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AN INVESTIGATION OF THE SENSITIVITY OF THE INDIAN OCEAN MFCL YELLOWFIN TUNA STOCK ASSESSMENT TO KEY MODEL ASSUMPTIONS.

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A range of model runs were undertaken to investigate the sensitivity of the 2011 YFT IO MFCL assessment model to key structural assumptions (Langley et al 2011). The analysis was, in part directed by a review of the assessment conducted on behalf of the Secretariat (see Appendix 1).

For comparative purposes, most of the model sensitivities were conducted using a base model with longline selectivity parameterised using a logistic function (full selection of the older age classes). Most of the model options were examined using the same MFCL code used to undertake the 2011 stock assessment.

1. Natural mortality

The current stock assessment assumes age specific M is known without error. The average value of M is based on a consideration of the initial results from the analysis of the tagging data (IOTC 2008) while the variation in M with respect to age is equivalent to the M-at-age applied to the WCPO yellowfin stock assessments.

The time-series of tag recoveries from the IO fishery has the potential to provide some information regarding the natural mortality of yellowfin in the IO. The base MFCL assessment model was given freedom to estimate the overall average level of M and the age specific deviations from the mean. M for the last 8 age classes was assumed to be equal. The MFCL default penalty values for the smoothing of the M-at-age estimates were applied.

Natural mortality was estimated to be considerably higher than the level currently incorporated in the assessment (Figure 1).

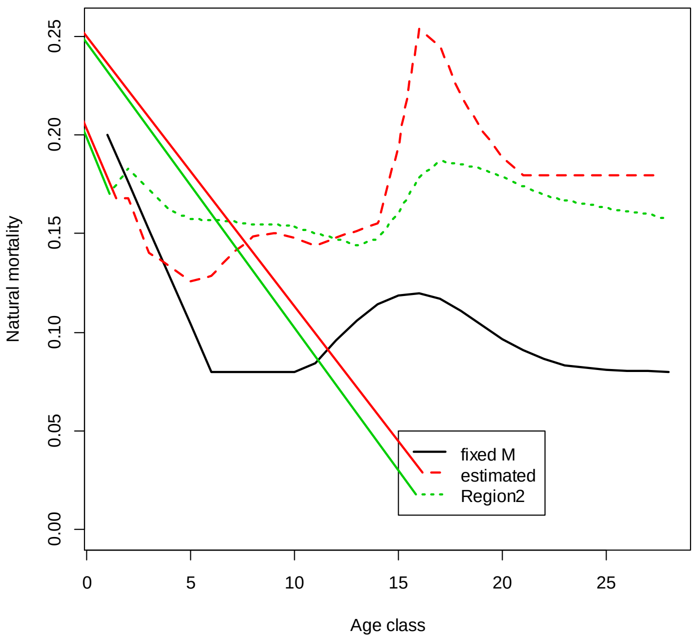

Figure 1. Comparison of fixed and estimated M at age from the MFCL model.

There was a considerable improvement to the fit to the tag data (with the tag likelihood component decreasing from 2931.8 to 2903.7) and a substantial improvement in fit for the overall model (decrease in LL from -306250.3 to -306565.85).

The analysis may be sensitive to assumptions regarding tag mixing (within region 2 and among regions). A further analysis was conducted using the single, region 2 model. This model estimated M-at-age values that were comparable to the full 5-region model (Figure 1).

The sensitivity of the M estimates to the other data sets (LL CPUE and length data) was examined by repeating the analysis with a substantial lower weighting assigned of these data sets. Comparable estimates of age-specific M were attained from these analyses (not presented).

Other issues to consider. The assessment model assumes that there is no temporal variation in tag recovery rates for fleets (once data have been corrected), tag loss and tag mixing (=movement), etc. These parameters are also invariant with respect to age. There is also a strong interaction with selectivity assumption for LL fisheries (for the older age classes only).

Recommendation: WPTT reconsider the base level of natural mortality informed by external analysis of tag data.

2. Longline CPUE indices

The current assessment model assumes the LL CPUE indices are the prime index of stock abundance in each region. The CPUE indices were assigned a high level of precision (cv 10%) to ensure the estimated biomass trends were consistent with the CPUE indices. However, there is potentially conflict between the CPUE indices and tagging data and the sensitivity of the assumed error associated with the LL CPUE indices was investigated.

A sensitivity was undertaken with LL CPUE assigned a CV of 25% (LL CV 25%). This resulted in little change to the biomass trajectory but an improvement to the fit to the tag data (tag likelihood 2883.75) (Figure 2).

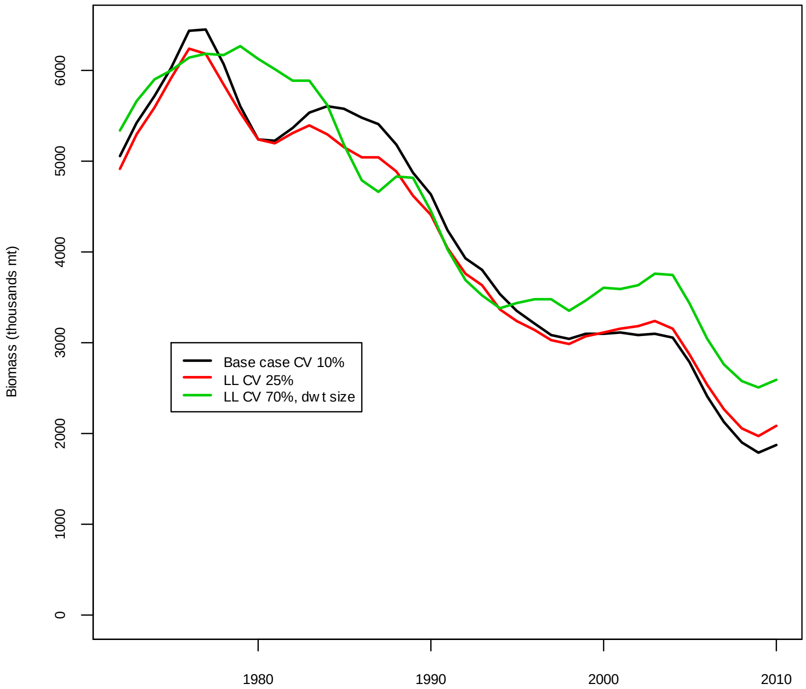

Figure 2. Comparison of biomass trajectory with different relative weighting to the LL CPUE indices.

A further (extreme) sensitivity was undertaken whereby the LL CPUE indices were greatly down-weighted and the length data were also down-weighted (LL CV 70%, *dwt size*). The higher relative weight given to the tagging data yielded considerably higher levels of stock biomass during the mid 2000s (Figure 2) and a considerable improvement in the fit to the tag recovery data (Figure 3) (tag LL 2804.65). There was a considerable shift in the selectivity functions for a number of fisheries. These were typically fisheries with limited (or no) length frequency data (HD1, OT1, TR2, OT5, TR5, PSFS3, TR3) and the resulting selectivities typically became more strongly modal (probably reflecting the assumed age of the limited number of tag recoveries from these fisheries). The OT1 and TR2 fisheries have a reasonable number of tag recoveries and the OT1 fishery shares a common selectivity with OT5, while the TR3 and TR5 fisheries share a common selectivity with TR2. The selectivity functions for the main PS fisheries essentially remained unchanged with the downweighting of the other data sets.

Recommendation: Maintain LL CPUE CV at the current level and continue to investigate factors contributing to conflict between CPUE, LF and tag data. Determine the sensitivity of stock status to the assumptions regarding selectivity of the artisanal fisheries.

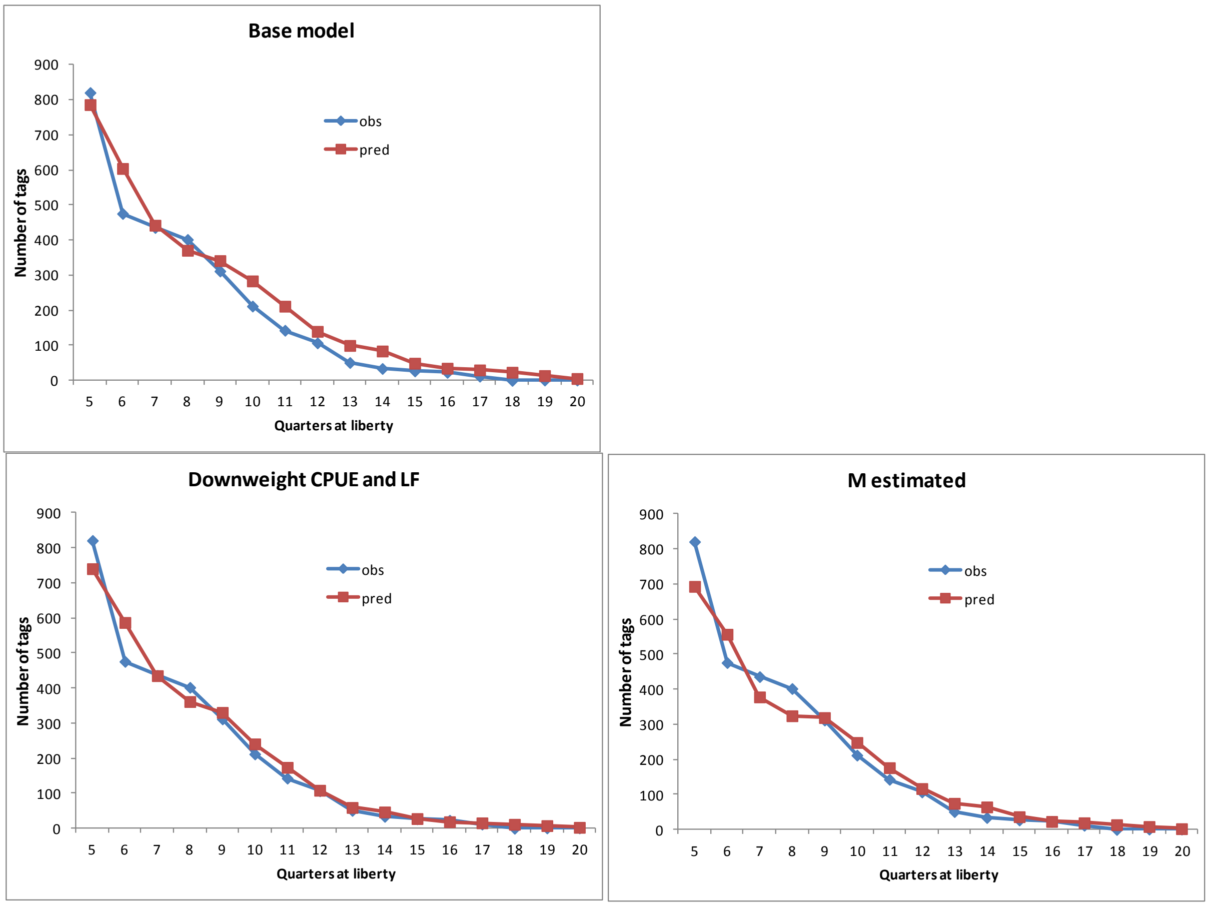

Figure 3. A comparison of the fit to the pooled tag recoveries over the recovery period (following a mixing period of 4 quarters) for a range of model options.

3. Tag data excluded

The influence of the tagging data is simply illustrated by excluding these data from the model. This resulted in a substantial reduction in the overall biomass level, although the relative biomass trend is comparable (Figure 4). Excluding the tag data resulted in a change in the selectivity of the free-school and FAD based purse-seine fisheries. In particular, the selectivity of the latter fishery is much tighter when the tag data were excluded (Figure 5). This may be suggestive of a conflict in the assumed growth parameters between the modal length frequency data and the tag recoveries from the fishery (although it is important to note that the tag recoveries from the two purse-seine fisheries are pooled so that this may result in a merging of the selectivities for the two fisheries). The higher selectivity of the PS LS fishery for the 9-14 age classes may be contributing to the lack of fit to the observed number of recoveries from the longer periods at liberty.

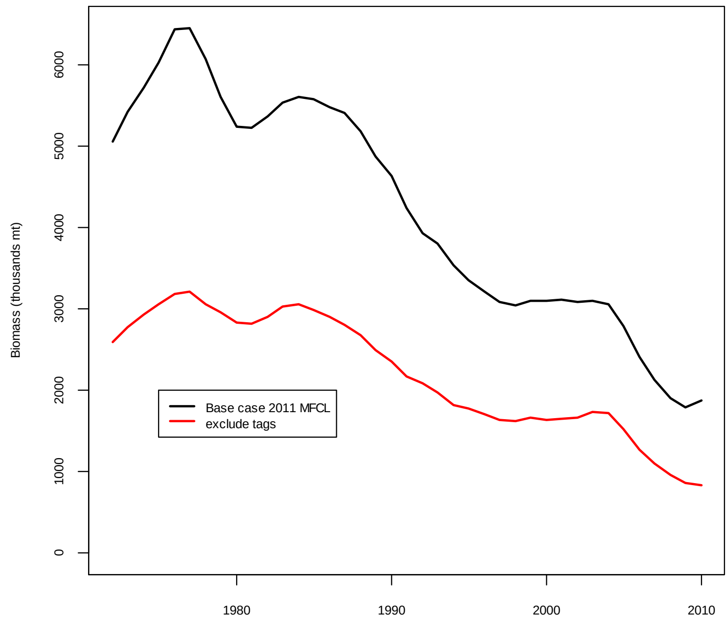

Figure 4. Comparison of biomass trajectory for model runs including and excluding the tag data.

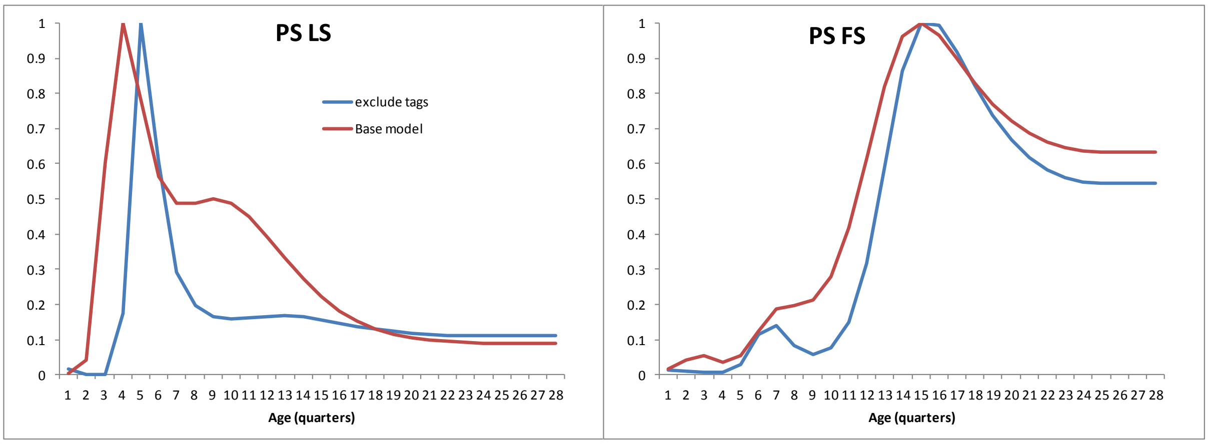

Figure 5. Comparison of the purse-seine selectivities from model runs including and excluding the tag data.

A large number of tag recoveries at liberty for over 12 months were recorded to have been recovered from FADs (Figure 6). However, the growth rate in the model would predict that these fish would be considerably larger and no longer vulnerable to the FAD fishery (the growth model predicts tagged fish released at 45 cm are 65 cm after 12 months at liberty). Are these fish genuinely slower growing (does not appear the case) or have the tags been assigned to the incorrect set type.

A model was implemented with the FAD based tag recoveries excluded (*tagXfad*). The model estimated age-specific selectivities for the PS LS fisheries that were comparable to the model with all tag data excluded. However, there was no substantive change to the biomass trajectory (Figure 7).

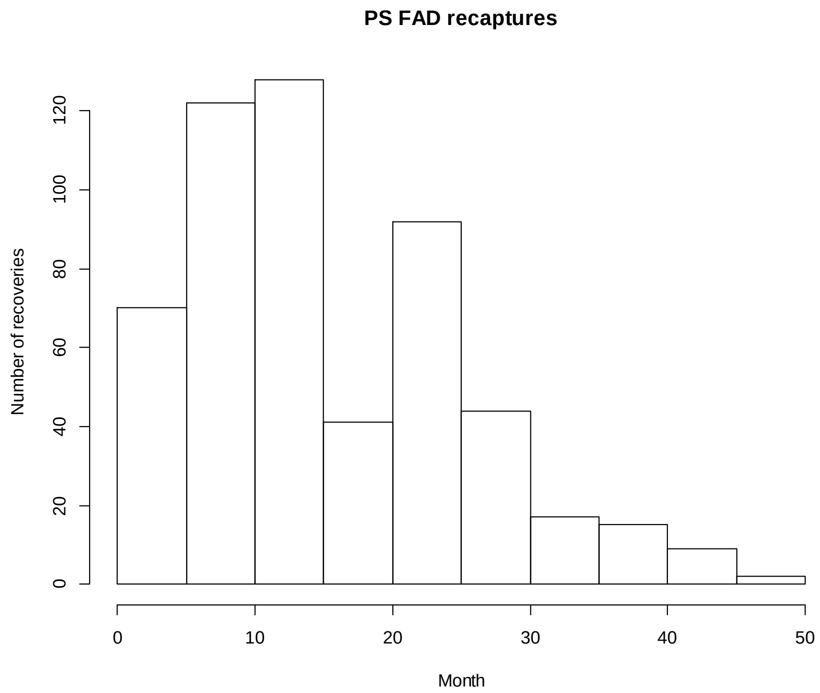

Figure 6. The period at liberty (months) for the yellowfin tag recoveries assigned to the PS FAD fishery included in the MFCL tag data set. Recoveries of less than 12 months are encompassed by the defined mixing period.

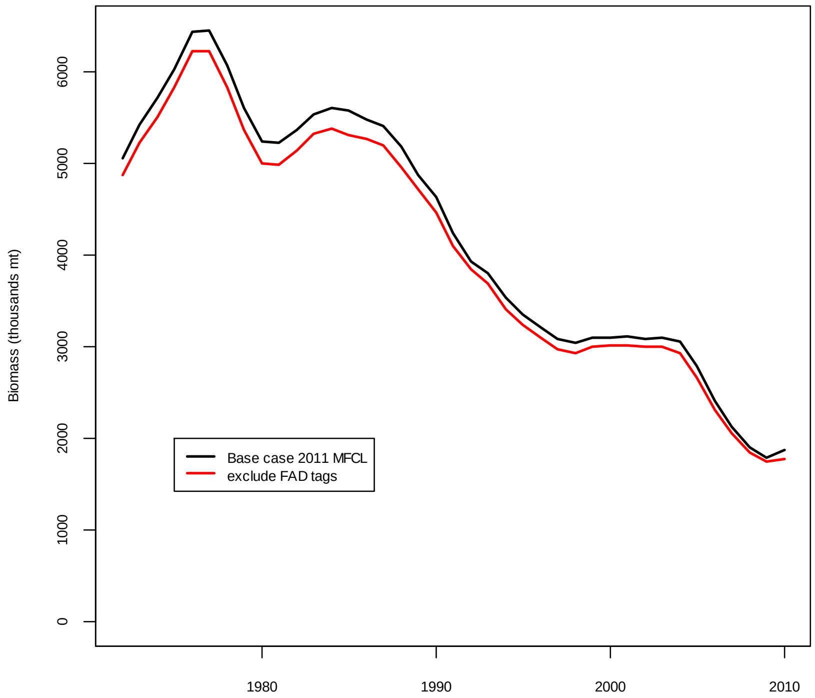

Figure 7. Comparison of the biomass trajectory excluding tags recovered from FAD sets.

Recommendation: Further analyses required to refine the tag data set included in MFCL. Assignment to either PS fishery shouldn't be an issue as tags are pooled anyway, but this could be an issue if the catch mix (by set type) landed to SEY differs (substantially) from the total catch.

4. Variation of mean length at age

Currently, the standard deviation of length at age is fixed (at a value of 9.5 based on other YFT studies) and does not exhibit substantial variation with age. The assumed values should be revised based on an external analysis of growth parameters from the tag data (and other sources).

5. Tag mixing

The base assessment assumes that tags are completely mixed (within each region) after 4 quarters following release. This seems like a reasonably conservative assumption. The estimated biomass level is sensitive to the assumed mixing period. A comparison between the base model (4 quarter mixing period) and a model with a mixing period of 2 quarters revealed that the overall level of biomass was lower for the shorter mixing period (Figure 8).

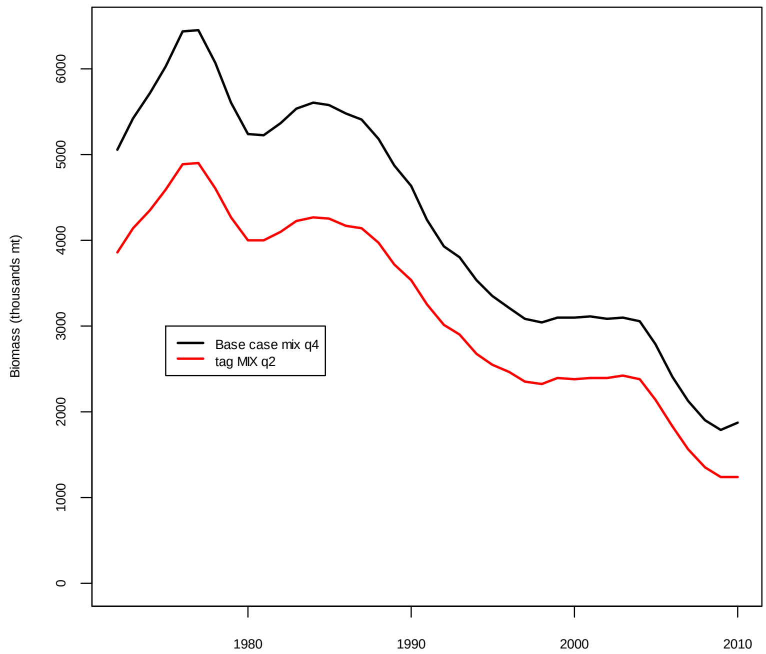

Figure 8. Comparison of biomass trajectory for model runs with tag mixing periods of 4 quarters (base model) and two quarters (tag MIX q2).

Additional analyses have been conducted to investigate tag dispersal and **recommend a mixing period of three quarters** (see Langley & Million 2012).

Recommendation: Adopt a tag mixing period of three quarters for the 2012 assessment.

6. Movement dynamics

A range of arbitrary movement assumptions (no movement, high movement) were tested and revealed that the biomass level was highly sensitive to the assumptions related to movement. Currently the assessment model estimates movement between adjacent regions. However, there is very little information included to estimate movement. There is potential to fix movement in the model but, again, there are no data available to formulate strong (and highly influential) prior assumptions regarding movement.

For illustrative purposes, the influence of contrasting levels of movement was examined in alternative model runs. Movement was fixed at a high level per quarter (resulting in only 60% of fish remaining within region 2 in each quarter) and compared to a model option with no movement between regions. By contrast, the maximum movement rates estimated for the base model result in a movement of about 10% of the fish from region 2 in a single quarter. The model results are highly sensitive to the fixed level of movement (Figure 9). However, the high movement option produces model results that are inconsistent with the main data sets, in particular the regional specific trends in the CPUE indices, and the purse-seine tag reporting rates are at the lower bounds. Conversely, tag reporting rates are at the upper bound if movement is set to zero.

Estimates of movement are likely to be confounded to some extent with fishery selectivities and regional recruitment distribution (and recruitment deviates). These trials indicate that model results are highly sensitive to highly informative assumptions regarding movement.

Recommendation: Movement parameters should only be constrained when informative priors are available from the external analysis of available movement data (or inferences from other sources, e.g. ocenography).

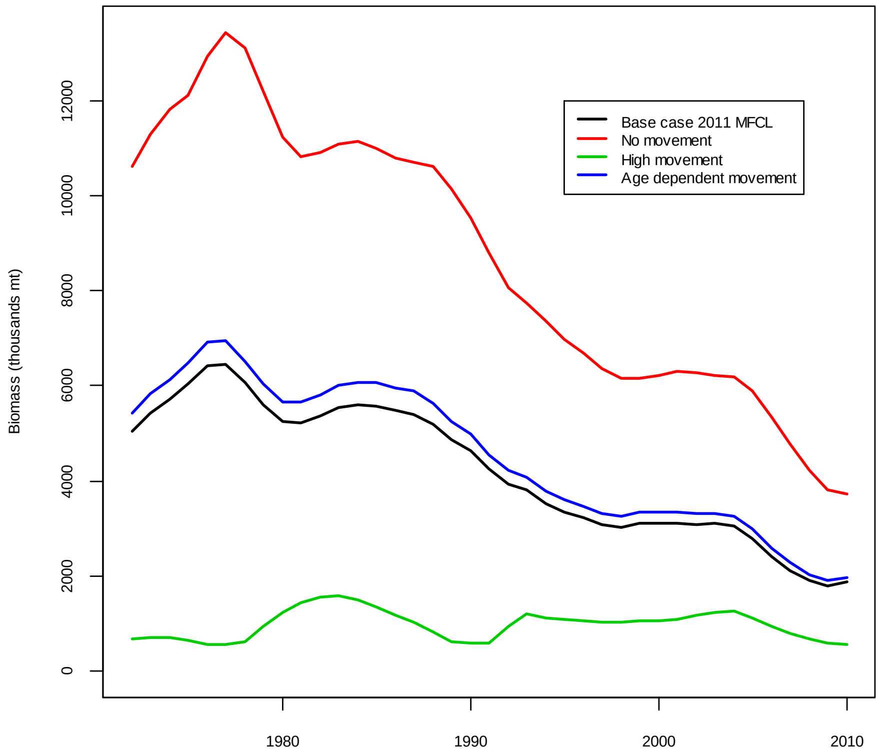

Figure 9. A comparison of biomass trajectories from model options with different assumptions regarding movement.

7. Region weighting

A persistent (and reasonable) criticism of the current assessment model is the high level of biomass attributed to model regions beyond the core region of the fishery, primarily region 5 which is estimated to have a similar biomass level to region 2. The decline in biomass in region 5 through the model period (following the LL CPUE index) is estimated to be primarily due to a decline in recruitment (which seems rather implausible). To a lesser extent, the biomass in region 3 is relatively high although there is likely to be considerable movement between region 2 and 3 (based on tag data – there is also a proposal from Allain Fonteneau to revise the boundary between these two regions).

Region 5 (northwestern IO) has a moderate level of catch. The base model estimates a modest level of movement from region 5 to region 2 and negligible movement from region 2 to region 5.

The large biomass in region 5 is estimated due to the assumption of constant LL catchability among regions (once the CPUE indices are rescaled relative to the historical abundance of fish in each region; i.e. area scaling factors). The area scaling factors assign a relatively high biomass to region 5 (0.85 of the region 2 level) based on the historical LL CPUE.

I examined the derivation of the area scalars (once again). They are derived from data from the 1960-1975 period. This is the period when the JP LL fishery was operating over the entire domain of the IO. The analysis was repeated on a decadal basis – computing areal scalars for each decade for which there was sufficient JP LL catch and effort data covering the IO region. There is some variability among the decades but in all cases the region 5 values were comparable to the region 2 levels (Table 1). On that basis, there is no rationale for assigning a lower relative weighting to region 5 (compared to current assessment).

Table 1. Relative regional scaling factors derived from JP LL data by decade.

Decade	R1	R2	R3	R4	R5
base	0.21	1.00	0.55	0.15	**0.85**
1960s	0.26	1.00	0.56	0.14	**0.87**
1970s	0.12	1.00	0.75	0.40	**1.15**
1980s	NA	1.00	0.65	0.21	**0.98**
1990s	NA	1.00	0.76	0.32	**0.76**

The base model assumes LL catchability is equivalent among regions. This assumption results in the high initial level of biomass in region 5. Removing the catchability constraint for the region 5 LL fishery (i.e. estimating a separate temporally invariant q for LL 5) resulted in a lower initial biomass level in region 5 but very similar biomass levels in the other four regions (Figure 10 and Figure 11).

This suggests that LL catchability could be considerably higher (approximately double) in region 5 compared to the other regions. However, is there any information available to suggest that this might be the case? Some possible considerations include:

- Does the operation of the purse seine fishery in region 2 restrict the longline fishery to more marginal areas within region 2 (lower catchability)?
- Are the oceanographic conditions sufficiently different to result in a higher availability of yellowfin to the longline fleet operating in region 5 (higher SST, shallower thermocline, etc)?
- Are there different patterns of species targeting between the two regions (2 and 5) that are not adequately accounted for in the calculation of the regional scaling factors? For example, is there a higher degree of bigeye tuna targeting in the western IO? This doesn’t seem to be the case as bigeye has represented a higher proportion of the longline catch in region 5 compared to region 2.

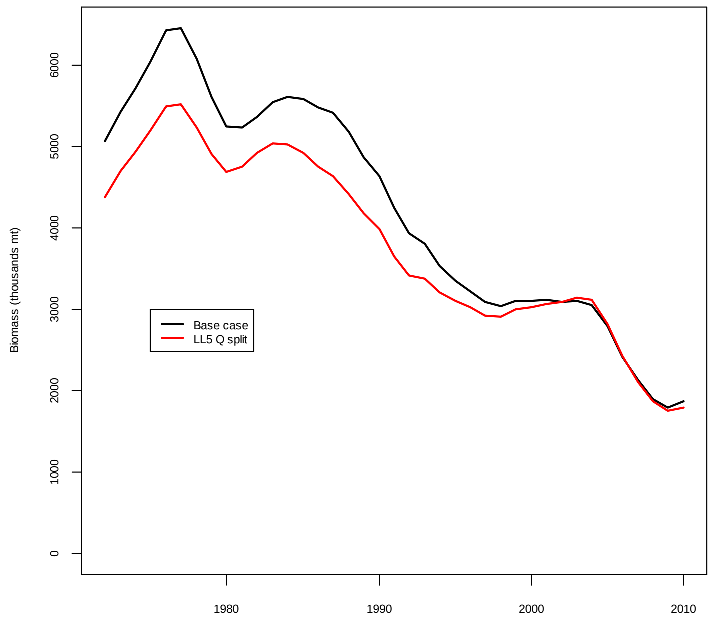

Figure 10. A comparison of the total biomass trajectory from the base model and a model sensitivity with LL catchability in Region 5 (LL Q split).

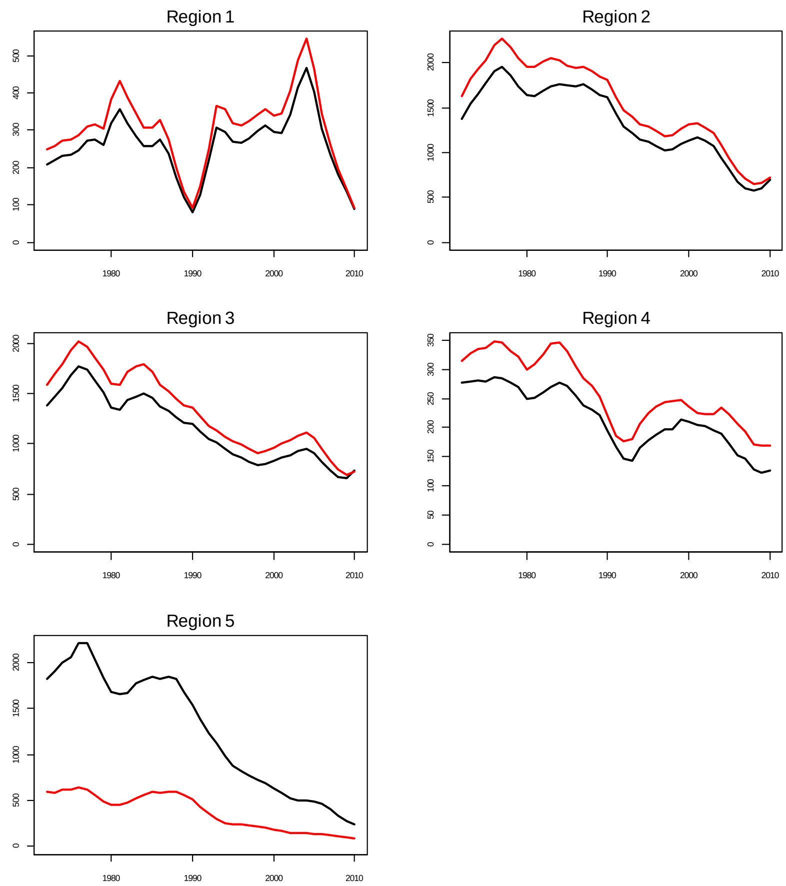

Figure 11. A comparison of the regional biomass trajectories from the base model and a model sensitivity with LL catchability in Region 5 (LL Q split).

8. Spatial structure

The spatial stratification was implemented to reflect the spatial domain of the main purse-seine fisheries and to partition the spatial heterogeneity in the trends in longline CPUE indices. Most of the tags releases and recaptures are also encompassed within a single region (region 2). The spatial structure increases the complexity of the model, although it enables heterogeneity in the broader Indian Ocean stock to be explicitly considered and is more consistent with the spatial scale of the tagging data.

Accordingly, the stock assessment results are sensitive to the spatial structure of the model. The most influential assumptions relate to the boundary between region 2 and region 5. These two regions are estimated to encompass most of the total stock biomass. A sensitivity analysis was conducted whereby these two regions were amalgamated. This may be a reasonable alternative model as the LL CPUE trends in the two regions are very similar.

The longline length frequency data sets were also compared between the two regions (Appendix 2). The comparison of quarterly length compositions did not enable strong conclusions regarding the regional structure; some quarters had very similar length compositions from the two regions, while large difference were evident for other quarters. The analysis was refined to compare the length structure from yellowfin longline catches from longitudinal blocks across the equatorial region (Appendix 3). There are four main longitudinal blocks (40-60° longitude, 60-80°, 80-100°, 100-120°) of which the two western blocks approximate the area within region 2 and the two eastern blocks approximate region 5. Overall, the annual compositions from the two eastern blocks are comparable to each other and generally dissimilar from the other two areas. The length compositions from the two western blocks are generally quite distinct; however, the LFs are more similar between these areas than compared to the LFs from the two eastern blocks. This analysis is more consistent with the current (5 region) spatial structure.

For the sensitivity analysis (region 2 and 5 combined), the region 2 LL CPUE index was assumed to represent the new amalgamated region (the LL CPUE index was given the combined area weighting of region 2 and region 5). The resulting model yielded a substantially lower level of total biomass than the base case (Figure 12). This difference in biomass equates to the level of biomass attributed to region 5 in the base case model as well as a somewhat lower level of biomass estimated for region 3.

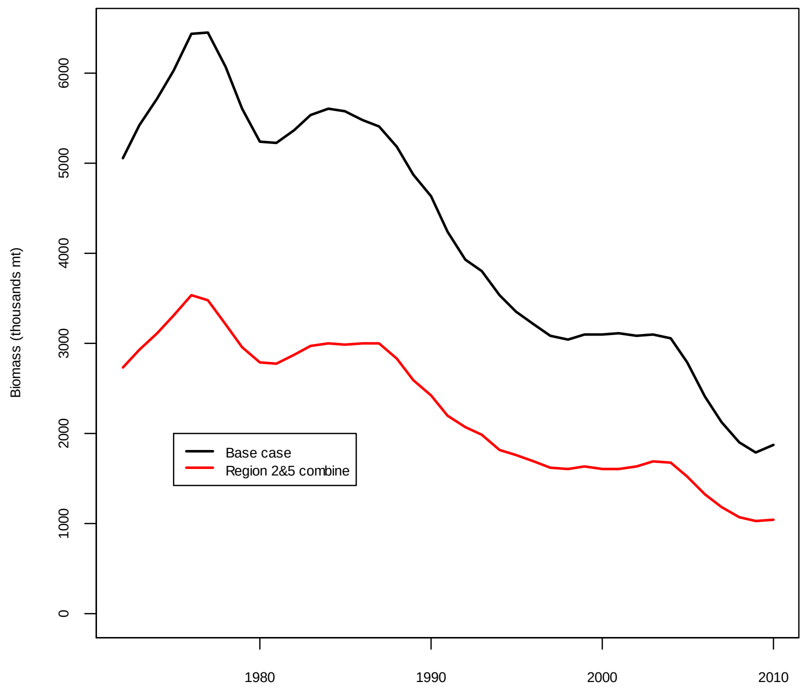

Figure 12. Comparison of the biomass trajectory between the base case model and the model with regions 2 and 5 amalgamated.

The amalgamated region2/5 model has the expectation that tags will be available to the fleets previously isolated in region 5. These fleets have recovered very few tags from the RTTP. The model deals with the low tag recoveries by estimating negligible tag reporting rates for the fleets in the region (TR, GI, OT, and LL).

Clearly, the model is sensitive to the regional structure assumptions. There are probably four main options that should be considered regarding the regional structure. Probably still need to estimate movement between regions as there is insufficient information to develop some reliable priors for movement.

Options:

a. **Status quo**. 5 regions. PROS: Based on Longhurst regions; partitioning of the PS fishery (regions 2 and 3) and tag data sets; different trends in LL CPUE between (some) regions. CONS: No distinct spatial delineation of catch at regional boundaries (not isolated populations); estimated regional biomass levels, movement dynamics, etc; model complexity.
b. **Amalgamate regions 2 and 5** – Use region 2 CPUE but need to rescale to allow for larger biomass in combined regions. Best to derive a CPUE index specific to the new amalgamated region. PROS: similar trend in LL CPUE between region 2 and 5; simpler model structure. CONS: lack of tag recoveries from fisheries in region 5 (reporting issue or lack of mixing); assumption of homogeneous population through the two regions; PS fishery operates in limited area; tag recoveries from PS fishery determine level of biomass for entire region (r2+r5 as evidenced by comparing region 2 biomass with region 2+5 biomass). [What is a reasonable mixing period for tags over the broader region 2&5 area?]

c. **Single region model.** PROS: simple model. CONS: different trends in CPUE in other regions, although trends similar in two main biomass areas (need to use overall CPUE index); assumes mixing of tags over entire region (other fisheries low tag RR), overall biomass (largely) determined by PS fishery in region 2 (from tag recoveries, ratio tags/catch).
d. **Separate western and eastern assessment models.** Possibly the most realistic (and pragmatic) option. Retain three western regions (1-3). PROS: Based on Longhurst regions; partitioning of the PS fishery (regions 2 and 3) and tag data sets; different trends in LL CPUE between (some) regions; west/east division is consistent with limited movement of tags to the east; longline length frequency data are suggestive of division between west and east; summary of oceanographic data also suggestive of mechanism for west/east split (Langley & Million 2012); removes uncertainty associated with regional biomass levels in east (region 5 especially). CONS: No distinct spatial delineation of catch at regional boundaries (not isolated populations); model complexity, including estimated regional biomass levels, movement dynamics, etc; no assessment for eastern region.
e. **Region 2 only model**. For comparative purposes only (previously model runs have estimated comparable levels of biomass to region 2 from 5-region model).

The single region model produces a biomass trajectory that is comparable to the model that amalgamates region 2&5 (Figure 13). This could be expected as both models are largely dominated by the LL CPUE indices from region 2 and the tag releases/recoveries from region 2. There are some minor differences in how the tag data are applied in the single region model (all releases are in the same region and therefore releases from regions 1 and 3 are immediately available to the PS fisheries following the mixing period).

The western Indian Ocean model estimates a recent biomass level very similar to the 5 region model (Figure 13). The biomass trajectories for the three common regions (1-3) are also very similar between the two models. However, the potential yields and biological reference points are considerably different (Table 3). This is due to the differential between the exploitation rates in the western and eastern regions of the Indian Ocean. The equilibrium levels of recruitment for the eastern regions (mainly region 5) are estimated to be quite high, while the exploitation rates in the region are relatively low. Thus, under equilibrium conditions (applied to derive MSY reference points) the higher biomass levels in the eastern areas of the Indian Ocean will sustain the yields from the more highly exploited western region. This is primarily an issue related to the temporal trend in recruitment from region 5. It may be more appropriate to derive the reference points based on the recent recruitment distribution rather than the long-term average level (mediated by the SSR).

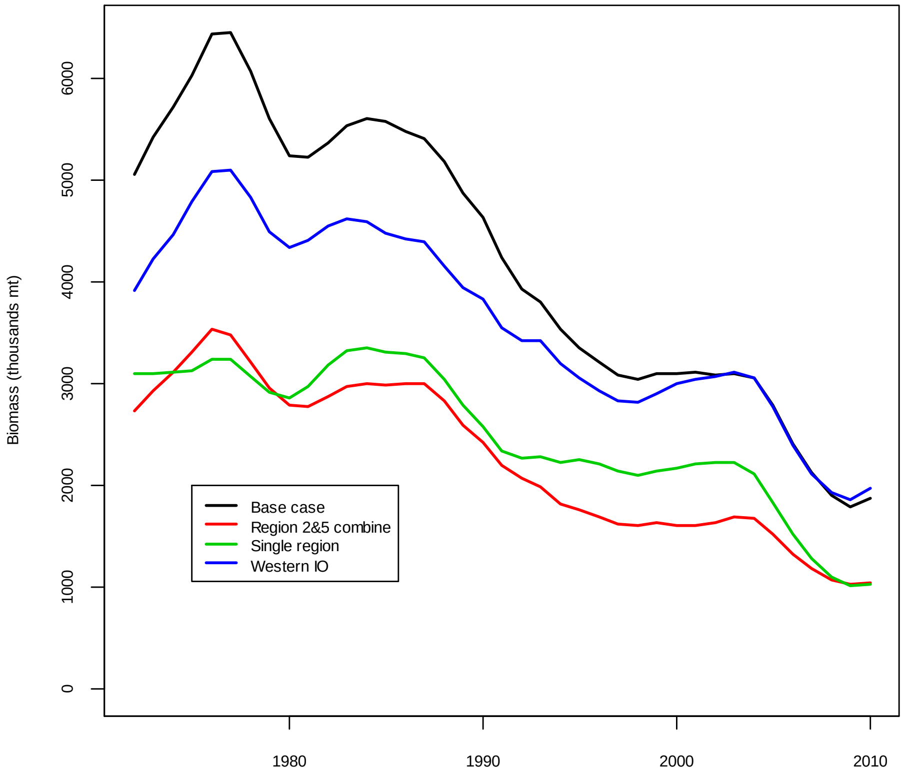

Figure 13. Biomass trajectories for the model options with alternative regional structures.

Recommendation: Key issue for consideration by the WPTT. An initial proposal is to conduct assessments based on the 5 region model and the western Indian Ocean models. Consideration of the proposal for revision to the boundary between region 2 and region 3.

9. Tag likelihood

The tag data are included in the model objective function as a negative binomial likelihood with added zeros. An over-dispersion parameter is estimated for the purse-seine tag recoveries and for the tag recoveries for the other fisheries. For the purse-seine fisheries, the model estimates over dispersion parameters that are at or close to the lower bound. The parameterisation of this variable and how it translates to the beta parameter in the likelihood is poorly documented and not well understood by other MFCL users. However, the biomass level is sensitive to the over-dispersion parameter. Higher values of beta result in lower variance and, hence, give more weight to the tagging data. This was evident from a small number of trials conducted assuming different values for the over dispersion parameter.

Recommendation: Maintain status quo for the 2012 assessment awaiting review of treatment of tag data within MFCL (by SPC/OFP).

10. MFCL new version

The 2011 assessment model was rerun using a more recent (January 2012) version of MFCL. The new version of MFCL yielded a somewhat lower level of biomass (Figure 14) and a considerable improvement in the fit to the data (306271.55 obj fnt and tag component 2925.58 compared to 2011 model obj fnt 306250.369 and tag component 2931.80). A number of changes have been made to the

MFCL code (including related to tag data) and it was not possible to identify the factor or factors that have caused the change in the model fit.

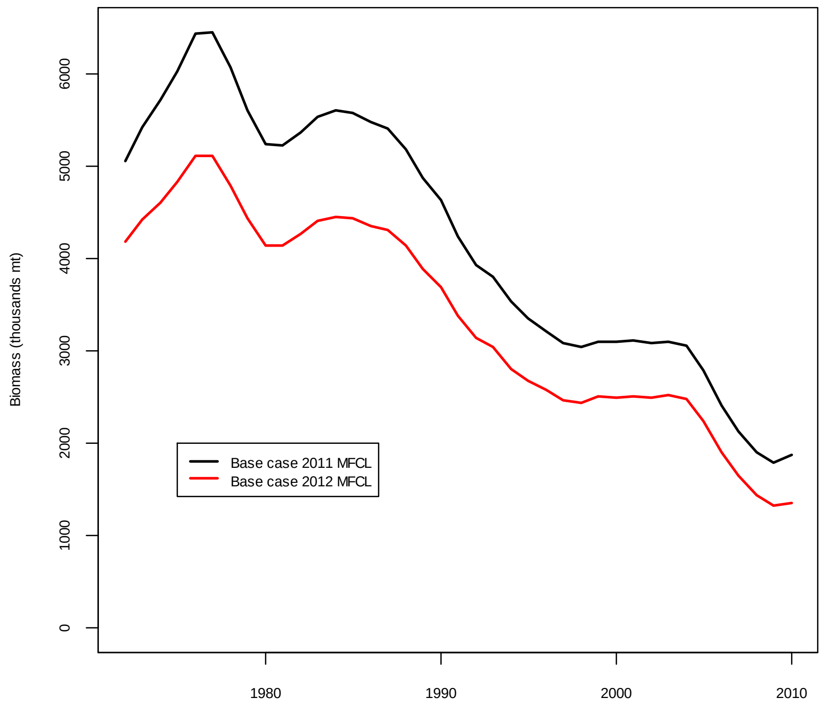

Figure 14. A comparison of the base case model from the 2011 assessment and the equivalent model run using a more recent version of MFCL.

Recommendation: Adopt the latest version of MFCL and assume recent changes in the code have rectified previous issues.

11. Inclusion of additional tagging data

Further consideration of the utility of the tagging data from the small scale tagging programmes conducted in the Indian Ocean.

SUMMARY

A range of outstanding issues have been investigated and recommendations for improvements to the 2012 yellowfin stock assessment have been formulated. This has resulted in a matrix of model runs proposed for the 2012 yellowfin assessment; a total of 8 main model options are proposed (2 region * 2 longline selectivity * 2 natural mortality) (Table 2). The final range of sensitivity analyses will also include the range of steepness values adopted in the previous (2011) assessment.

The most tractable issue that has the potential to substantially reduce the uncertainty of the stock assessment is the reconsideration of the level of natural mortality (Table 3). The current lack of fit to the tag recovery data may indicate that the assumed level of natural mortality is too low. However, the estimation of natural mortality within the assessment model is confounded with other key parameters (esp. longline selectivity). Other researchers are encouraged to undertake additional analyses of the tagging data to derive estimates of (age-specific) natural mortality that can be incorporated in the 2012 stock assessment.

Table 2. Summary of the range of initial model runs proposed for the 2012 yellowfin stock assessment.

Structural assumption	**Main options**
Regional structure	i. Region 5 model ii. Western Indian Ocean model
Longline selectivity	i. Logistic ii. Cubic spline (may be unnecessary if new, higher estimates of *M* are available).
Natural mortality	i. Fixed, status quo ii. Revised values (if available).
Growth	Options to be determined from other analyses.
Variance lgth age	External analysis
Tag mixing	4 quarters, consider excluding all FAD recoveries.
Movement	Estimated
SSR steepness	0.7, 0.8, 0.9

Table 3. Key reference points from the range of model sensitivities investigated. All assume a steepness of 0.80.

	MSY	F/Fmsy	Bmsy	B/Bmsy
Base 2011	315,320	0.95	1,732,000	1.19
Cubic spline LL	400,800	0.68	2,509,000	1.46
M estimated	472,800	0.58	1,643,000	1.12
Tag data upweighted	304,280	0.85	1,856,000	1.47
Tag data excluded	231,400	1.99	1,347,000	0.78
TagXfad	307,800	0.98	1,736,000	1.15
Tag mix Q2	269,560	1.28	1,440,000	1.04
LL Q split R5	285,880	1.06	1,666,000	1.23
Single IO region	249,280	1.47	1,325,000	0.93
Region 2 and 5 combined	245,080	1.50	1,290,000	0.89
New MFCL	276,840	1.20	1,500,000	1.06
Western IO	171,800	1.45	1,990,000	1.04

References

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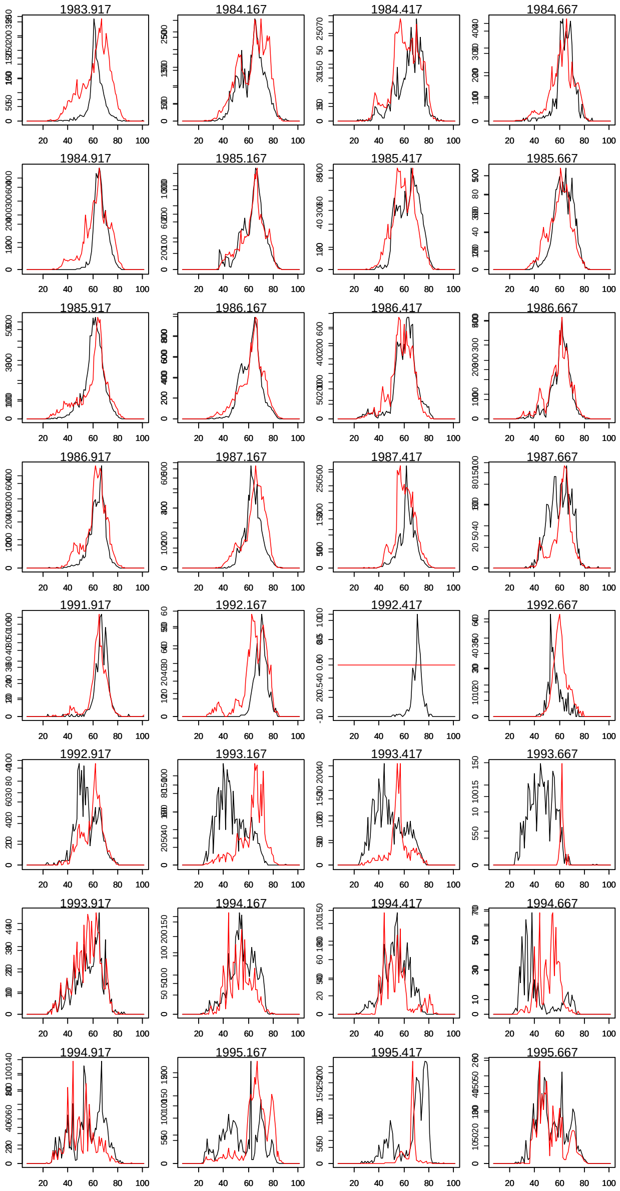
Langley, A., Herrera, M., Million, J. 2011. Stock assessment of yellowfin tuna in the Indian Ocean using MULTIFAN-CL. IOTC-2011-WPTT-13.

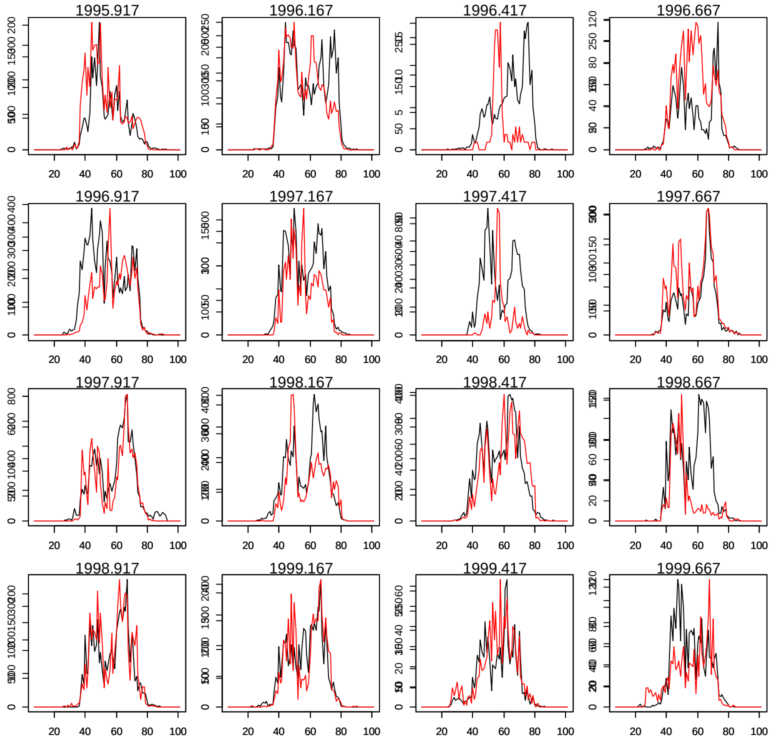
Langley, A., Million, J. 2012. Determining an appropriate tag mixing period for the Indian Ocean yellowfin tuna stock assessment. IOTC-2011-WPTT-14.

Appendix 1.

1. To conduct a number of different sensitivity runs with different parameters (*e.g.* natural mortality, growth, selectivity, steepness aggregate *vs.* disaggregated spatial structure, *etc…*) including the following:
   - Review the spatial stratification:
     - The present yellowfin assessment structure includes 5 regions defined by fishery operations, catch-at-size distributions and Longhurst biogeographical areas. Unfortunately there are limited tag recoveries and no reporting rate estimates outside of the core purse seine fishery region (region 2). This induces limitations for the model to estimate movement rates between areas, for which the current results appear to be unrealistic.
     - If we cannot estimate movement among all regions, is there a good justification to retain this structure in the model and management advice, or should it be simplified? If we actually believe the movement estimates, would be better off treating YFT as 2 separate populations (West and East)? Or a single Indian Ocean stock?
     - Is there anything to be gained by further partitioning the core purse seine area, into smaller sub-regions from which it may be possible to estimate movement?
   - Integration of small-scale tagging data: a substantial number of tags from the small-scale tagging programmes have been released and recovered (particularly for skipjack, and to a lesser extent yellowfin). Depending on the results of the analyses described in point 5, 7-8, and in relation to the objectives of 8, explore whether these data should be used and whether the Maldives fishery should be disaggregated into a separate region
   - Explore alternative M values. The different tuna-RFMOs use very different M estimates/assumptions in their tropical tuna stock assessments, but it is not clear that there is compelling evidence for real biological differences.
     - Range of values accepted in other RFMOs
     - Values estimated using independent B/BP estimators (from 7)
     - Internal estimates from the integrated model
   - Movement estimates are doubtful when inferred in the absence of tag recoveries. For any spatial structure that includes such estimates, effort should be made to describe the movement uncertainty:
     - How do the other parameter estimates and stock status inferences change when alternative fixed migration rates are imposed for the areas and ages with few recoveries and unknown reporting?
     - If B/BP movement estimates (from analyses described in 7-8) can be used as fixed input, how do they affect the model dynamics? Do they provide compelling evidence for variability in movement by age/season or year that cannot be adequately described in the integrated models?
     - How do the movement rates vary in relation to the variance-related assumptions for CPUE and size composition data?
     - In the yellowfin assessment, there appears to be sensitivity to stationary purse seine selectivity assumptions (likely change around the 2004-2006 peak catch years). Alternative options of temporal variability in selectivity should be explored, especially in relation to the independent F estimates derived from the B/BP analyses (in points 7-8).
     - All tuna stock assessments are also sensitive to longline selectivity assumptions (logistic vs. dome-shaped). This question should be investigated in relation to alternative M options.
   - Examine conflicts among different sources of data and assumptions. In addition to the explorations above, interactions/conflicts among the tagging, CPUE and size frequency should be quantified by down-weighting the different data sources.
   - The above explorations should be summarized to describe which of the plausible assumptions have important implications for management advice. The interactions among the most important assumptions should be recognized in the stock status advice. Estimates of uncertainty need to be provided in relation to all of the important structural assumptions and parameter estimation errors that are of interest for management.

Appendix 2. A comparison of the quarterly length frequency distributions of the yellowfin catch sampled from the longline fisheries within region 2 (black) and region 5(red).

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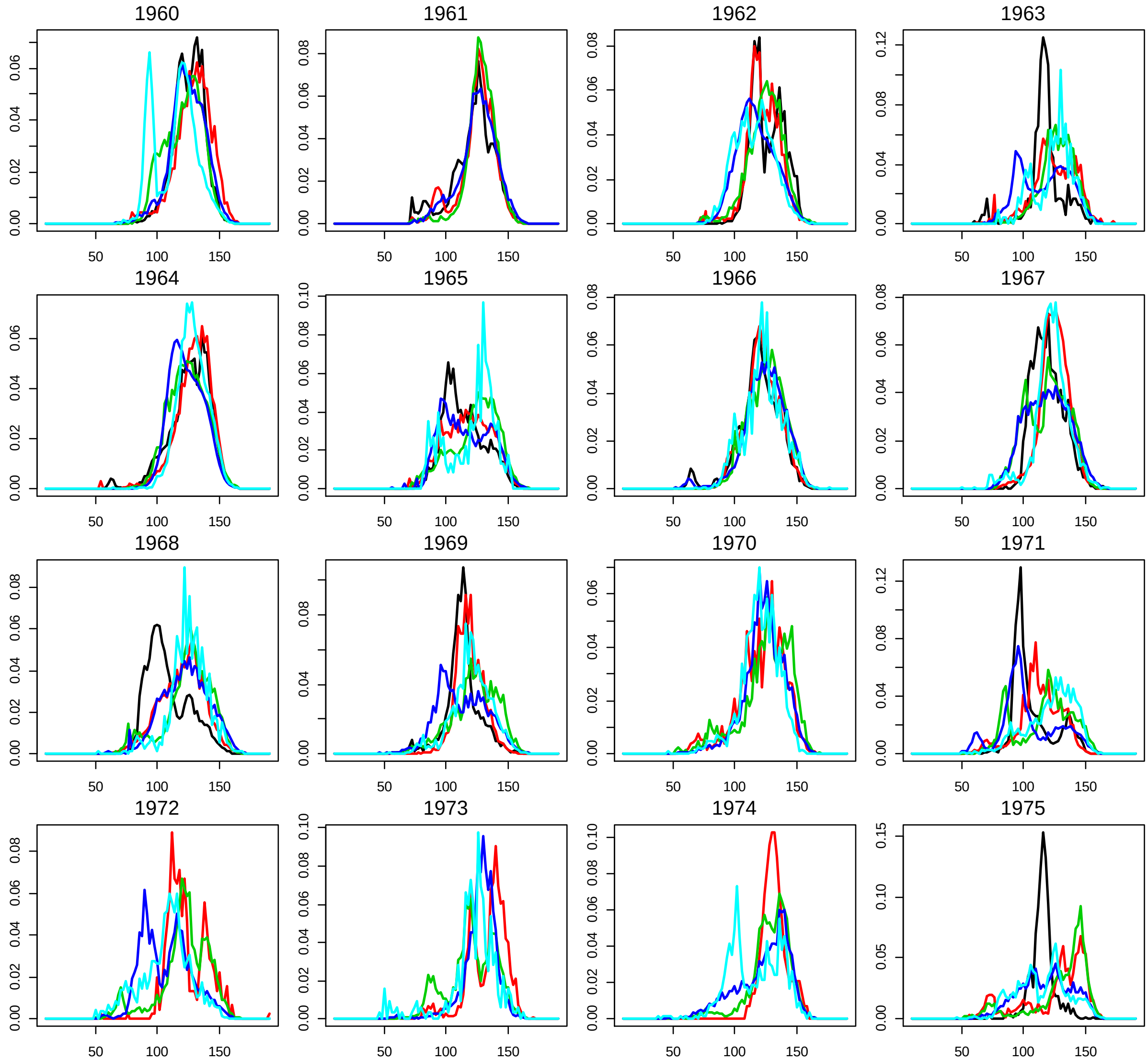
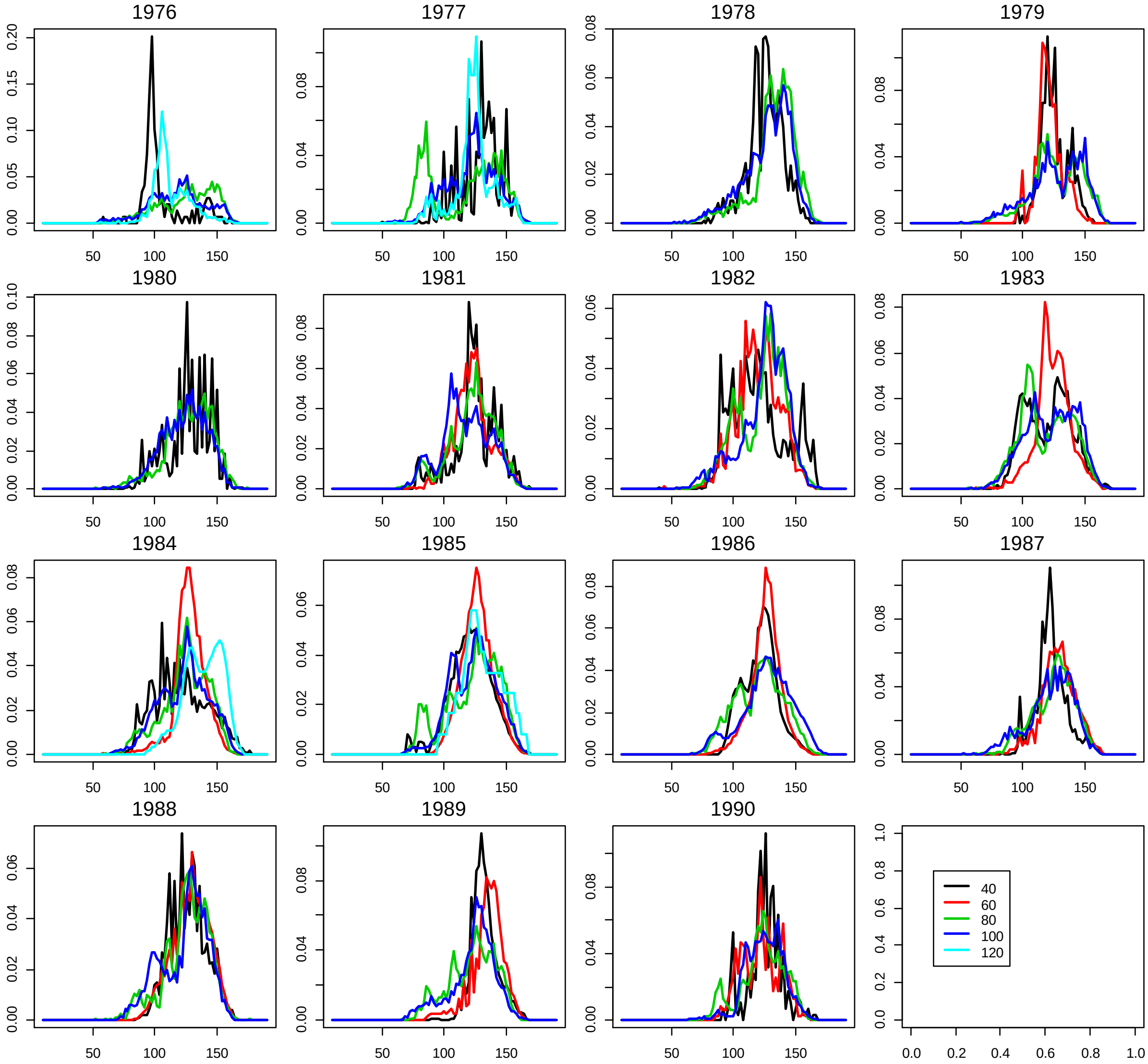
Appendix 3. A comparison of the annual length frequency distributions of the yellowfin catch sampled from the longline fisheries from the equatorial region of the Indian Ocean by 20 degree longitude cells (20*10 deg cells).

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