUE indices. | Numerical issues were encountered – no results obtained. |
| **Wed_2** | Estimate point estimate selectivity-at-age for the PS-OBJ fishery which aggregated into a single unit over the model spatial domain. | Somewhat higher indices were obtained for ages 3 to 5 quarters relative to the base case function. Very high indices at ages > 15 quarters were estimated, probably due to the infrequent presence of large fish observed in some years. The retrospective pattern of high recent recruitments was minimised by the selectivity assumption investigated in this run, and the patterns in LF residuals of the PS-OBJ fishery were improved. A 70-point improvement was made in the value for PS-OBJ LF likelihood term. No substantial change occurred to the management quantities. The absence of any effect of the estimated high PS-OBJ selectivity for large fish suggests that LF data in these size intervals have limited influence on model estimates. Consequently the right-hand limb of the selectivity could be assumed, or the PS-OBJ LF data could be truncated for intervals > 70 cm. |

## NATURAL MORTALITY

| Name | Run description | Results |
|---|---|---|
| **Tue_12** | Estimate female natural mortality for the old age classes while assuming the offset value for males, and assuming fixed growth parameters taken from the external integrated model analysis. Specifically this run considers changes in parametric uncertainty, the Hessian, and recruitment estimates with respect to the base case. | Relatively poor selectivity estimates were obtained. The estimated M for older ages was a little higher relative to the base case values, while the estimate at age zero was a little lower. There was no substantial visible change to PS-OBJ LF residual pattern, however, a worse total LF likelihood term was obtained, especially for the OBJ-N fishery (*cf.* run with integrated-model growth estimates produced worse fit to LF term).<br>A somewhat worse fit to the CPUE was obtained for the LL-S fishery, but better fit was obtained for the PS-DEL fishery. Wider confidence intervals were obtained on the model estimates for recruitment and biomass. The run time was 4 hours. |
| **Wed_5** | Combined estimation of M and growth. Repeat run **Tue_12** that estimates natural mortality for mature female with fixed male offset rate, while estimating growth using priors specified from the external integrated analysis, and excluding the otolith data from the model fit. Specifically look at parametric uncertainty, Hessian, and recruitment estimates with respect to the base case. | This appears to be the only model run requested that achieved reasonable growth estimates within the model with the estimate of $L_2$ being plausible. However, $M_{female}$ was exceptionally high for ages > 15 quarters being 0.7 vs 0.45 assumed for the base case. Temporal variation in recruitment was visibly reduced. The fit to the CPUE was improved, but a worse fit to the LF data was obtained, with the total likelihood about the same as the base case. Although this run simultaneously estimated two highly correlated parameters, they had highly informed priors. |

## RELATIVE WEIGHTING AMONG DATA

### LF DATA

| Name | Run description | Results |
|---|---|---|
| **Mon_3** | Down-weight the importance of the LF data by reducing the effective sample sizes by applying a lambda = 0.1 (10% of the relative weight assumed for the base case). Examine the impact of this on the estimated root mean squared error of the LL-S CPUE data. | A large improvement in CPUE likelihood term was obtained, with an improved fit to the peak in the indices for the LL-S fishery around 2000. This was indicated by the RMSE for the LL-S fishery improving from 0.36 to 0.3. There is not much improvement for the other fisheries and little change to the management quantities. This suggests some conflict among the data in respect of the estimates of recruitment variability but this has limited effects on model absolute abundance estimates or derived quantities from the model. |

### CPUE DATA

| Name | Run description | Results |
|---|---|---|
| **Mon_5** | Sensitivity to the relative weight assigned to CPUE data - examine the fits to the length composition data to determine which size composition data set(s) is in conflict with the LL-S CPUE. | Changing the relative weight of the CPUE data in the model fit resulted in no change to the absolute abundance estimates, most likely because the CPUE index only informs the model of relative changes given the short-lived nature of yellowfin and the absence of large catch fluctuations that produce contrast in the productivity signals. |
| **Mon_5.a** | Fit to the CPUE for the LL-S fishery only (exclude other CPUE indices from the model fit). | A better fit to the CPUE was obtained, but it was still poor in the first 10 years (most probably due to a conflict with the size data). The estimate of average recruitment decreased slightly, resulting in more pessimistic management quantities. |
| **Mon_5.b** | High relative weight on the CPUE (assign a lambda = 10). | A better fit to the CPUE was obtained, and the estimate of average recruitment decreased noticeably relative to the base case, as did recent absolute biomass (a greater decline in recent years) resulting in more pessimistic management quantities. |
| **Mon_5.c** | Exclude all CPUE from the model fit. | No sensitivity was seen in the absolute abundance estimates, but there was some sensitivity to the biomass trend in the most recent years. |

## MODEL CALCULATION PERIOD

| Name | Run description | Results |
|---|---|---|
| **Tue_7** | Model run starting in 1993. This omits all of the early data, which may be reasonable because the historical estimates of recruitment appear to be relatively insensitive to changes in the model assumptions regarding the PS-OBJ fishery. | Recent recruitment estimates were high, indicating higher uncertainty due to the retrospective pattern. Average recruitment was higher and consequently management quantities were more optimistic. Significant gains were made in respect of the run time; less than half that of the base case. |
| **Tue_18** | Model run starting in 2000. This run makes no assumptions regarding the catch species composition, since data for this is available throughout the model calculation period. | Substantially higher absolute abundance estimates were obtained, of an order similar to that for the run assuming $L_2 = 170$. Presumably this was because the period over which recruitments were estimated includes mostly high recruitments so the average is higher. This has implications for the recruitment assumptions made in model projections. However, the gain made in terms of time required to achieve a model solution is useful for developing the model and undertaking model structural uncertainty analyses. |
| **Wed_4.a and 4.b** | Model having a truncated calculation period, starting in: **a.** 1993, and **b.** 2000, with estimation of time-variant selectivities (5-year window) for the PS-OBJ fishery. | The average selectivity and the temporal variants for the PS-OBJ fishery were similar in both runs. The recruitment trends were similar to the base case over the corresponding years (post-1993 and -2000). No uncertainty due to the retrospective pattern in recent recruitments was apparent. Estimates of average recruitment were higher than the base-case model for run **Wed_4.a** which scales up projection biomass. For run **Wed_4.b** average recruitment is similar that of the base case. Run times were 38 and 22 minutes respectively. |