Indian Ocean Skipjack Tuna Stock Assessment 1950-2013 (Stock Synthesis)

PREPARED BY: IOTC SECRETARIAT[1], 31 OCTOBER, 7, 14 NOVEMBER, 2 DECEMBER 2014

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Summary

NOTE that the revised grid results are in Appendix 3 that was adopted by the WPTT as advice for skipjack for the IOTC. All results in this paper are based on the grid prior to that, and using a different PS series for fitting in these models.

A stock assessment of the Indian Ocean skipjack tuna (*Katsuwonas pelamis*, SKJ) population from 1950 to 2013 has been conducted and is presented. The analysis follows the first two assessments developed by Kolody *et. al.,* 2011 and Sharma *et. al.* 2012. In this assessment spatial structure was not considered due to limited time constraints. In future years the focus should be on a 2/3 area assessment with some finer fisheries resolutions as was done in 2012. The primary fleets that were used for CPUE indicators were the Maldivian Pole and Line fleet (IOTC-2014-WPTT-1), and the European Fad based PS CPUE that was presented in 2013 (IOTC-2013-WPTT-23).

Core assumptions in all models included:

- Spatial one area model, age-structured population, iterated on a quarterly time-step 1950-2013.
- Four fisheries (catch in mass extracted without error):
  - PL – Maldivian Pole and Line (baitboat) fleet
  - PSLS - FAD/log associated Purse Seine (PS) sets from the EU/Seychelles fleets
  - PSFS – Free School (unassociated) Purse Seine sets from the EU/Seychelles fleets
  - Other - includes PS from other nations and all other fleets (primarily gillnet fleets from Sri Lanka, Iran, Pakistan and Indonesia).
- Relative abundance indices:
  - Pole and Line fishery standardized CPUE (2004-2012)
  - Standardized CPUE from the FAD PSLS fishery on juveniles was tested (1983-2010).
- Beverton-Holt stock-recruit dynamics, with fixed steepness and spawning biomass proportional to the total mass of mature fish. Models were compared with deterministic and stochastic recruitment (annual deviates 2004-2010 with estimated variance, and quarterly deviates from 2004-10).
- One von Bertalanffy length-at-age relationship was reported (though the ability to check multiple growth curves has been analyzed in this and previous assessments as well):
  - L_{inf} = 70cm, k=0.37, L(age 0) fixed at 20cm.
  - *Richards curve to model the Paige Eveson growth curve. Parameter estimates for the Richards curve were* L_{inf} = 70cm, k=0.34, L(age 0) fixed at 5 cm, and Richards parameter, 2.96, the age at which inflexion occurs on the skipjack.
- Maturity was invariant over time with 50% mature at length 38 cm (~1.75 y).
- Non-parametric (cubic spline) length-based selectivity was estimated for each fleet independently (with sufficient flexibility to describe logistic, dome-shaped or polymodal functions).
- Two approaches were used for including the tagging data, though only the RTTP-IO and small scale Maldives tagging are reported in the final results:

  - Small-scale tagging programmes from the Maldives and RTTP (~100 000 combined releases) were used to estimate spatial complexity (movement) of the Skipjack stock in the Indian Ocean. An alternative with only RTTP-IO (~ 78000 tagged skipjack) ignoring the small-scale tags was examined though not presented in the final report.
- Objective function terms included:
  - likelihoods for:
    - PL CPUE and nominal PSLS CPUE in some cases.
    - Catch-at-Length from all fleets (with assumed sample sizes generally much lower than observed),
    - tag recoveries from the EU/Seychelles fleets, and Maldives PL fleet.
  - Priors on all estimated parameters.

Results are presented for the single area models and compared to a simple Peterson Mark-recapture derived estimate for the Pole and Line fishery and the Purse Seine fisheries for 2006-2009.

In addition, sensitivity to different assumptions namely steepness, natural mortality and the use of CPUE series was examined, including two sensitivity runs for CPUE, one using only the Maldivian CPUE series and the second using both the Maldivian and EU PSLS series and recruitment deviates estimated for an earlier period, back to 1985. These assumptions were also examined through different weighting schemes for the likelihood; i) equal weight to all components of the likelihood between the CPUE series, length composition and tagging data, ii) lower weight to the length composition and tagging data as compared the CPUE data, iii) no weight on tag data, but using the length comp data with equal weight to the CPUE data, and iv) no weight to the length composition data, but equal weight on the tagging data and CPUE data. Based on our current understanding of the productivity parameters, and the lack of a long-term time series on abundances, the model is highly sensitive to the use of different series and how we weigh the pole and line CPUE series versus the PSLS series, and the use of the length composition data and the tagging data. For the base case assessment we used the tag based natural mortality estimates, the Richards growth parameters, the Maldivian PL CPUE series only and equal weight on the tag and the length composition data.

Key reference points and Kobe plots examining the stock trajectory over time are presented for the one area model based on steepness values of 0.9 and tag based estimates of M (the model is only fitted to the PL CPUE series as this is the cleanest dataset available for SKJ). Based on our current understanding the following are the current stock status reference points for the one area model (80% CI):

  - SB_{2013}/SB_{MSY} = 1.06 (1.02 – 1.10)
  - F_{2013}/ F_{MSY}= 0.77 (0.74-0.80)
  - MSY 529 (495-562) thousand t (C_{2013}= 425 thousand t)

Examining all the structural uncertainty in the parameters (M, h, CPUE series, and data weights produce a much larger range of uncertainty):

- SB_{2013}/SB_{MSY} = 1.06 (0.72-1.97)
- F_{2013}/ F_{MSY}= 0.77 (0.12-1.70)
- MSY 529 (377-1129) thousand t (C_{2013}= 425 thousand t)

2. Base run model outputs with comparisons to the entire grid are shown in Figure 1. Note that a certain set of the model runs resulted on a very pessimistic outlook for the stock with values in the red quadrant. These were models in which the tagging data and the CPUE data received equal weighting and the Length composition data received no weight (as defined above, weighting scheme iv). Using equal weighting for CPUE and tag data, led to two possible scenarios: i) either model fits to the tagging data are reliable and the stock is in an overfished condition, or ii) model fits to the tagging data are unreliable and the F's computed through the model don't make sense. On the contrary, models based on equal weighting of all data, either using the PSLS from 1985 or not, rendered more plausible results, as shown in Figures 2 and 3 below.

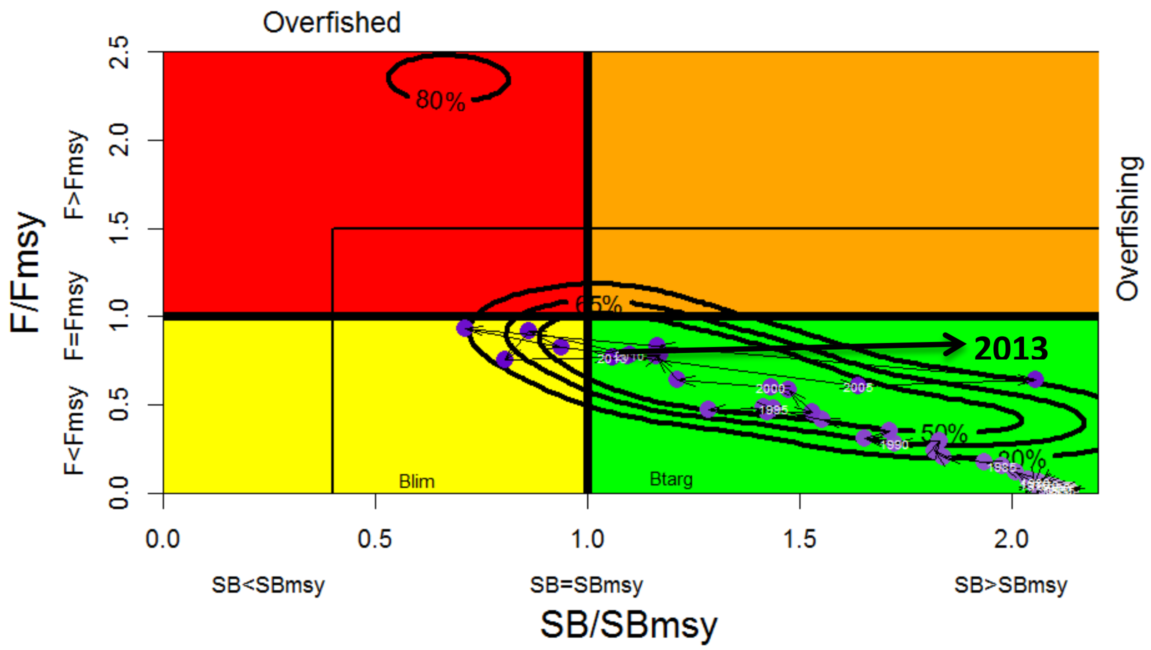

Figure 1: Structural Uncertainty grid in comparison with the base case model runs

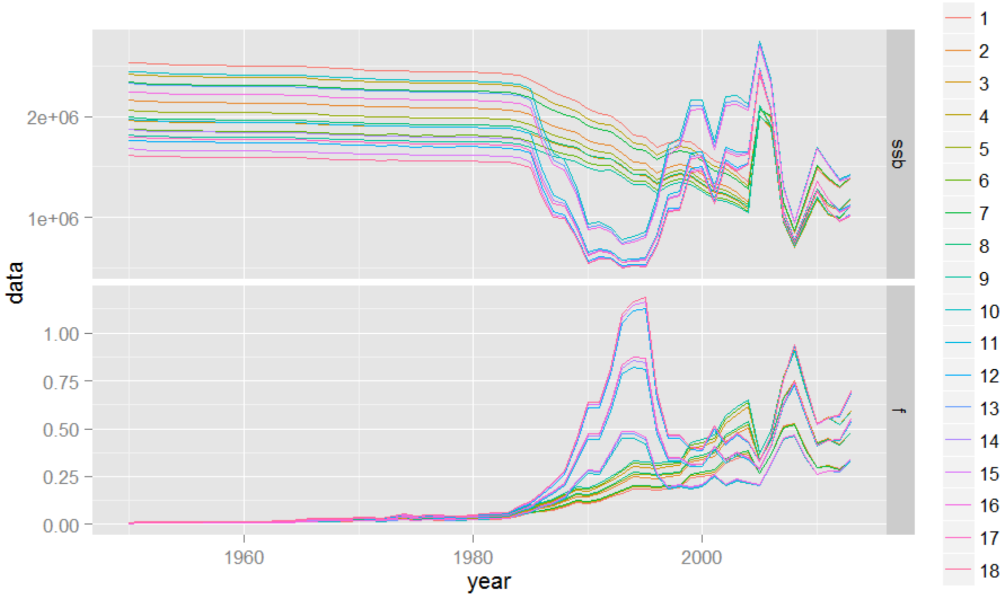

Figure 2: Skipjack trajectories based on most plausible sets of models using the Richards growth curve, sensitivity on M and steepness and equal weight on all data used (uncertainty in figure 3 below).

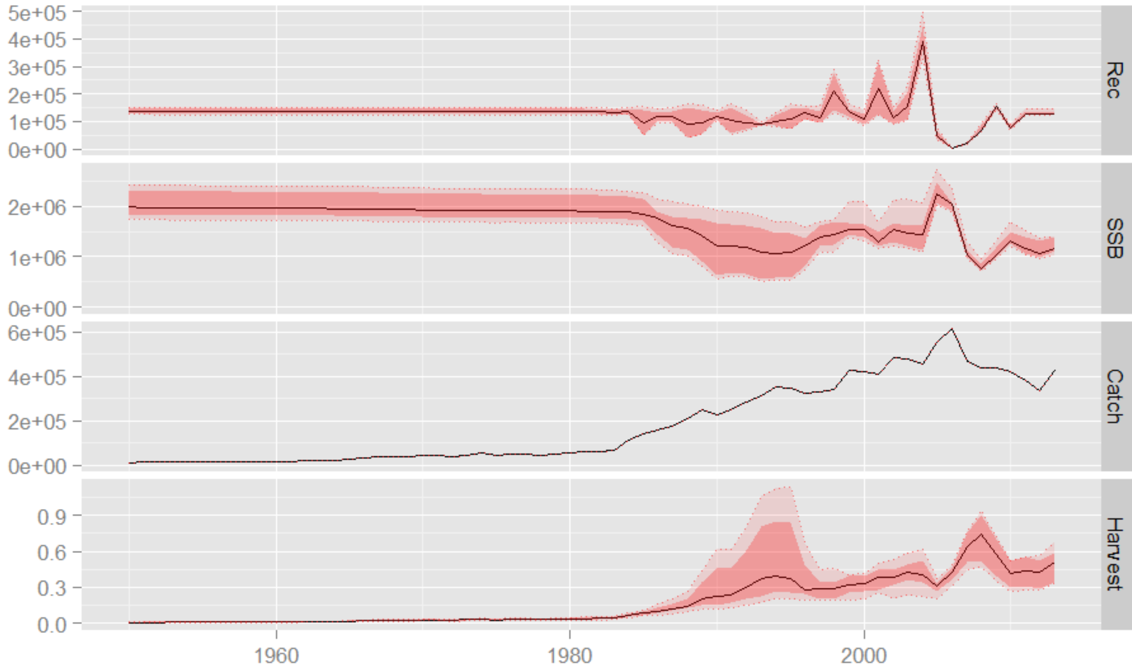

Figure 3: Uncertainty with median trajectories for the most plausible set of runs

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Introduction

The Indian Ocean skipjack tuna (*Katsuwonus pelamis*, SKJ) fishery is one of the largest tuna fisheries in the world, with total catches of 400-600 thousand t over the past decade (Figure 1). Some bioeconomic modelling of the fish population and fishery was undertaken a few years ago (Mohamed 2007), and this is the third attempt of presenting an integrated assessment to the Indian Ocean Tuna Commission (IOTC). The previous two were undertaken by Kolody et. al. (2011) and Sharma et. al. (2012).

The other tropical tuna RFMOs have conducted model-based assessments for SKJ (Maunder and Harley 2003, ICCAT 2009, Hoyle et al. 2011, Rice et. al. 2014). However, this is recognized as a difficult species to assess (e.g. because the population dynamics are very rapid, spawning may be continuous, the selectivity is generally uninformative about year-class strength, and relative abundance indices derived from pole and line and purse seine fisheries are generally considered to be less reliable than those derived from longline fisheries). These problems have led the Inter American Tropical Tuna Commission (IATTC) to move away from model-based assessments to provide advice on the basis of data-based indicators (Maunder, 2009).

A key feature of the work in 2012 was the illustration of using a single or multi-area assessment provides different inferences about stock status (Sharma et. al. 2012). In addition as indicated in last year's work (Kolody *et al.* 2011), the model estimates are extremely sensitive to assumptions about parameters estimated, prior choice and likelihood weightings. The assessment presented here took a similar approach as Kolody et. al. (2011) took to the assessment, presenting a large grid of structural uncertainty to the different sources of data used in the assessment, estimating recruitment deviates with the PS series back to the mid 1980's, and also running sensitivities to the values of M used in the assessment along with changes in steepness parameters used in the assessment. The implications of many alternative assumptions on growth, and their interactions, and the stock status advice is presented for the most plausible hypothesis (base case) with uncertainty as exhibited through the estimation process.

Fishery History

The Indian Ocean SKJ catch history is shown in Figure 1.

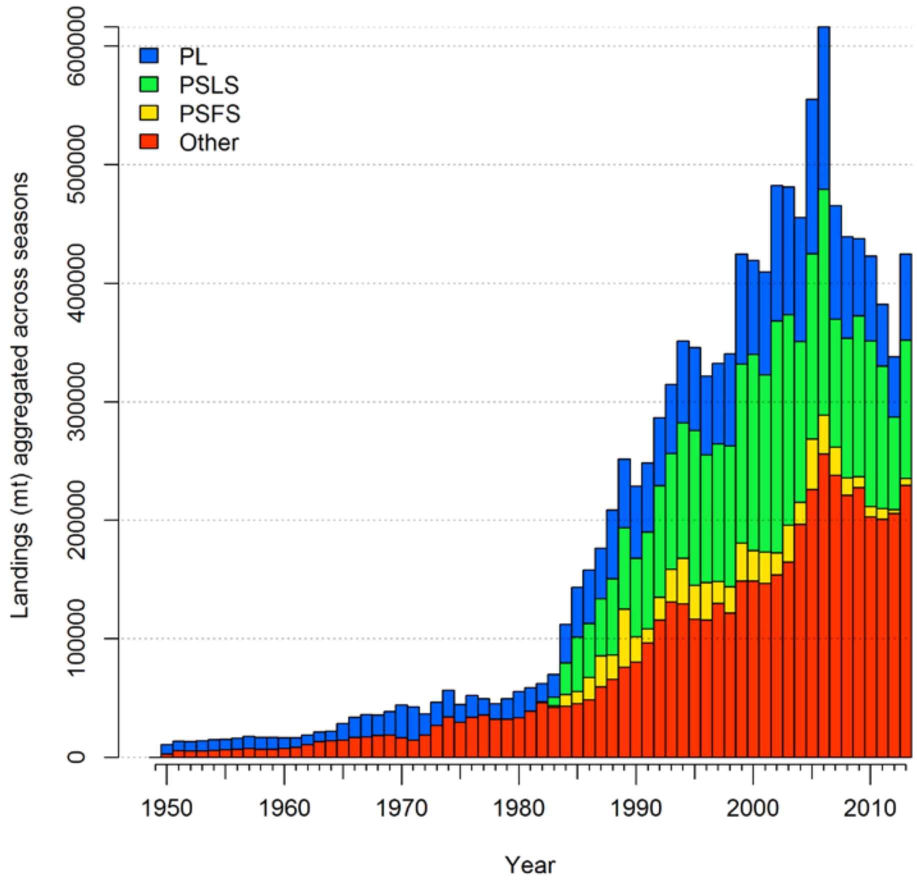

Figure 1. Aggregate Indian Ocean SKJ catch in mass over time disaggregated by the fleets defined for the assessment.

Catches increased steadily from the 1980s to a peak in 2006, and catches in 2007-12 have been declining steadily, with a slight increase in 2013 (425K t). Figure 2 illustrates the spatial distribution of the catches (the locations are not very accurate for most of the coastal fleets).

The Maldives has sustained a pole and line (PL, bait boat) SKJ fishery for many centuries, with catches increasing dramatically due to mechanization and deployment of larger vessels starting in the 1970s, and installation of anchored FADs in the 1980s. The Maldives has experienced substantial catch declines since the peak in 2006, for reasons that are not entirely clear. Adam (2010) suggests that this may reflect declining SKJ abundance, limitations to bait availability or changing economic incentives (e.g. high fuel prices). In addition, in recent years some bait boats have moved from mono-specific targeting of skipjack tuna using pole-and-lines to a mixed targeting of skipjack tuna, using pole-and-line gear, and yellowfin tuna using handlines (Adam 2010).

The catches of skipjack tuna increased markecly following the arrival of purse seine fleets in the Indian Ocean in the early-1980s (e.g. Pianet et al. 2011). Purse seine catches for the EU and the Seychelles have fluctuated considerably since the year 2000, not showing a clear trend.

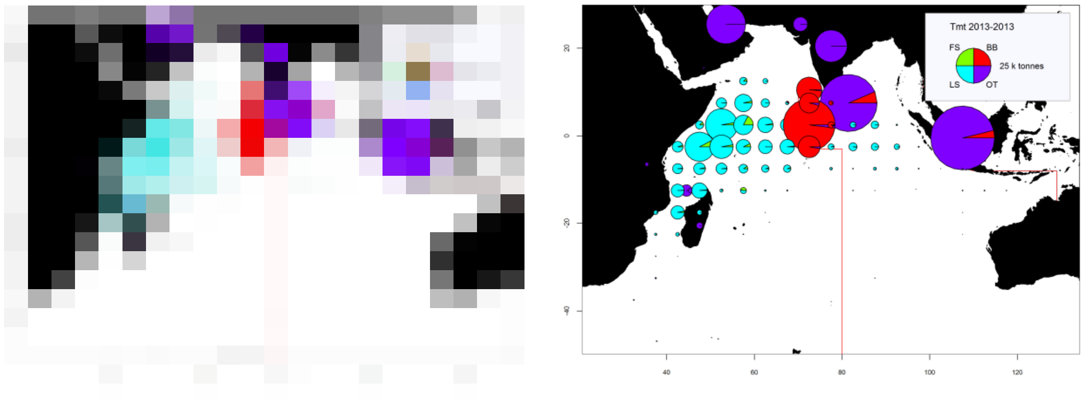

Figure 2: Indian Ocean SKJ catch distribution in 2012-13. Note that the spatial distribution is not accurate for most of the *other* (OT) fleets (catches are represented over the flag countries concerned, in particular adagascar, Comoros, Iran, Pakistan, India, Sri Lanka, and Indonesia).

around 2000 without a clear trend.

Between 2008 and 2011 piracy in the prime fishing areas, off Somalia, affected the way in which purse seiners operated, leading to a drop in the levels of purse seine effort in the Indian Ocean. However, in recent years effort levels seem to be recovering. There has been a steep decline in the nominal purse seine FAD-set catch rates since 2002, however, this decline is not seen in the free school sets from the same fleet, and the interannual catch rate variability is very high (Dorizo et al. 2008). From 2003-06 the decline was due to very good fishing of large YFT on free-schools. After 2007 Piracy or other ‘unknown’ reasons maybe the cause of the decline. Fishing for free-schools does not normally happen in waters off Somalia. This may be the reason why catch rates for PS FS are not affected but they are for LS (Figure 3).

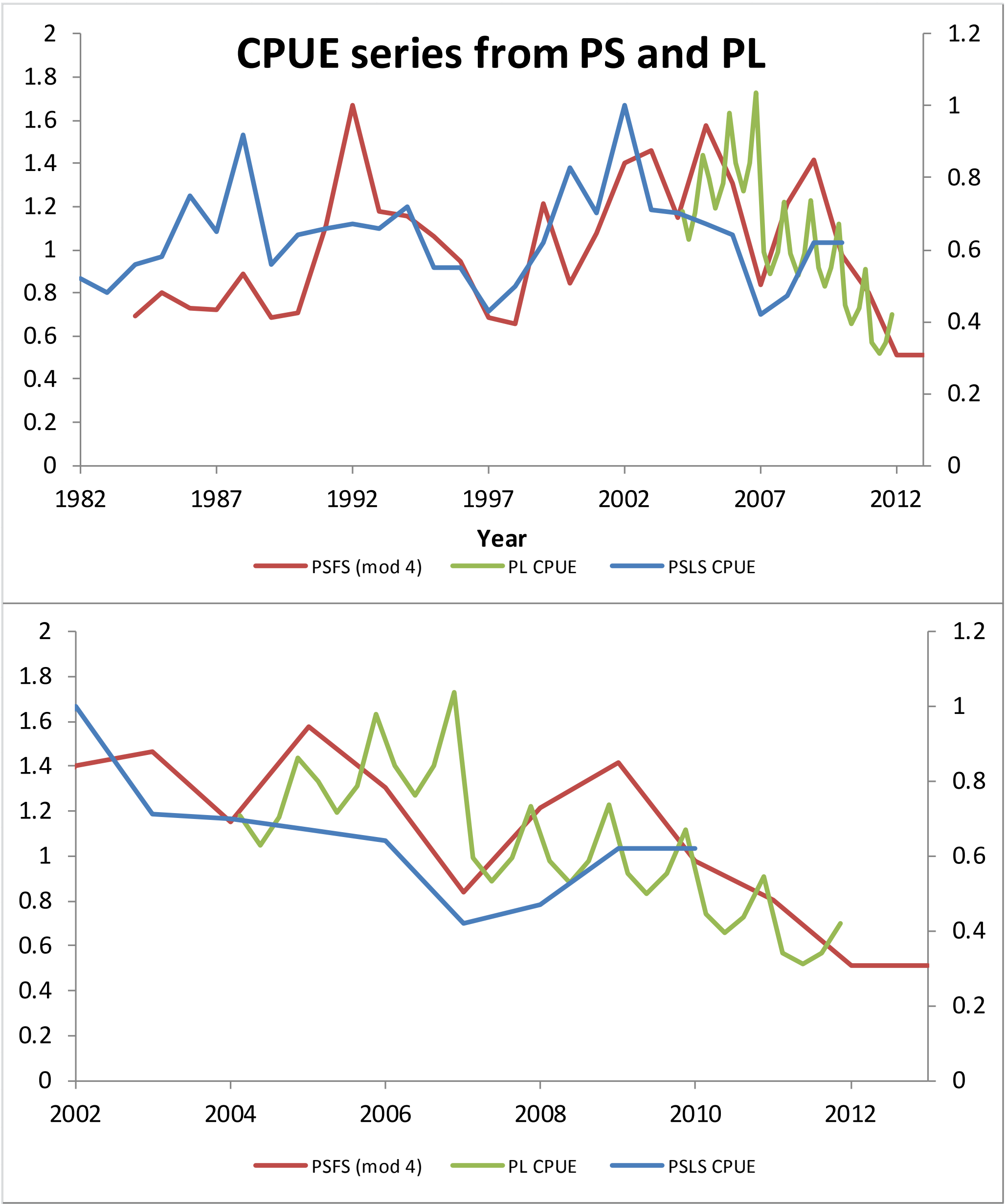

Figure 3: CPUE series used in current assessment (PSLS and Maldivian PL, compared to PSFS datasets). Note the graph below shows the same information above on a different time scale (2002-2013).

A substantial portion of the total catch is taken by a mix of artisanal and semi-industrial gears, with minor catches dating back before the pre-industrial period. For the assessment, these fleets have been pooled together, in the heterogeneous *Other* fleet (Figure 1). The bulk of the recent catch in this fishery is from the gillnet fisheries of Sri Lanka, Indonesia, Iran and Pakistan. These fleets were mostly operating in coastal waters historically, but long distance trips to international waters have been noted in recent years (spatial data is largely unavailable for these fleets). The aggregate catches of these fleets has been increasing steadily (with a minor decrease from 2006 to 2010, but increasing again in 2013, Figure 1).

Methods

Software

The model was implemented with the 32 bit MS Windows version of Stock Synthesis V3.24a (SS3). Technical details are (mostly) described in Methot (2000, 2009). This is a powerful and flexible stock assessment package with efficient function minimization, implemented with AD Model Builder (http://admb-project.org/). For the models explored here, function minimization generally required ~6 minutes on a 3.0 GHz PC (not including inverse Hessian calculations).

Data and Model Assumptions

For continuity of the arguments, related data and model assumptions are described together. The SS3 template control file is appended (attachment 1) to resolve incomplete or ambiguous descriptions of the models. Note, that while the model is sensitive to a number of the assumptions shown (Kolody *et al.* 2011), the data used here examines some data weighting issues and possible different growth curves similar to Eveson et. al. (2012) approach. In addition, the models examined here are compared to closed population estimates of Skipjack within the Indian Ocean using simple Mark recapture techniques. In order to deal with the closed area assumption, only tags recovered within the year of tagging and in close proximity to the initial tagging, were used to estimate the vulnerable Biomass, minimizing the effects of Natural mortality and movement to other areas (no mixing period was assumed in this analysis, as we wanted a localized population estimate for the different locations, i.e. Maldives and east, and west of the Maldives).

Spatial Structure

A single area covering the entire Indian Ocean was used in the assessments: The model examined was similar in spatial structure to previous year's analysis (Kolody *et. al.* 2011 & Sharma et. al. 2012). This model examined the entire Indian Ocean area as one unit, with the different fisheries operating in this one area.

Temporal units

Data were disaggregated by quarter (quarter 1 = Jan-Mar), and the model was iterated on quarterly time-steps, to represent the rapid dynamics of this population, over the period 1952-2013 (plus 10 years of projections).

Age Structure

The SKJ population was represented with an annual/four season configuration. SS3 can resolve many population features on a seasonal basis (e.g. recruitment, fishery removals, M_{age}). However, the tags can only be assigned to annual age classes (discussed below).

The age structure in 1950 was assumed to be in unfished equilibrium (ignoring the small artisanal catches that were taken historically).

Sex Structure

The model was sex-aggregated (and reported spawning biomass is the summed mass of all mature fish).

Fishery definitions

Four fleets were defined on the basis of gear type and area of operation (Figure 1):

1. PL – Maldivian Pole and Line fleet.
2. PSLS - FAD/log associated Purse Seine (PS) sets from the EU/Seychelles fleets.
3. PSFS - unassociated PS sets from the EU/Seychelles fleets.
4. Other - includes all other fleets, primarily gillnet fleets from Sri Lanka, Iran, Indonesia and Pakistan, but also non-EU/Seychelles PS fleets, and small coastal fleets (including non-PL fisheries from the Maldives), and a trivial catch from longliners.

The *Other* fleet is a heterogeneous mix of fisheries. However, further partitioning this fleet is not expected to make much difference to the analysis because the size composition data are poor for most of these fleets. None of these fleets are considered to be informative with respect to catch rates or tag recoveries, and we would not expect that the relative year-class strength information derived from the stationary selectivity assumption to be reliable.

Total catch

The total catches were calculated by the Secretariat (Herrera et al., 2014). This is a complicated process that requires a number of approximations and substitutions for fleets with poor data (including those discussed below under size composition data). The catch time series for the 4 fleets is shown in Figure 1. The model uses the standard difference form of the Baranov catch equations to describe the populations dynamics. Catch in mass was used in the model for all fleets, and was assumed to be known essentially without error and extracted precisely to within the numerical tolerance in the iterative solving of the (SS3 'hybrid') catch equations.

CPUE as a relative abundance index and catchability assumptions

Sharma et. al. (2014) describe the standardized Maldives PL CPUE series adopted as the relative abundance index for the period 2004-12 (Figure 3 above). There are a number of concerns about using this CPUE series in this assessment, stemming from the fact the time series is too short, the spatial area may not represent the Indian Ocean, and may not be representative of the overall abundance due to the effort being concentrated on FADs in recent years (Kolody *et. al.* 2011, Sharma et. al. 2013). However, the standardization has tried to account for these factors and is presented in WPTT-16-1.

Possible reasons for these differences may stem from the fact that increased baitboat effort was put on yellowfin tuna through the use of handlines as explained in the previous section. For e.g., the use of handlines and pole-and-lines during the same trip may lead to reduced catch rates of skipjack per trip; as 1 baitboat trip will still be used as a proxy to 1 fishing day, irrespective of the amount of effort used for handlines or pole-and-lines (In the past only PL was used). Also it is likely that some large vessels expend more than one day at sea and therefore 1 Trip is not necessarily 1 fishing day any longer, as it was in the past.

Longer term nominal CPUE abundances from the Pole and Line fleet were also examined (1970-2003). However, the history of the fishery has changed quite dramatically (Adam 2010), and has moved from a non-mechanized fleet (1970's) to an almost 100% mechanized fleet (2000's). Hence even though these fits were examined, they were non-informative and were finally discounted in the final analysis.

Standardization of CPUE indices derived from PS fisheries is problematic, but we expect that such indices would be at least as good as those derived for the PL fishery, because those fleets operate over a broader area, and encompass a broader time period. However, standardizing PS CPUE is difficult and it is unlikely that it represents an index of abundance (lack of information on technological improvements over the years, numbers of FADs used by the fishery, and there is difficulty in separating effort for FADs and free schools which represent two separate fisheries). In some of the models examined, the standardized log school PS series from the EU Fleet was included (Soto et al. 2013) in combination with the PL series. Another series, the PSFS series examined by Marsac et. al. (2014) was also examined in a sensitivity analysis (Figure 3). This was based of the French fleet and examined for the whole Indian Ocean (Marsac pers. Comm., 2014)

The standardized PL, the standardized French PSFS CPUE series, and the PSLS are compared in Figure 3. All series indicate a strong peak around 2005-6, with a decline after that. The PSFS shows a substantial decline and has not increased in 2013, whereas the PL series shows increasing trends in the 4th quarter of 2012. Two sets were examined for the base case with sensitivity.

a) preferred PL CPUE series only (zero catch observations were treated as indicative of targeting other species) estimating recruitment deviates only between 2004 and 2010.
b) U1 = preferred PL CPUE series and PSLS series with recruitment deviates back to 1985.

Quarterly indices were used for the PL CPUE, with an assumed CV of 5% (lognormal observation errors in order to force the model through the CV). Only annual series were available for the PSFS CPUE, and these were (arbitrarily) assigned to quarter 2 only (also assumed CV of 40%). We do not actually believe that the CV of 5% is realistic for the PL fishery. However, in general, we would not have much confidence in stock status inferences from models that fail to fit the core features of the relative abundance series.

Size Composition Data

The catch-at-length data were compiled by the secretariat (Herrera et al., 2012). This process involves a number of approximations and substitutions because some fleets have very poor data, and some fleets do not report data at the appropriate resolution.

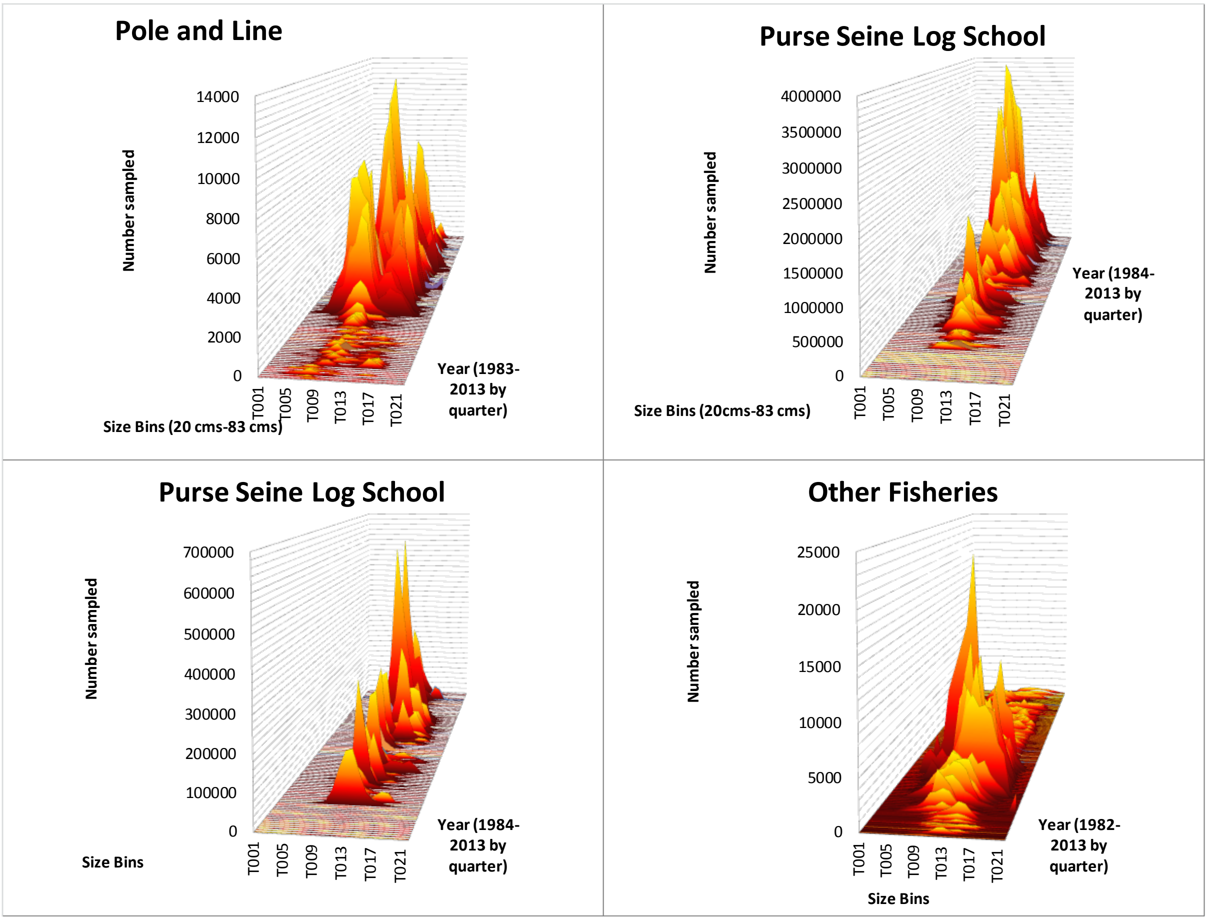

Figure 4: Length composition of catch data over all years by fleet

Catch-at-length distributions aggregated over time (Figure 4) and by season and fleet (Figure 5) are shown.

There is no obvious pattern to indicate strong seasonal recruitment. The bimodal distribution in the PL fishery suggests a heterogeneous mix of two life history stages (or possibly two different fleets being aggregated into one fleet, or fleets fishing in different areas giving the appearance of one fleet with a bimodal structure). Brief exploration did not reveal any obvious spatial/seasonal explanation for the two modes, but this is worth further investigation. The recent decline in mean size in the *Other* fleet probably reflects the erratic sampling from this fleet. In the future it might be worth further partitioning these fleets to reflect likely differences in selectivity to the extent possible (but this is expected to be a low priority for the assessment overall).

Catch-at-length sample sizes are often very large, however, in these sorts of models, it is generally a bad idea to allow the size composition data to be weighted too highly. The size composition data influence these models in two main ways: i) ensuring that the correct age distribution is removed from the population by the fishery, and ii) providing information about relative year class strength through the stationary selectivity assumption.

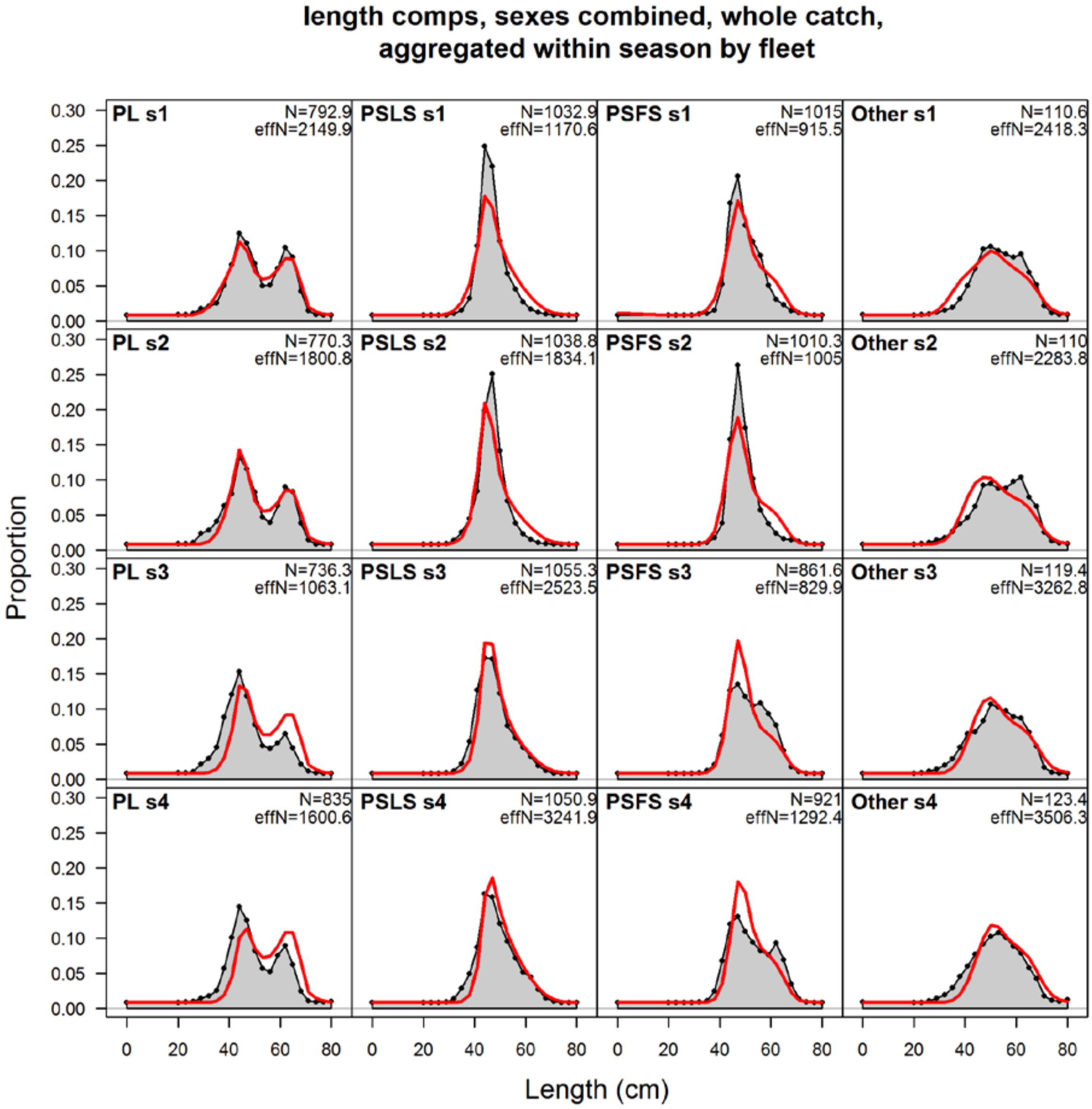

Figure 5: Length composition overall years by season and fleet.

In this assessment, all length composition samples were down-weighted to a considerable degree, and a range of options were explored to test if the model was sensitive to these assumptions. The *Other* fleet was further down weighted, because it represents a heterogenous mix of fisheries, many of which are poorly and/or inconsistently sampled. We used a choice of weighting the data based on the following: CL1: $N_{PL,PS\ input}$ = min(N_{obs} /10, 1000) and $N_{OTHER\ input}$= min(N_{obs} /10, 100). Using the lambda multiplier a down weighting of all size data by 50% was examined, i.e. the ESS becomes either 500 or 50. Other examinations either used the length composition data with the CPUE data, but without any tagging data, and the alternative examination where the length samples were discounted but not the tagging data.

The catch-at-size distributions are aggregated in 22 bins of length 3 cm (≤20 to >80 cm). The multinomial likelihood was used in the model, with an additional 1% added to each length bin (predicted and observed) to make the term more robust to outliers.

Selectivity

A non-parametric, pseudo-length-based function was estimated independently for the selectivity of the 4 fleets. Selectivity parameters were estimated for a series of length-class nodes, with cubic spline interpolation between nodes (the default specification was adopted in which the node spacing and initial parameter values were calculated within SS3). The length-based concept is applied in the calculation of the predicted catch-at-length distribution. However, the length-based selectivity is converted to an age-based selectivity for purposes of removing the appropriate portion of the population in the catch (i.e. cumulative effects of length-based selectivity on the length-at-age distribution are not described in the model). The function is flexible enough to represent dome-shaped, monotonically increasing (e.g. logistic), and polymodal functions (and was motivated by the clear bimodal distribution of the PL fleet). Seven nodes were estimated for the PL fleet, and 5 nodes for the PSLS, PSFS and Other fleets. Stationary selectivity was used in the final analysis due to problems in convergence in time-varying selectivity as a number of parameters were hitting the boundary conditions for the time varying component.

Size-at-Age

Two relationships for mean length-at-age were examined (Figure 6) though only one is presented in the results, representing updates of previous analyses, but using the most recent tagging data. The two curves followed the standard von Bertalanffy growth function, with Length (a=0) fixed at 20cm. If the absolute age is wrong because of error in the Length (a=0) assumption, this would manifest itself primarily as an incorrect lag between the timing of spawning and recruitment. Since the stock recruitment relationship is highly uncertain, and the lag error is likely to be short for this species, this is expected to have a negligible impact on the assessment (furthermore, in the current configuration, SS3 only calculates spawning biomass once annually, even with quarterly recruitment). The two growth curve options were:

- L70 – L_{inf} = 70cm, k = 0.37 (A. Anganuzzi and J. Million, IOTC Secretariat, pers. comm., update of Hillary et al. 2008)
- Richards curve: L_{inf} = 70cm, k=0.34, L(age 0) fixed at 5 cm, and Richards parameter, 2.96, the age at which inflexion occurs on the skipjack. Note this curve estimates the two stanza curve of Eveson (2014) shown in Figure 6 below.
- L83 – L_{inf} = 83cm, k = 0.22 (Eveson 2011, update of Eveson and Million 2008, not used in this assessmen).

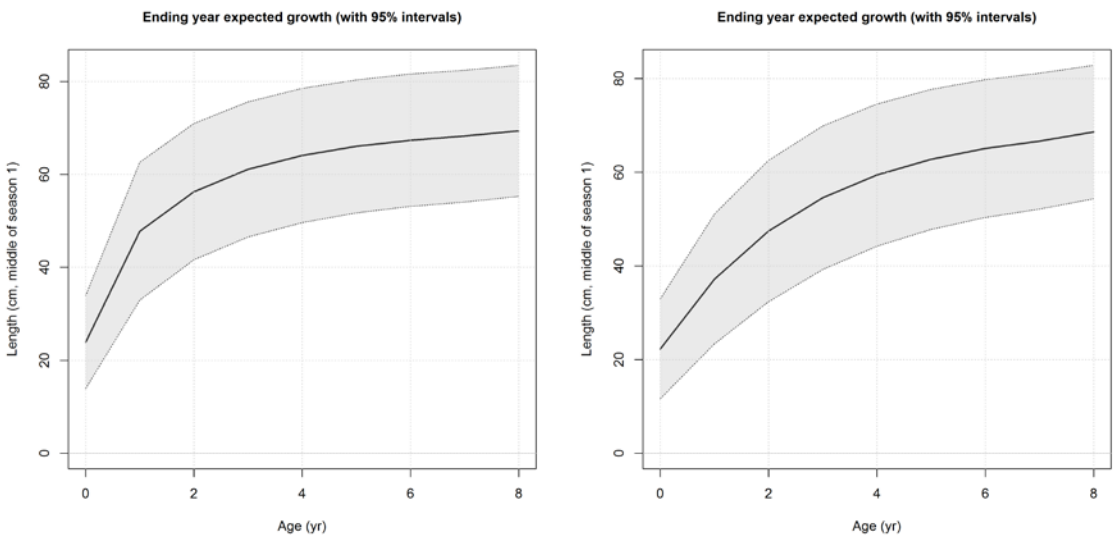

Figure 6: Richards curve approximating the 2 stanza curve of Eveson et. al. (2012) on the left panel as compared to the traditional VB Curve (linf=70 cms, right panel).

We chose both the VB and the Richards option to model growth in the analysis, and present results of the Richards model in the base case.

The L70 curve was estimated with unconstrained L_{inf}. The mass-length relationship is adopted from Secretariat (2005): *mass* = 5.32E-6 $Length^{3.35}$.

Maturity

Maturity estimates from Grande et al. (2010) were adopted: invariant over time, with 50% maturity at length 38 cm. This is very similar to the 40 cm value reported in the WCPFC assessment (Hoyle et al. 2011), and the knife-edge age 2.0 y assumption adopted for the Atlantic (ICCAT 2009).

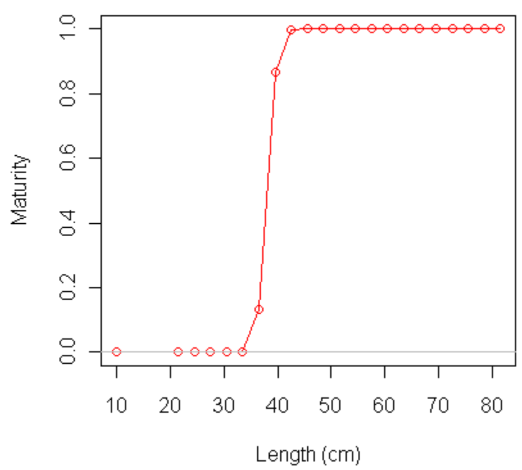

Figure 7. Assumed SKJ maturity-at-length (proportion).

Stock Recruitment

A Beverton-Holt stock recruit relationship was assumed (the SS3 'flat-top' version in which R_t does not increase beyond R_0 if SB_t happens to exceed SB_0). It was assumed that spawning biomass is equal to the mass of the mature population. In recognition of the difficulty in estimating steepness (h), different fixed values were examined as in Kolody *et. al.* 2011. Values of 0.7, 0.8 and 0.9 were examined for skipjack which is a highly resilient fecund species that spawns multiple times over a year. The value of 0.9 was used in the base case assessment.

Deviations from the stock-recruitment relationship were assumed to follow a lognormal distribution, with constant recruitment until we have more informative data on age structure, i.e. annual deviates from 1985-2010 ($\sigma_{R,\ annual}=0.6$), with some flexibility in quarterly deviates from 2004-2010 ($\sigma_{R,season} < \sigma_{R,\ annual}=0.6$) if we used the PS series. If we didn't use the PS series we estimated recruitment deviates from 2004-2010, as the PL series was shorter and there was therefore less information on the earlier recruitment deviations.

The period 2004-2008 was given extra recruitment flexibility because of the informative tag data during this period. The lognormal bias correction ($-0.5\sigma^2$) for the mean of the stock recruit relationship was applied during the period 1985-2010. Deviates were not applied in 2011 and 2012 primarily due to non-informative CPUE data (no PL CPUE available after 2012), and too much weight being given to the length composition data estimating very high recruitment. For 2011 and 2012, constant recruitment assumption was used.

Tags

Tag Release and Recovery Data

Hallier and Million (2009) provide an overview of the RTTP-IO tagging project (~78000 SKJ releases). In 2012, additional tagging data (~22000 SKJ releases) from several small-scale projects were merged with the RTTP-IO database. The largest number of small-scale SKJ releases were in the Maldives (Jauharee and Adam 2009), but SKJ were also released near Lakshadweep, Mayotte, Sumatra, offshore eastern Indian Ocean, and the Andaman Islands. Figure 8 describes key features of the two tagging data sets explored in the assessment in terms of locations and recoveries. Figure 8 and Figure 9 provide graphical summaries of tag releases, recoveries, time at liberty and net displacements.

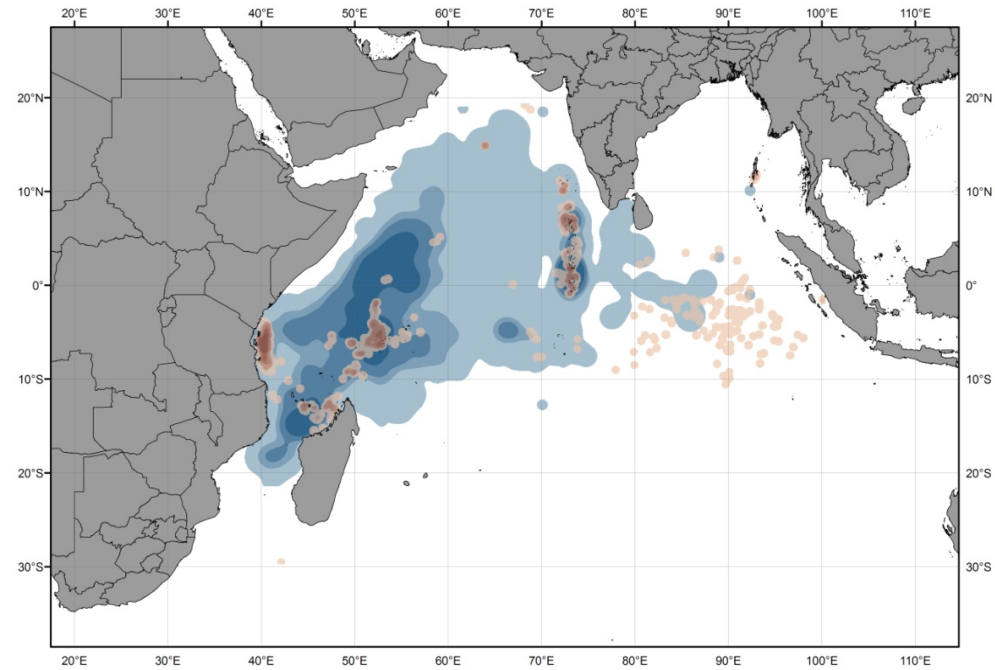

Figure 8. Summary of SKJ tag releases (red) and recoveries (blue) from the RTTP-IO and small-scale programmes 2003-2010.

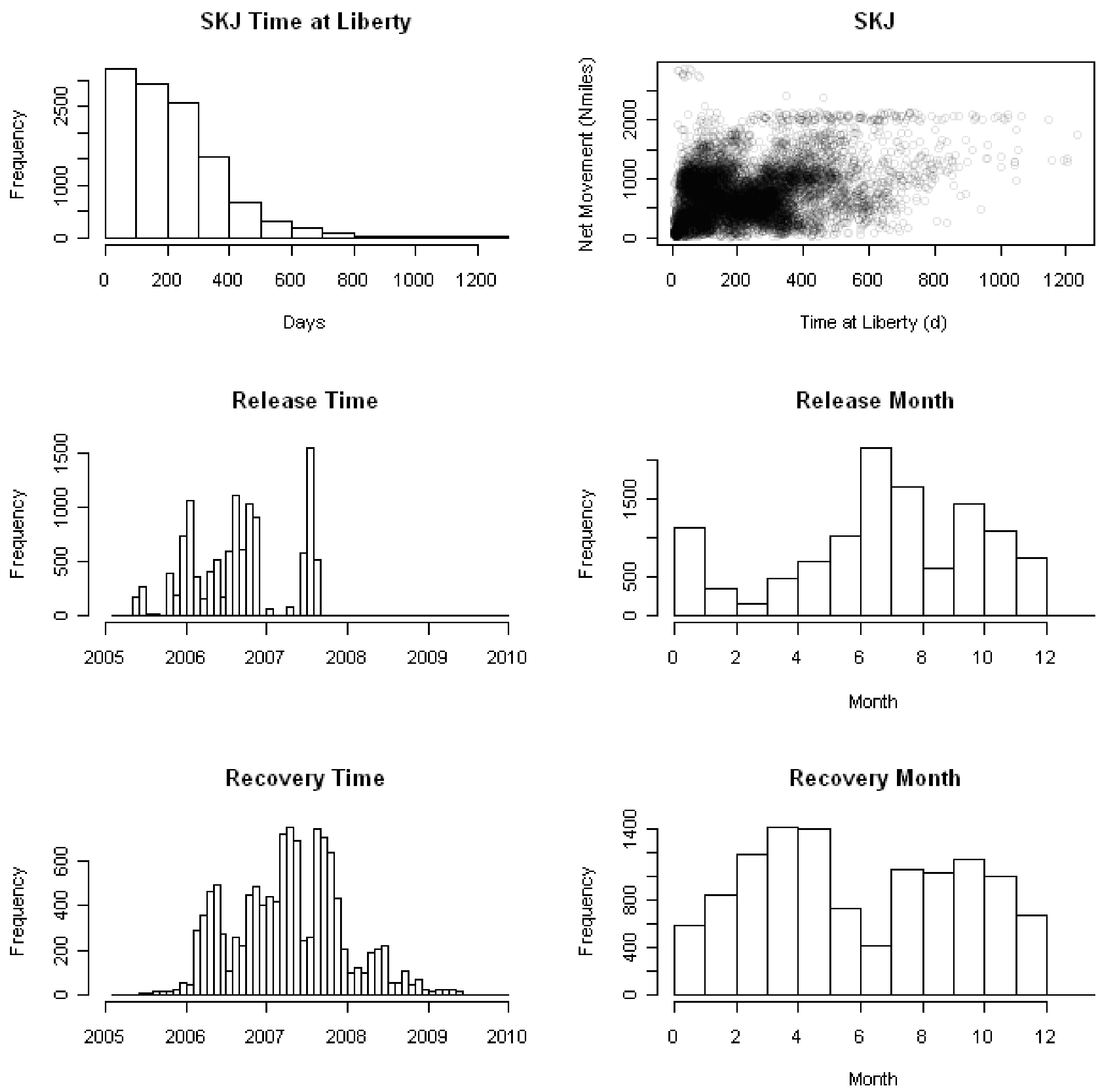

Figure 9. Summary of RTTP-IO SKJ tag release and recovery information 2005-2009.

We have more confidence in the RTTP-IO data than in the data from the small-scale tagging projects, because the RTTP-IO released a much larger number of tagged fish, used more experienced taggers under more consistent conditions, and a database that has been gradually developed over time by the IOTC Secretariat. In contrast, the small-scale tagging programs were only recently merged with the RTTP-IO database (such that there may be undiscovered errors), we have no tag shedding estimates for these fleets (very few fish were double-tagged, and no analysis has been conducted to date), and tag-induced mortality may be higher for some small-scale programmes (e.g. particularly for the smallest fish, and purse seine releases in the eastern Indian Ocean). However, there are possible benefits to the inclusion of the small-scale tagging programmes due to i) substantially more tags, ii) longer release time series, and iii) inclusion of a broader range of fish sizes/agesWe have the most confidence in the tag recovery data from the PSLS and PSFS fleets, because of the reporting rate estimates derived from the tag seeding experiments (e.g. Hillary et al. 2008; updated by A.

Anganuzzi, IOTC Secretariat, pers. comm.). Quarterly point estimates of the reporting rates were included as shown in Table 1.

Table 1. Raw tag seeding data for the EU/Seychelles PS vessels unloading in the Seychelles, and the reporting rate (point estimates) adopted in the assessment (Alejandro Anganuzzi, IOTC, pers. comm.).

Year	Quarter	SKJ Tags Seeded	SKJ Seeds Recovered	Reporting Rate in the assessment
2004	1	1	-	0.485
2004	2	1	-	0.595
2004	3	11	5	0.488
2004	4	2	1	0.664
2005	1	36	23	0.595
2005	2	21	19	0.696
2005	3	72	37	0.597
2005	4	47	25	0.754
2006	1	-	-	0.918
2006	2	36	36	0.946
2006	3	69	60	0.918
2006	4	204	191	0.959
2007	1	99	91	0.972
2007	2	77	73	0.982
2007	3	188	173	0.972
2007	4	151	139	0.986
2008	1	30	30	0.945
2008	2	22	16	0.964
2008	3	78	74	0.946
2008	4	52	45	0.973
2009	1	29	25	0.970
2009	2	-	-	0.980
2009	3	-	-	0.970
2009	4	-	-	0.985

We do not have reporting rate estimates from the PL fleet. However, as appreciable numbers were returned, it is thought that recoveries from this fleet might still be informative. In model runs that included the PL recoveries, a stationary reporting rate for the PL fleet was estimated (with a very diffuse prior). In addition based on work done by Caruthers *et. al.* 2012, a low reporting rate of 23% was estimated and used in the assessment, though in final results we let the model estimate this value only for the PL fleet (the PS were kept fixed at 100%, and there were no recoveries from the other fleet used in the analysis). In general we have a poorer understanding of the operations of the *Other* fleets, and there are no reporting rate estimates. These recoveries were excluded from the analyses, and reporting rates set to 0.

Several irregularities in the tagging data were addressed in the following ad hoc ways:

- A small number of SKJ releases were omitted from the analysis because of:
    - no recorded release length,
    - no recovery fleet,
    - no release or recovery date (or recovery precedes release)
- A small number of releases recaptured by the tagging vessels were ignored.
- The EU PS tag recoveries of unknown set-type were assigned a set-type according to the total proportion of known FS and LS set types in the PSFS and PSLS fisheries (by quarter).
- The coastal fleets on the east coast of Africa, *i.e.* in Kenya and Zanzibar, have presumably intercepted some tags near the primary release location, before they were fully mixed with the broader population. This represents an unknown, but probably small number of tags.

Tag Recovery pre-processing for Stock Synthesis

The model tracks multiple homogenous tag groups over time, where a tag group consists of all individuals of a particular age class released in a particular year/quarter. For the 2-3 fleets which were considered informative, each tag recovery observation for a particular tag release group and recovery period was calculated:

$$R_{LS}^{Total} = \frac{1}{r^{sea}} \left(R_{LS}^{sea} + \hat{P}_{LS}^{sea} R_{unk}^{sea}\right) + \frac{1}{\hat{P}_{outside}} \left(\frac{1}{r^{SEZ}} \left(R_{LS}^{SEZ} + \hat{P}_{LS}^{SEZ} R_{unk}^{SEZ}\right)\right) \quad (1)$$

$$R_{FS}^{Total} = \frac{1}{r^{sea}} \left(R_{FS}^{sea} + (1 - \hat{P}_{LS}^{sea}) R_{unk}^{sea}\right) + \frac{1}{\hat{P}_{outside}} \left(\frac{1}{r^{SEZ}} \left(R_{FS}^{SEZ} + (1 - \hat{P}_{LS}^{SEZ}) R_{unk}^{SEZ}\right)\right) \quad (2)$$

$$R_{PL}^{Total} = R_{PL}^{MLD} \quad (3)$$

where:

subscripts indicate fishery/landing types (LS = EU/Seychelles PS log set, FS = EU/Seychelles PS free school set, unk=unknown set-type, PL = Maldivian Pole and Line, outside = EU/Seychelles catch landed outside of the Seychelles),

superscripts indicate recovery locations (sea = aboard fishing vessel, SEZ = port of Seychelles, MLD = Maldives).

For readability, scripts denoting tag release group and recovery time period are omitted:

R^{Total} = number of 'observed' recaptures for a particular fishery (and tag group and time period), as input to the model.

r = the reporting rate. Note that for PS tags removed at sea, r was assumed to be 1.0. Reporting rates from the Seychelles are listed in Table 1. Within the model, PS reporting rates were set to 1.0, while PL reporting rates were estimated as a free parameter (and ignored in the pre-processing).

$\hat{P}_{LS}$ is the proportion of PS tags recovered from unknown set-type which are actually of set-type LS, estimated as the proportion of tags of known set-type LS recoveries at sea of all known set-type recoveries at sea (by quarter).

$\hat{P}_{outside}$ is the scaling factor to account for the EU PS recaptures not landed in the Seychelles, estimated by the mean of the proportion of EU PS catch landed in the Seychelles relative to the total EU PS catch (by quarter).

These calculations provide a point estimate for the total number of tag recoveries that should have been made in the PS fisheries, such that the reporting rates can be set to 100% in the model. In part, this represents a work-around solution because *Stock Synthesis* cannot represent temporal variability in reporting rates. This ignores potential variance implications, but given that the reporting rates were generally very high for the PSFS and PSLS fleets, this is probably not important. The alternative work-around solution of defining a different fleet for each recovery time period could be employed, but this extra complication does not seem justified in this case.

Tag Mixing

In the population model, tagged fish are assumed to have identical dynamics to the general population. We expect that a reasonable period of mixing is required before this assumption would be valid. Figure 8 suggests that maximum tag displacements within the core PS area reach a plateau within a few weeks of release. If this displacement was entirely due to random movement, it might suggest that 1 full quarter would be sufficient to achieve full mixing. However, the figure does not account for the distribution of fishing effort (i.e. if all the gear is deployed a long way from the release site, all recoveries will suggest rapid movement, but they might not represent the movement of the general population). Also, directed seasonal migration can cause large displacements, without necessarily resulting in uniform mixing. We assumed a mixing period of 2 quarters based on Kolody *et al.* 2011. Analysis performed by Langley (Adam Langley personal communication, suggests that 2 quarters are sufficient for spatial mixing, though in some cases there maybe clustering occurring). Due to time constraints in running the assessment in 2014, we used the same dataset that was calculated in 2012.

Tag Age Assignment

The length of release of each tag is recorded in the database, but the model dynamics require tags to be assigned ages. The age of each individual tag was estimated from the mean growth curve, and a unique tag group was defined for each age/year/quarter release strata. The age estimation occurs external to the model (in a process similar to 'cohort-slicing' that is sometimes used to infer catch-at-age from catch-at-length data). Note that this annual resolution of tag age assignments might introduce substantial aggregation errors for this species (i.e. tags of age 1.0 and 1.75 are assigned identical biological characteristics, but in reality may be very different). It might be desirable to assign tags to quarterly age classes; however, this was not done in the first instance (Kolody *et. al.* 2011) though an attempt was made to define quarters as years that did not converge, and was abandoned in 2012 (Sharma et. al. 2012). Due to time constraints in running the assessment in 2014, we used the same dataset that was calculated in 2012.

Tag-induced Mortality and Shedding

Following Gaertner and Hallier (2009), we assumed that the chronic tag shedding was very low (0.015 y^{-1}). The initial tag shedding was omitted, but represents a trivial number of tags (i.e. initial retention estimated as 0.987).

Tag recovery likelihood

The negative binomial distribution allows for overdispersion relative to the ideal, independent movement, fully-mixed, tag recovery distribution (*e.g.* which might be expected to conform to the Poisson distribution). However, note that increasing the overdispersion to a very large number is not the same as down-weighting the tag recovery likelihood term. Three options were explored for the overdispersion parameter τ (applied equally across all tag groups) in Kolody *et. al.* 2011, and we used τ = 2 (close to ideal Poisson tag recovery assumptions) across the different model runs.

Natural Mortality

Given the reliance of this assessment on the tagging data, and the general success of the RTTP-IO, we considered the estimation of M to be worth attempting. M_{age} was described by a series of annual nodes (with linear interpolation for quarterly ages between nodes). Parameters consisted of a normal prior (SD=1) with mode 0.8 for the first age, and deviations from the preceding age for subsequent ages (prior log(dev) mean = 0, SD=1). We used both the small-scale data and RTTP data in our analysis, where age 0-4 NM rates were estimated (i.e. 0 was included due to the presence of substantial numbers of smaller fish that were tagged in the small scale programs).

Models with the M_a estimates from the independent Brownie tag analysis (Eveson et. al. 2014) and recent ICCAT assessments (ICCAT 2009) were also included (see Figure 10 below):

- M equal to the ICCAT value (0.8 all ages) alternative M values of 0.7 and 0.9 were examined in the grid.
- Preliminary estimates for natural mortality by age were obtained from Eveson et. al. (2012, personal communication).
- For a sensitivity analysis, WCPFC values were also examined (J. Rice Personal communication).

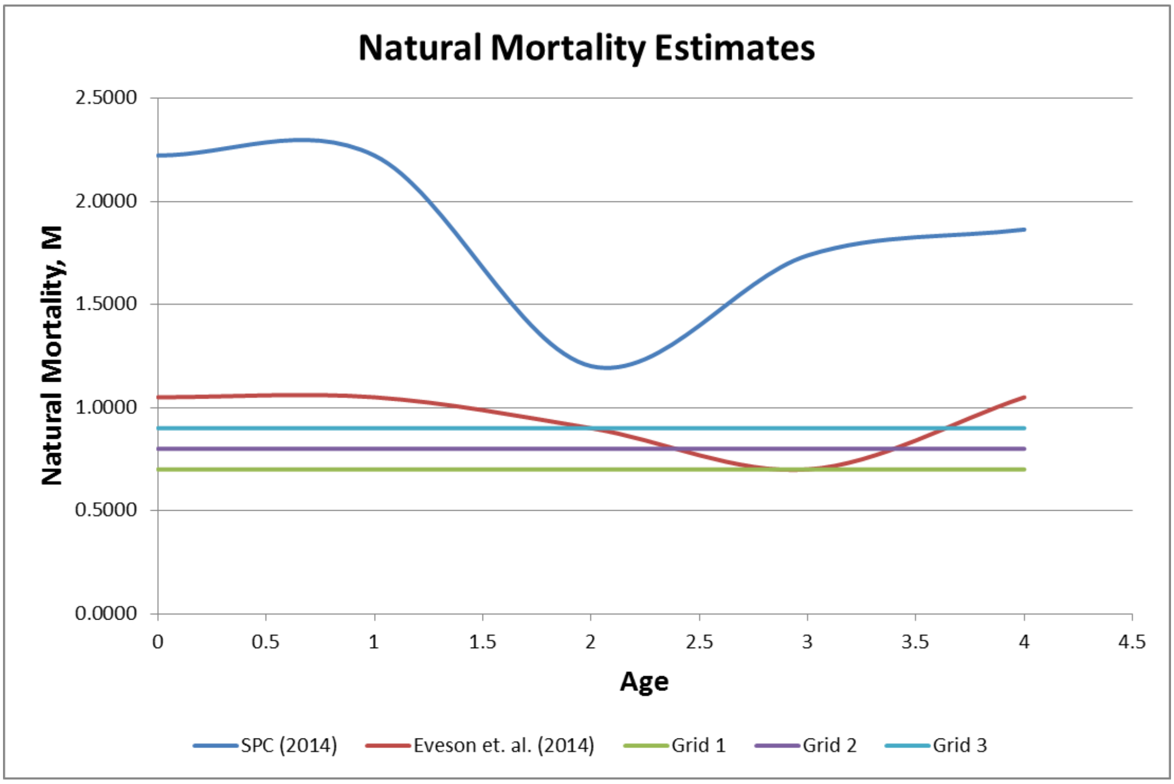

Figure 10: Natural Mortality rates that were examined in the base case, sensitivity and grid runs examined in this assessment

Model Specifications

MSY Calculations

MSY, B_{MSY}, F_{MSY} and equilibrium yield estimates are calculated on the basis of the F_{age} distribution estimated for 2013. The argument might be made that an average over several recent years may be more appropriate in general. However, this may not be true if there are strong trends in the catch distribution among fleets (which seems to be occurring in Indian Ocean tuna fisheries currently).

Seemingly due to the unusual dynamics of this fishery, the SS3 F_{MSY} calculations maybe suspect (see Kolody *et al.* 2011). As a consequence, *MSY* and B_{MSY} values were extracted from the peak of the equilibrium yield curve. . The proxy, C_t/MSY reported in previous assessments, maybe potentially misleading because: i) it may incorrectly suggest F/F_{MSY} is exceeded if biomass is high (in the early part of the fishery or following large recruitment), ii) it may incorrectly suggest that $F<F_{MSY}$ when the stock is highly depleted, and iii) due to flat yield curves, it is possible that $C \approx$ MSY even though $F<<F_{MSY}$.

Uncertainty Quantification

Derived parameter uncertainty was presented using the variance-covariance matrix as estimated in SS3 and also examined through MCMC runs (though not presented in the report). It is noted, however that this uncertainty is generally a lot lower than model selection uncertainty (as shown in Kolody *et. al.* 2011). A sensitivity grid (Table 2 below) was examined

Table 2: Structural Uncertainty examined in Skipjack Assessment in 2014.

Assumption	**Option**
Spatial domain	***io;*** Indian Ocean with one area
Beverton-Holt SR Steepness (h)	h=0.7 h=0.8 **h=0.90 (Base case)**
Growth, and Maturity	*VB;* ***Richards (base case);***
Natural Mortality	*0.7, 0.8 & 0.9* ***(Base case Eveson et. al. 2014, Figure 10)*** *Sensitivity* ***(SPC 2014 from J. Rice)***
CPUE* σ=SD lognormal errors	***PL****;* σ=0.1; (**σ=0.05 to force fit through CPUE, base case**) ***PSLS****;* σ=0.4;
Recruitment σ=SD(log(devs))	**σ=0.6 deviates estimated for PL series 2004-10** (**base case**) σ=0.6 deviates estimated for PL series and PSLS series 1985-2010.
Catch-at-Length (SS=assumed sample)	***CL1000****; SS* = $N_{PL,PS\ input}$ = min(N_{obs} /10, 1000) and $N_{OTHER\ input}$= min(N_{obs} /10, 100), lambda=1, **base case (note when we use these values ESS is corrected by another multiplier of 0.04, making the ESS 40 for PL&PS and 4 for the other fisheries components)** ***CL020****;* lambda=0.5,0.1. This means ESS is effectively 20, and 2 and 4 and 0.4 respectively.
Tag Data	*τ* = 2, implying the negative binomial component close to a Poisson in the likelihood of the tag data, mixing period=2 quarters (**base case)**

A total of (M=3xh=3xPS (recruitment)=2xESS combination=4xGrwoth=2, 144 Models) were examined to estimate effects of structural uncertainty

Projections

Projections were conducted across the grid 144 models(in mass) of 60%, 80%, 100%, 120% and 140% of 2013 levels (assuming relative F_{age} from 2013). The projections used deterministic recruitment from the stock recruitment relationship (starting in 2014, as recruitment deviates were not estimable due to unavailable CPUE data from 2010 or 2011). This approach ignores recruitment variability, but uses structural uncertainty from the parameter estimates based on the grid used. Ten year projection results are summarized in a management decision table (Kobe 2 Strategy Matrix). F_t/F_{MSY} and SB/SB_{MSY} were reported for 2016, and 2023 respectively.

Methods for a closed Population Mark Recapture Model

Simplistic Peterson Mark recapture estimators were used (eq. 4, Chapman 1954, Bailey 1951), assuming very little migrations from the Maldives tagging to other fisheries and vice versa (Table 2 partially justifies this, though we know that in reality that large scale movements are probably being observed across these groups over time). However, assuming most recoveries are occurring after release (at least in Maldives) very few assumptions are probably violated. In addition only tags recovered in the same year from the tagging program are used as we wanted to minimize the effects of natural mortality.

$$\hat{N}_{s,y} = \frac{(n_{c,y}+1)(n_{e,y}+1)}{m_{e,y}+1} - 1 \qquad (4)$$

$$v[\hat{N}_{s,y}] = \frac{\hat{N}_{s,y}(n_{c,y}-m_{e,y})(n_{e,y}-m_{e,y})}{(m_{e,y}+1)(m_{e,y}+2)} \qquad (5)$$

where $\hat{N}_{s,y}$ is the number of adults estimated in the Maldives PL/Purse Seine fishery from year y, $n_{c,y}$ is the number of skipjack tagged from year y, $n_{e,y}$ is the number of skipjack sampled in the catch in subsequent period from year y, and $m_{e,y}$ is the number of tagged skipjack in that sample.

Table 3: Proportion of recoveries by Fishery and location

Tagging Location	Paramters	Pole and Line Maldives	PS-FAD	PS-FS
Maldives Tagging	Mean (μ)	89.6%	5.2%	0.2%
	sd (σ)	24%	13%	0%
Indian Ocean Tagging	Mean (μ)	1.5%	78.3%	20.2%
	sd (σ)	2.1%	11.6%	12.3%

Assumptions of Normality were used to estimate the overall mean and variance for the distribution, and the likelihood function used was a Normal likelihood to exhibit uncertainty in the estimate obtained (eq. 6-8) making assumptions that at large sample sizes the Binomial distribution is well approximated by the Normal distribution.

$$E(m_{e,y}) = \hat{p}n_{e,y} \qquad (6)$$

$$Var(m_{e,y}) = \hat{p}(1-\hat{p})n_{e,y} \qquad (7)$$

where $\hat{p}$ is the estimated proportion of tags in the population, and the likelihood of the estimated population is given by eq.5.

$$L(\hat{N}_{s,y} \mid m_{e,y}, n_{e,y}) = \frac{1}{\sqrt{2\pi Var(m_{e,y})^2}} \exp\left[-\frac{((m_{e,y}) - E(m_{e,y}))^2}{2Var(m_{e,y})}\right] \quad (8)$$

Based on the population estimated, uncertainty in the fishing mortality rate (F) can also be estimated as a function of catch and numbers estimated.

Results and Discussion

Single Area Model- Base Case

Results from the single area model are presented (Figure 10). Biomass trajectories are similar to Kolody *et al.* (2011) and Sharma et. al (2012), and spawning Biomass trajectories (Figure 11) are also similar, though sudden spikes in F's appear to occur in the mid 2000's due to higher effort combined with lower recruitment.

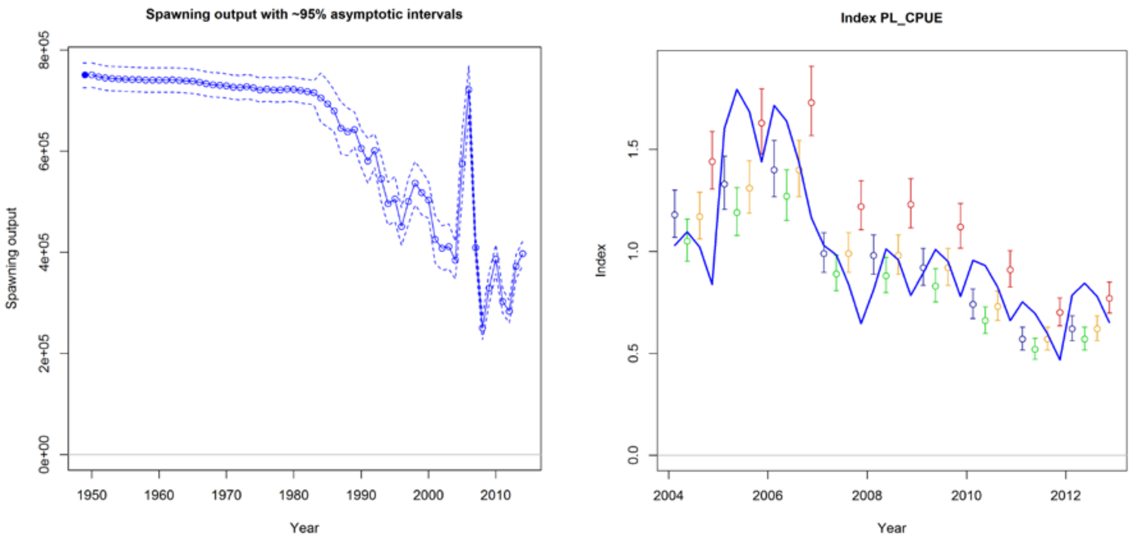

Figure 11: Spawning Biomass Trajectories for IO SKJ (left panel) and fit to the PL CPUE data (right panel)

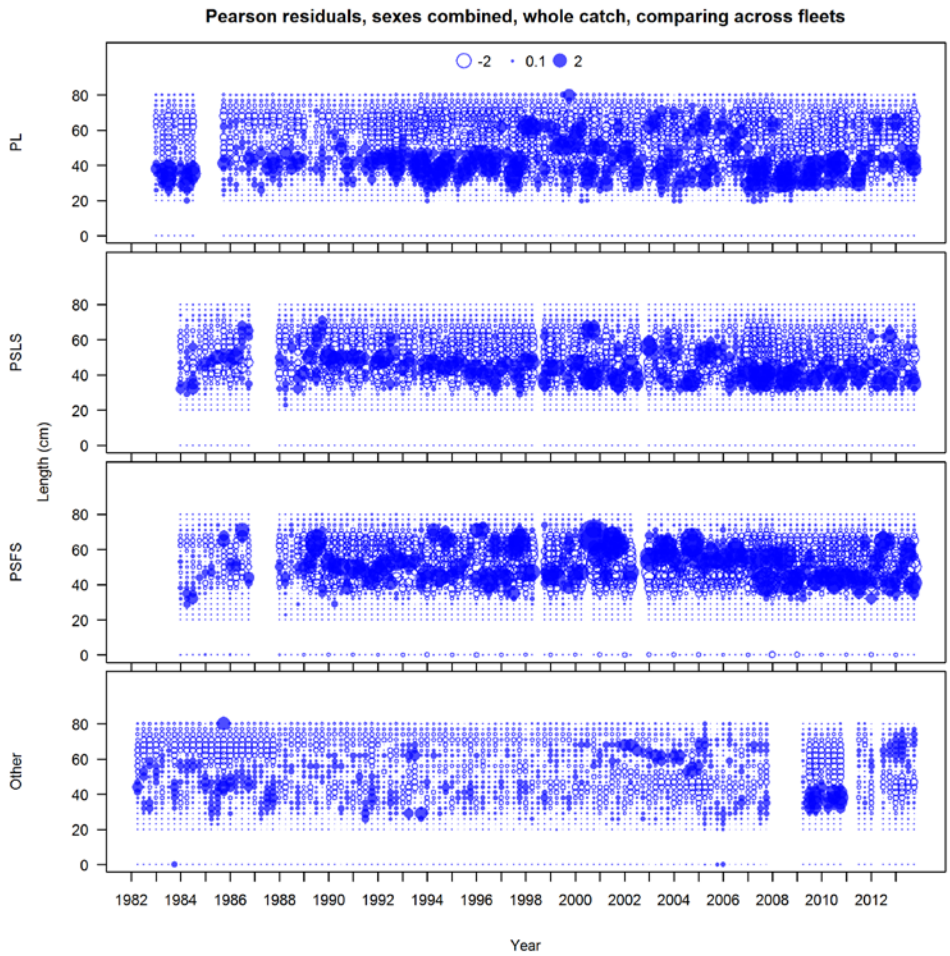

Figure 12: Pearson residuals for PL length composition data by fleets.

While yearly variations in model and the observed length compositions are fairly stable for the PSFS, and other fleets, both the PL and PSLS have departures from the average fits over time (Figure 12). While these departures would indicate a different fishery structure that may not be captured by a single selectivity over time for the respective fleets (PL and PSFS). It would thus be recommended to possibly split these catches into different fisheries in the model in subsequent years. In addition, time varying selectivity for different blocks could be attempted (and was for the PL fleet, see sensitivity) without much success in 2012 (Sharma et. al. 2012). Current selectivity estimates and overall fishing mortality rates are shown in Figure 14.

Catch composition estimates from the model follow the yearly and seasonal fits well for all gear types (Figure 13), though appear to miss the seasonality in the PL fleet for the earlier years (attempts to parse this out into 2 periods don't have significantly different results when done in 2012, see Sharma et. al. 2012). Overall fit to the tagging data are shown in Figure 15 (left panel) with the estimated time at liberty (Figure 15 right panel).

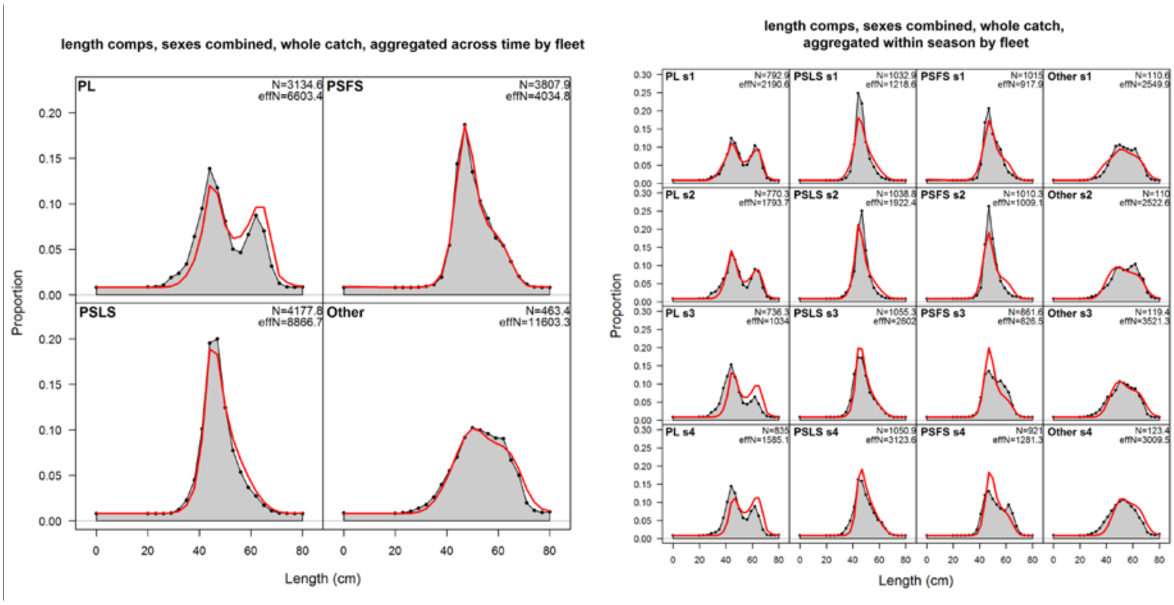

Figure 13: Overall fits to length compositions by fleets (left panel) and by season (right panel).

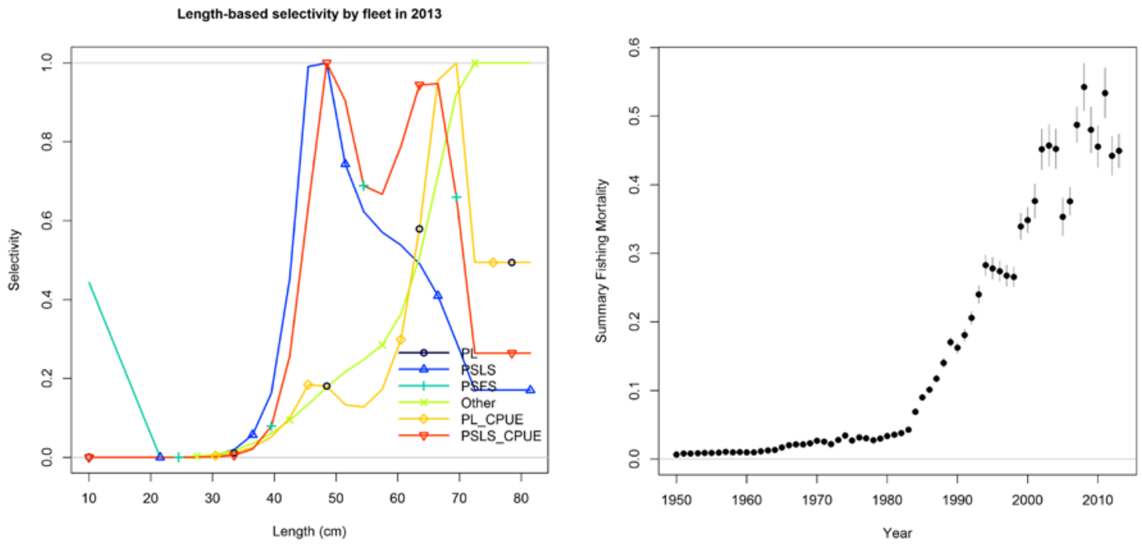

Figure 14: Gear selectivity (left panel) and overall F's estimated for SKJ (right panel).

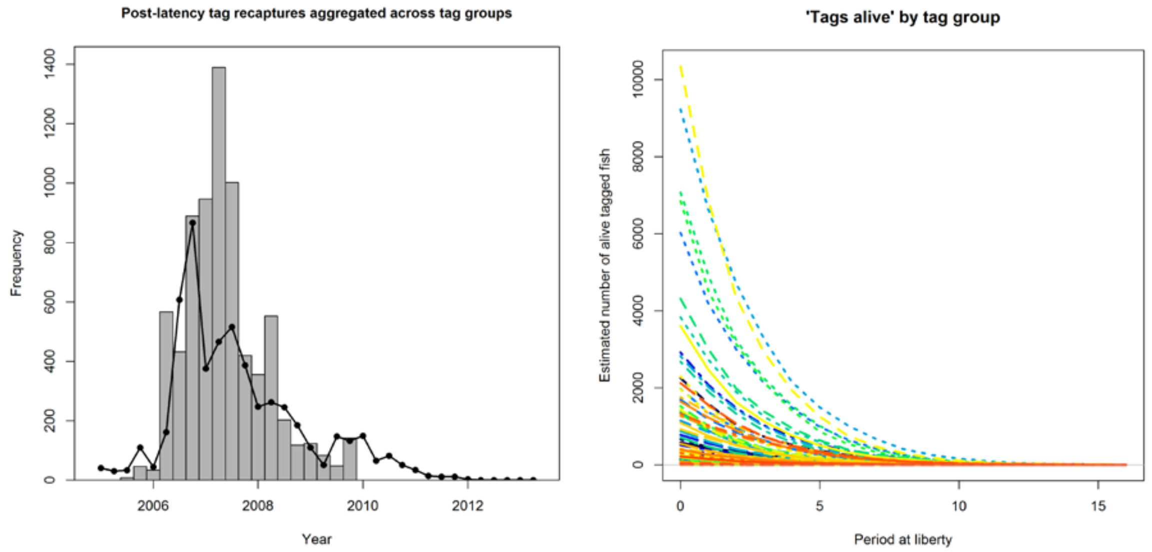

Figure 15: Fit to tag data across all groups (left panel) and period at liberty (right panel)

Closed population Mark Recapture Model

Maldives Pole and Line Population estimates (2004, 2008 and 2009)

An alternative approach was examined to test if the SS3 estimates were realistic enough in terms of the F's estimated by fishery in years in which we have the tagging data. In Maldives, we had tagging data from 2004, 2008 and 2009, and in the western half (Figure 16) we had 2005, 2006, and 2007. 2004 had to be discarded due to the poor number of recoveries observed in the fisheries from tags in 2004. High mortalities may have been observed on the tags in that year as well.

Estimated abundance in Maldives Pole and Line fishery are shown based on tag reporting rates in the Pole and Line fishery that is unknown. Corresponding F's are also estimated in these populations based on these reporting rates.

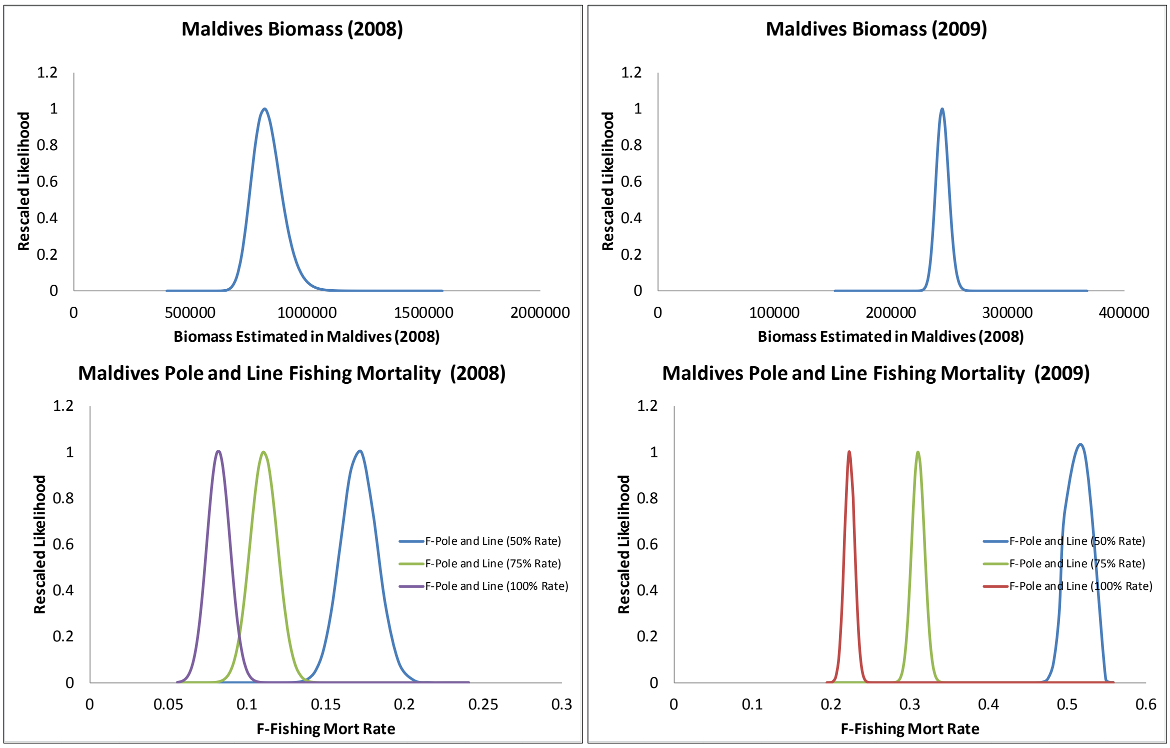

Figure 16: Assuming 75% reporting rates Biomass estimated in Maldives Pole and Line Fishery with Fishing Mortality estimates for different reporting rates in 2005 and 2009.

Indian Ocean PS Population estimates (2005, 2006 and 2007)

A Similar analysis was conducted with tagged data from the other regions by year, and using the PS fisheries as the recovery basis. Estimated population size using this technique by each year is shown below (Table 3). Recovery data was very limited for 2005 (less than 0.5% was recaptured from those release groups in the same year and was therefore not used).

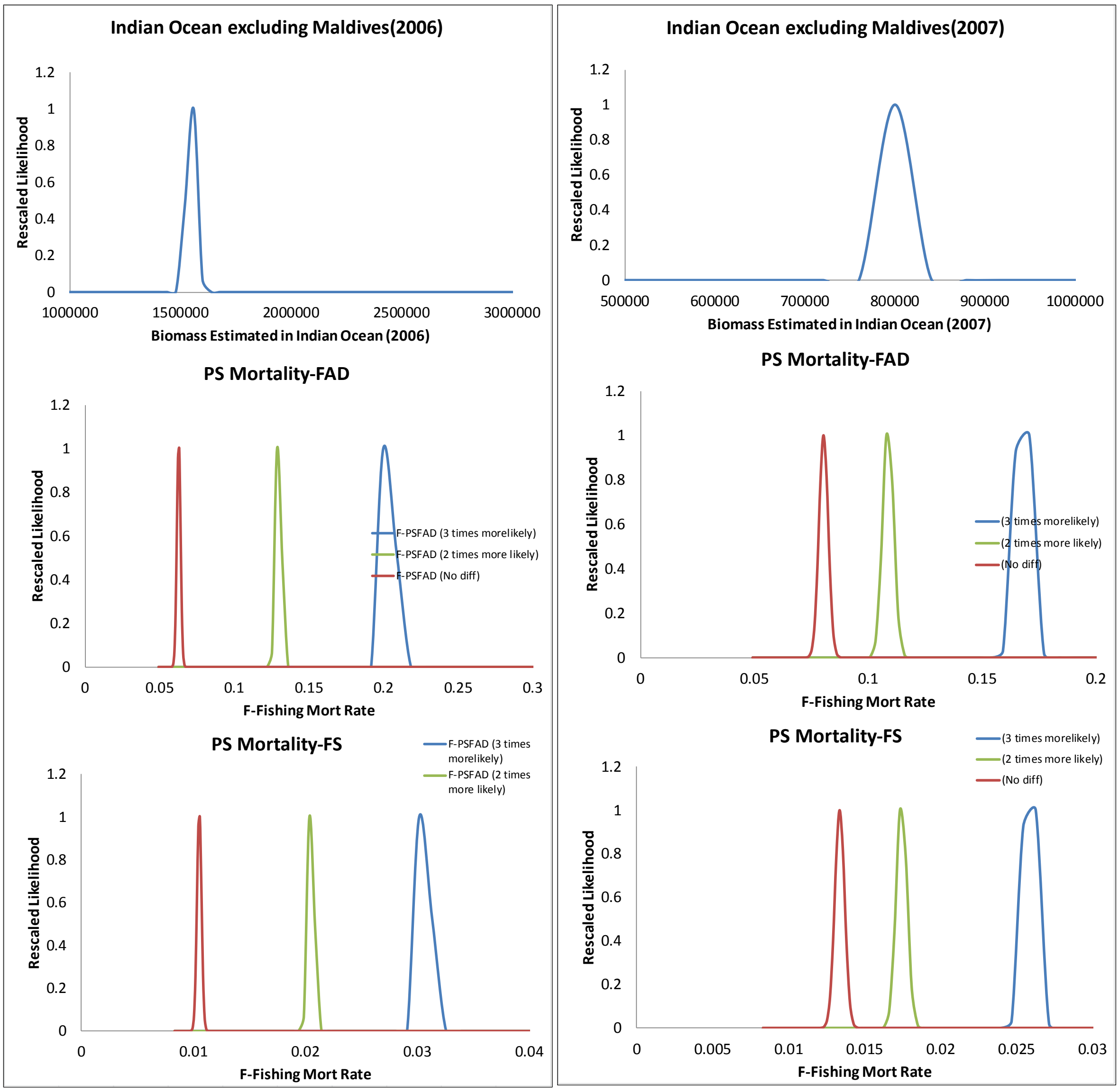

Figure 17: Fishing Mortality and Biomass estimates (assuming FADs aggregation rate account for an ascension rate of 50% (i.e. FADs are 2 times more likely to encounter fish) for the Indian Ocean (excluding Maldives) abundance in 2006 and 2007

Table 4: Biomass and F's in associated fisheries and Areas

Area		2006	2007	2008	2009
Indian Ocean Biomass (M t)	Estimate	1.55	0.80		
	SE	0.31	0.15		
	Estimate			0.82	0.24
Maldives Biomass	SE			0.92	0.07
Fishing Mortality					
Area		2006	2007	2008	2009
	Estimate	0.14	0.16		
Indian Ocean PS F	SE	0.02	0.03		
	Estimate			0.11	0.31
Maldives PL F	SE			0.04	0.07
Integrated Assessments					

SS3 (one area base case) TOTAL F		0.37	0.48	0.53	0.47

The data appear to give an indication that Biomass is declining from both the Free School/FAD associated PS areas from 2006-2007, and similarly form 2008 and 2009 in the Maldives PL areas. Table 2 also presents the estimated F's over all fleets from SS3. F based on fleets is not known but based on relative biomass can be inferred from the catches in the fishery. Results indicate that F's from the model SS3 over all fisheries is higher than those in ether the PL or PS fisheries respectively, which makes the estimates from the tag based study reliable.

Sensitivity Analysis

Effect of Growth

2 models were examined on growth. One using the VB with l_{inf}=70 cms, K=-0.37, and length at age 0 =20cms and another with the Richards curve (Figure 6 above). Results show similar trends between the two models (Figure 18) and trends in fits were also similar (Figure 18 right panel). Key reference points between the base case model using the Richards curve and the VB curve with the same M values are shown in Table 5. In essence the slower growth option shown by the VB curve implies that the overall yield is a lot lower than when we use something like a two stanza growth as seen with the Richards or VB log K curves. Implicitly this also has implications on the spawning biomass (Figure 18) and consequences on the assessment conclusions (Table 5).

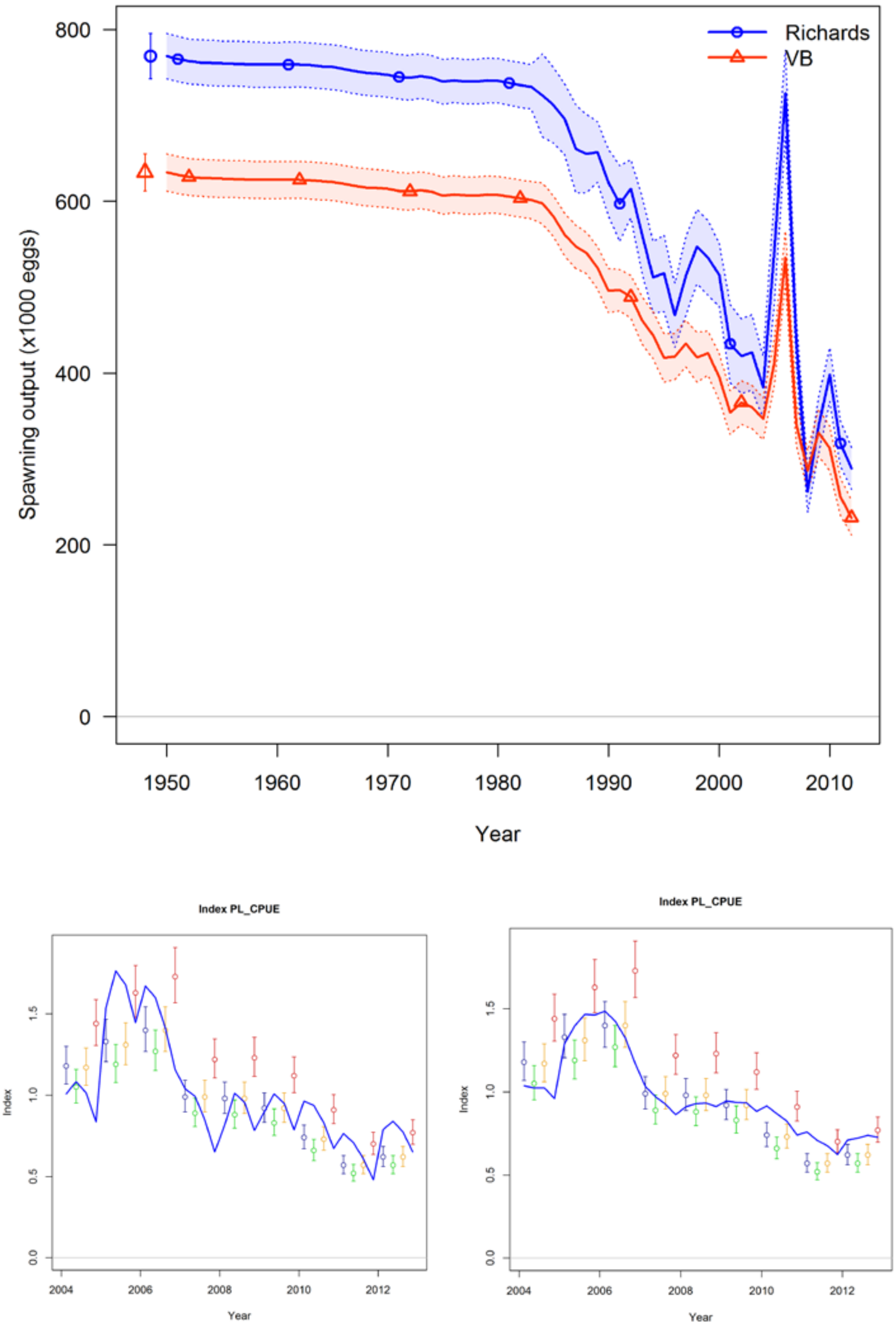

Figure 18: Biomass trends in the two model using a VB and Richards curve (above panel) and the fits to CPUE (bottom left panel Richards & bottom right panel VB)

Table 5: Derived management parameters using 2 growth curves (numbers in brackets are 80%CI).

Management Quantity	Base Case Assessment	VB Alternative Growth
LIKELIHOOD	9351	8757
Most recent catch estimate	424,581 t	424,581 t
Mean catch over last 5 years	401,132 t	401,132 t
MSY (1000t)	529K (495K-562K)t	435.4K (406.2K-464.8K) t
Current Data Period	1950-2013	1950-2013
F(Current)/F(MSY)	0.77 (0.74-0.79)	1.13 (1.05-1.19)
B(Current)/B(MSY)	na	na

SB(Current)/SB(MSY)	1.06 (1.02-1.10)	0.81 (0.75-0.88)
B(Current)/B(0)	na	na
SB(Current)/SB(0)	0.5 (0.48-0.52)	0.45 (0.42-0.48)

Effect of Natural Mortality

We examined different types of M's across all ages and how they interact with steepness and ESS of the other parameters that are used in the stock assessment. However, for illustrative purposes we show how the assessment is affected keeping all other parameters fixed (i.e steepness=0.9 recruitment deviates are only estimated from 2004-2010 using Maldives data, and other parameters in the base case assessment). The two cases examined are a fixed M of 0.8 across all ages and the natural mortality vector used by SPC (personal communication J. Rice). Figure 19 illustrates the dynamics of the SSB trajectories using the different assumptions, and Table 6 shows the key reference parameters that are affected by these assumptions. In essence, the values are almost the same in all cases as afar as both derived reference points and the fits are concerned, but the value of B0 is lowest with the natural mortality vector developed by SPC (as a function of Ro shown, in Figure 19 right panel). The yield target are highest with the SPC natural mortality estimates, implying a very fast turnover on skipjack and a highly resilient population that can take a lot of fishing pressure (Table 6 below).

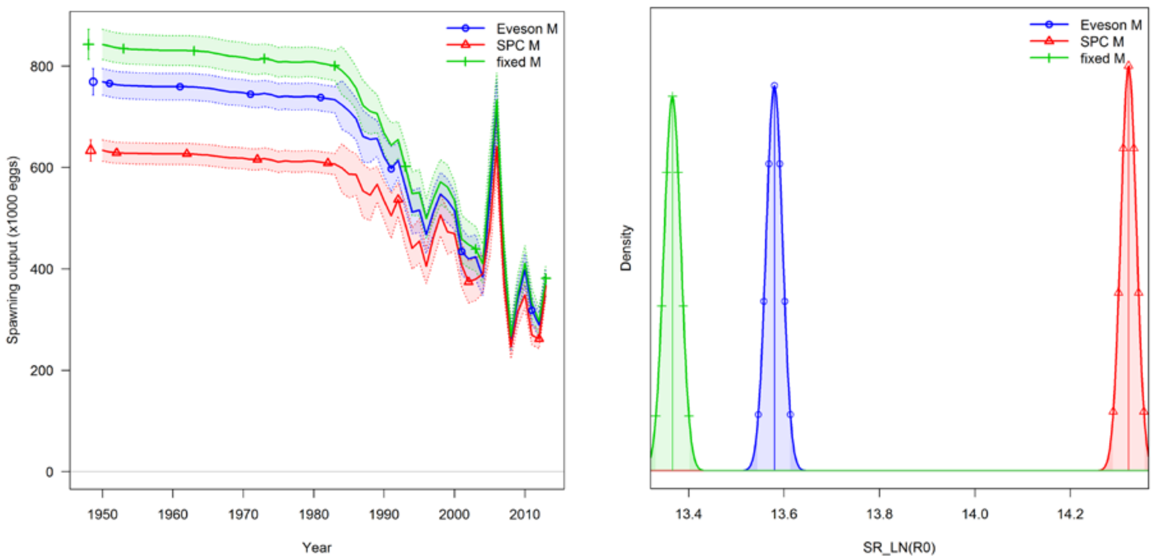

Figure 19: Different estimates of M and how they affect the assessment biomass trajectories (left panel) and R0 values (right panel).

Table 6: Derived management parameters using 3 natural mortality schedules (numbers in brackets are 80%CI).

Management Quantity	Eveson et. al. 2012 M, Richards growth	SPC M, Richards Growth	Fixed M=0.8 and Richards Growth
LIKELIHOOD	9351	9628	9481
Most recent catch estimate	424,581 t	424,581 t	424,581 t
Mean catch over last 5 years	401,132 t	401,132 t	401,132 t
MSY (1000t)	529K (495K-562K)t	586K (553K-619K) t	542.9 (504K-582.7K) t
Current Data Period	1950-2013	1950-2013	1950-2013
F(Current)/F(MSY)	0.77 (0.74-0.79)	0.65 (0.62-0.68)	0.69 (0.64-0.74)

B(Current)/B(MSY)	na	Na	na
SB(Current)/SB(MSY)	1.06 (1.02-1.10)	1.16 (1.09-1.23)	1.17 (1.05-1.28)
B(Current)/B(0)	na	Na	na
SB(Current)/SB(0)	0.5 (0.48-0.52)	0.58 (0.55-0.61)	0.45 (0.42-0.49)

Effect of Steepness

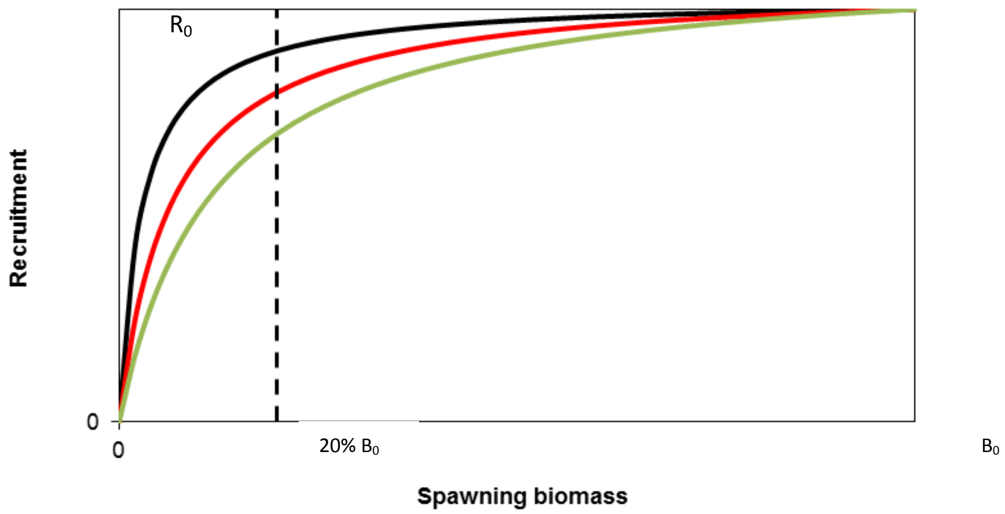

Figure 20: The concept of steepness is shown here where at 20% of Virgin Biomass, what percent of Virgin recruitment occurs (i.e. h=0.7 implies 70% of virgin Recruitment, h=0.8, implies 80% and so forth)

The analysis here looked at the base case assessment which uses a relatively large value of steepness (0.9) and compares it to lower values, namely 0.8 and 0.7 respectively. Results on the dynamics and derived reference points are shown in Figure 21 and Table 5 respectively. In essence the higher steepness values imply a healthier stock status and a larger yield than lower steepness values.

Table 7: The effect of steepness values on derived management parameters

Management Quantity	h=0.9	h=0.8	h=0.7
LIKELIHOOD	9402	9398	9390
Most recent catch estimate	424,581 t	424,581 t	424,581 t
Mean catch over last 5 years	401,132 t	401,132 t	401,132 t
MSY (1000t)	560K (542K-570K)t	547K (524.8K-569.2K)t	526.5K (510.8K-542.3K)t
Current Data Period	1950-2013	1950-2013	1950-2013
F(Current)/F(MSY)	0.66 (0.64-0.69)	0.68(0.63-0.72)	0.7 (0.65-0.75)
B(Current)/B(MSY)	na	Na	na
SB(Current)/SB(MSY)	1.18 (1.13-1.24)	1.19 (1.1-1.27)	1.2 (1.11-1.29)
B(Current)/B(0)	na	Na	na
SB(Current)/SB(0)	0.49 (0.47-0.51)	0.46 (0,43-0.49)	0.42 (0.39-0.45)

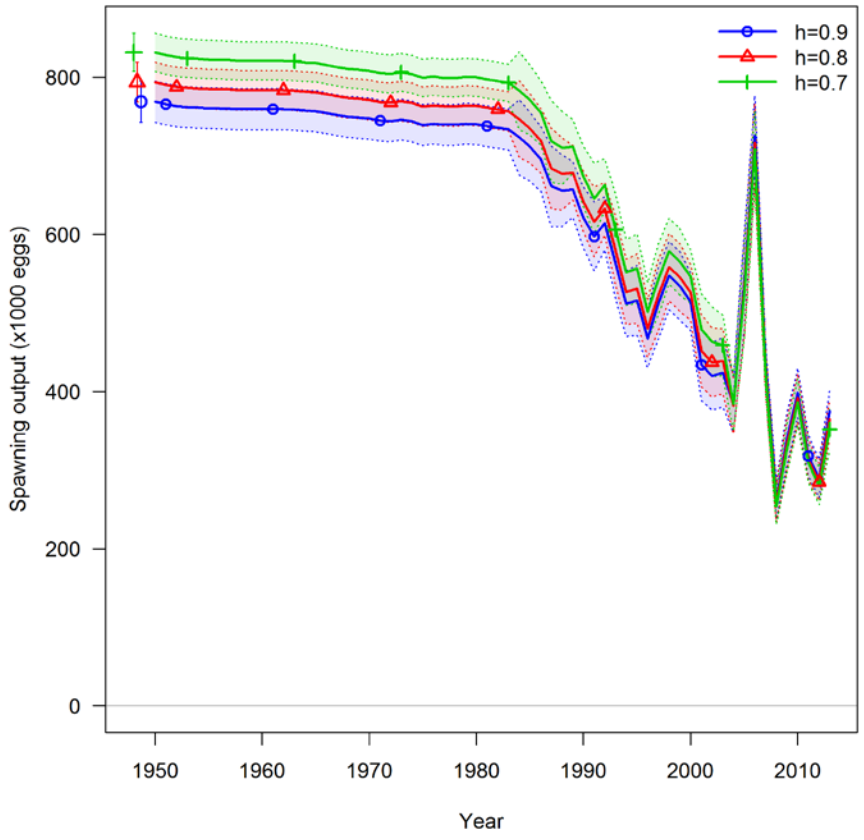

Figure 21: Biomass trajectories with varying values of steepness

Overall structural Uncertainty Results: Uncertainty in the entire Grid

In order to assess uncertainties with a combination of factors, runs were made with different weighting schemes and using either only the Maldivian CPUE series or both the PSLS series and the Maldivian series to estimate recruitment deviations from 1985-2010 or 2004-2010. In all these runs examined, we looked at either the VB growth curve, or the Richards growth curve and varied only the CPUE series, steepness values, a common M value across all ages, and how we weighed the length composition and tagging data as compared to the CPUE data.

The results are tabulated across all runs with the following chronology:

1) Figures 22 and 23 describe the runs using a VB curve and equal weights on all components of the likelihood (i.e. lambda of 1 across CPUE, length-composition and the tagged likelihood)
2) Figures 24 and 25 describe runs using a VB curve and higher weights on the CPUE versus the length-composition data and tag data (lambda of 1 for CPUE vs 0.5 for Length composition and tag data).
3) Figures 26 and 27 describe runs using a VB curve and equal weights on the CPUE and the length-composition data and no weight on the tag data (lambda of 1 for CPUE and length-composition and 0 for tag data).
4) Figures 28 and 29 describe runs using a VB curve and equal weights on the CPUE and the length-composition data and no weight on the tag data (1 for CPUE and length-composition and 0 for tag data).

5) Figures 30 and 31 describe the runs using a Richards curve and equal weights on all components of the likelihood (i.e. lambda of 1 across CPUE, length-composition and the tagged likelihood)
6) Figures 32 and 33 describe runs using a Richards curve and higher weights on the CPUE versus the length-composition data and tag data (lambda of 1 for CPUE vs 0.5 for Length composition and tag data).
7) Figures 33 and 34 describe runs using a Richards curve and equal weights on the CPUE and the length-composition data and no weight on the tag data (lambda of 1 for CPUE and length-composition and 0 for tag data).
8) Figures 34 and 35 describe runs using a Richards curve and equal weights on the CPUE and the length-composition data and no weight on the tag data (1 for CPUE and length-composition and 0 for tag data).

Results from the grid based approach by weight using the Von-Bertalanffy Growth curve

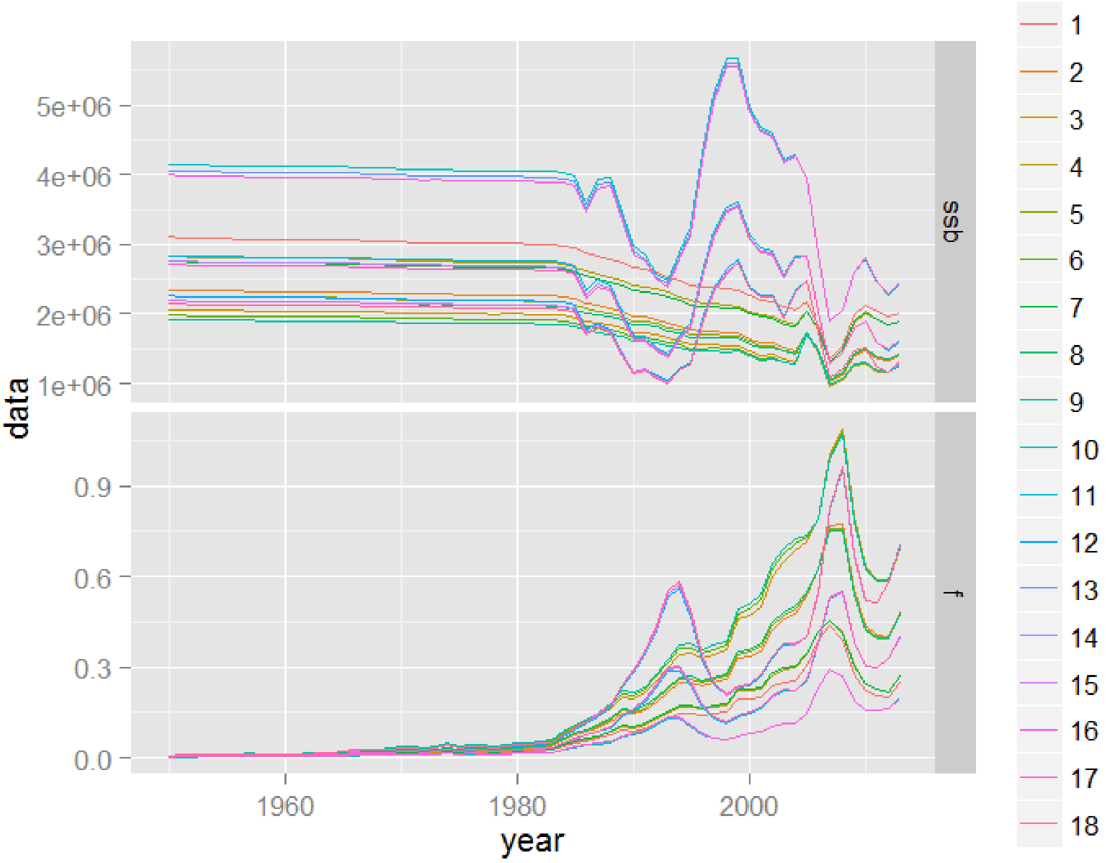

Figure 22: Stock trajectories using equal weights and either using the PL data only or bother the PL and PS data

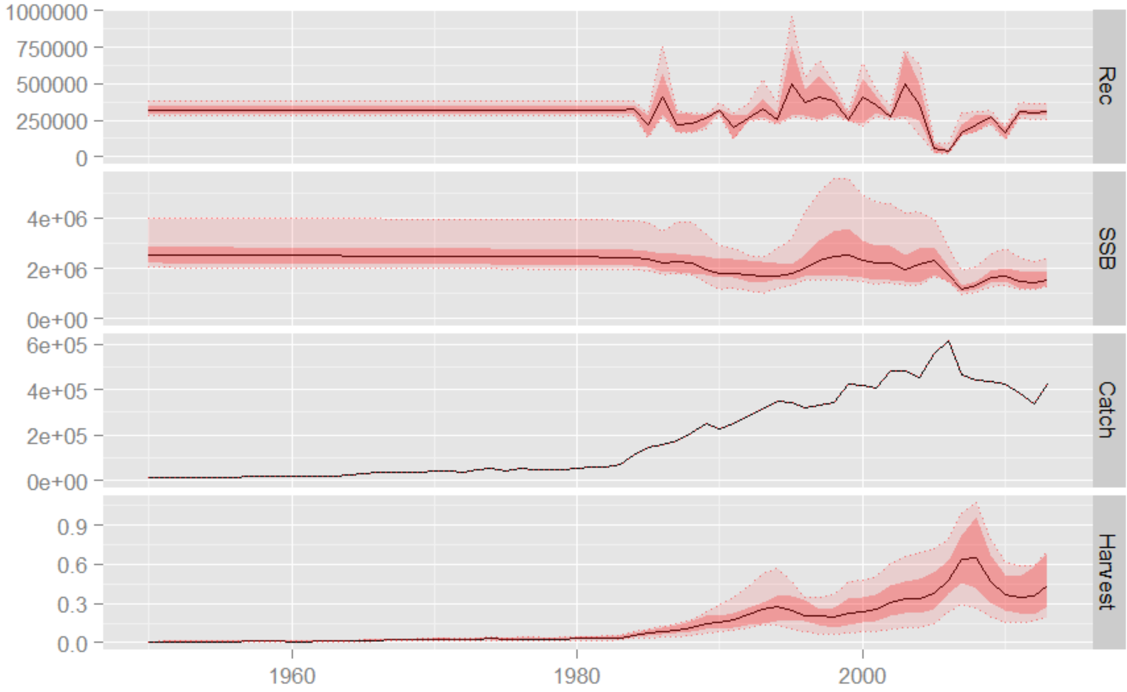

Figure 23: Overall uncertainty in Stock trajectories using equal weights and either using the PL data only or both the PL and PS data

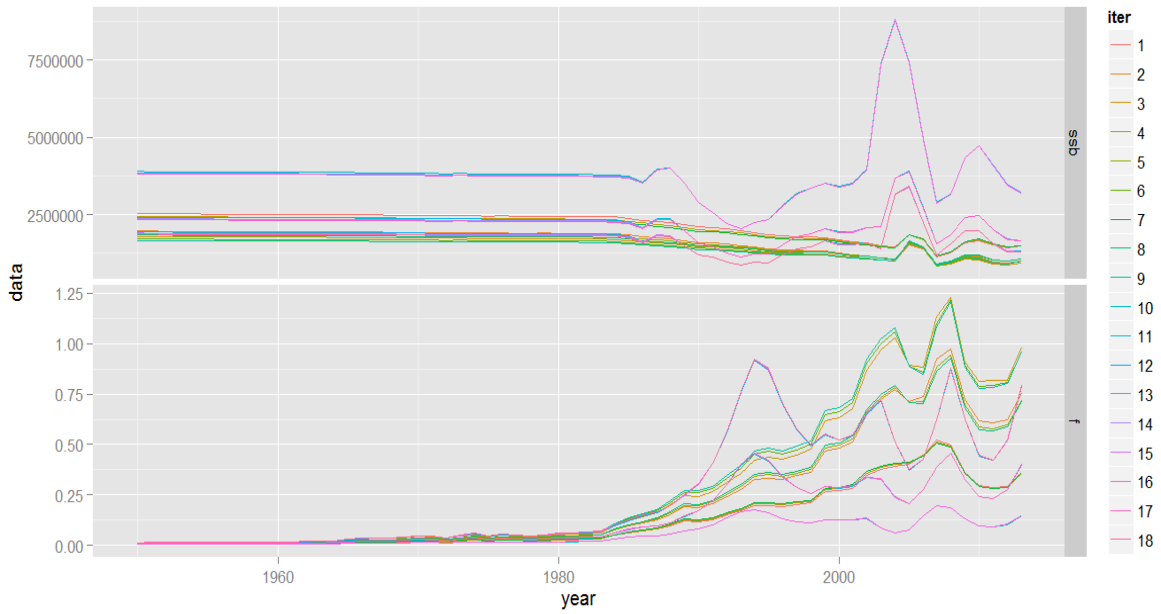

Figure 24: Stock trajectories using higher weights on CPUE vs length composition or tag data

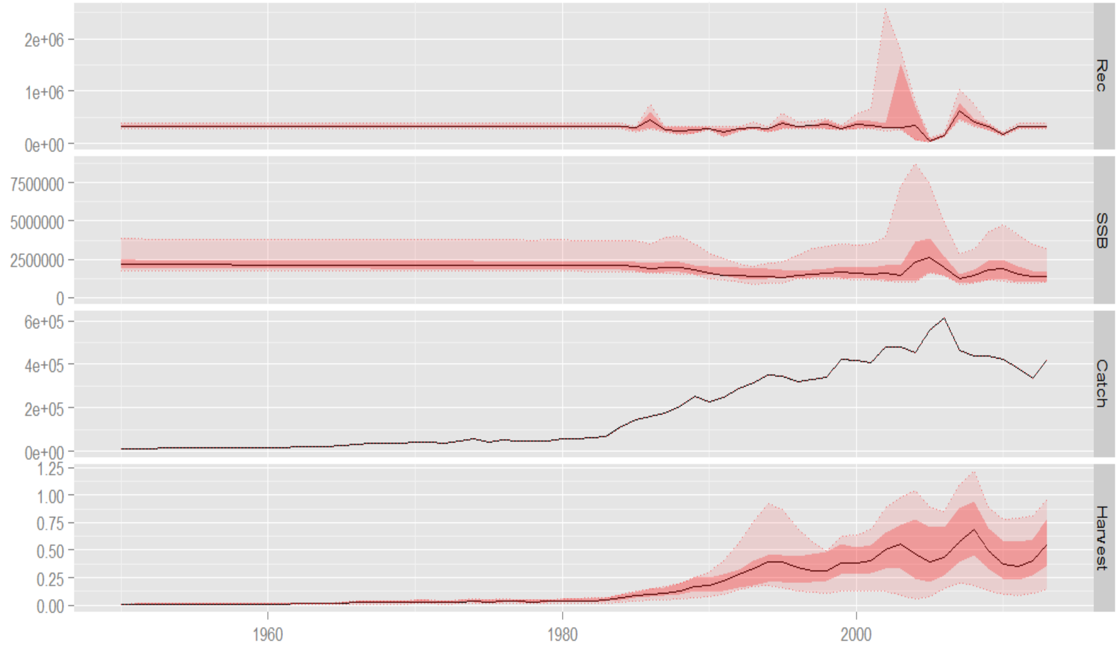

Figure 25: Overall uncertainty in Stock trajectories using higher weights on CPUE vs length composition or tag data

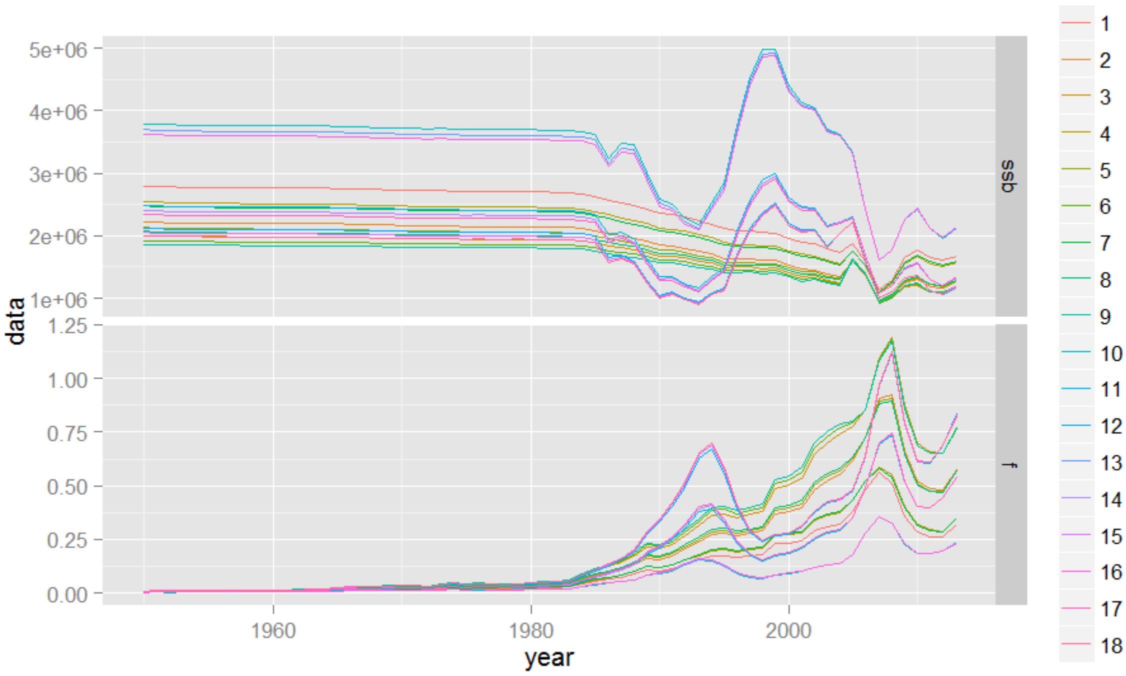

Figure 26: Stock trajectories using equal weights on CPUE and length composition and no tag data

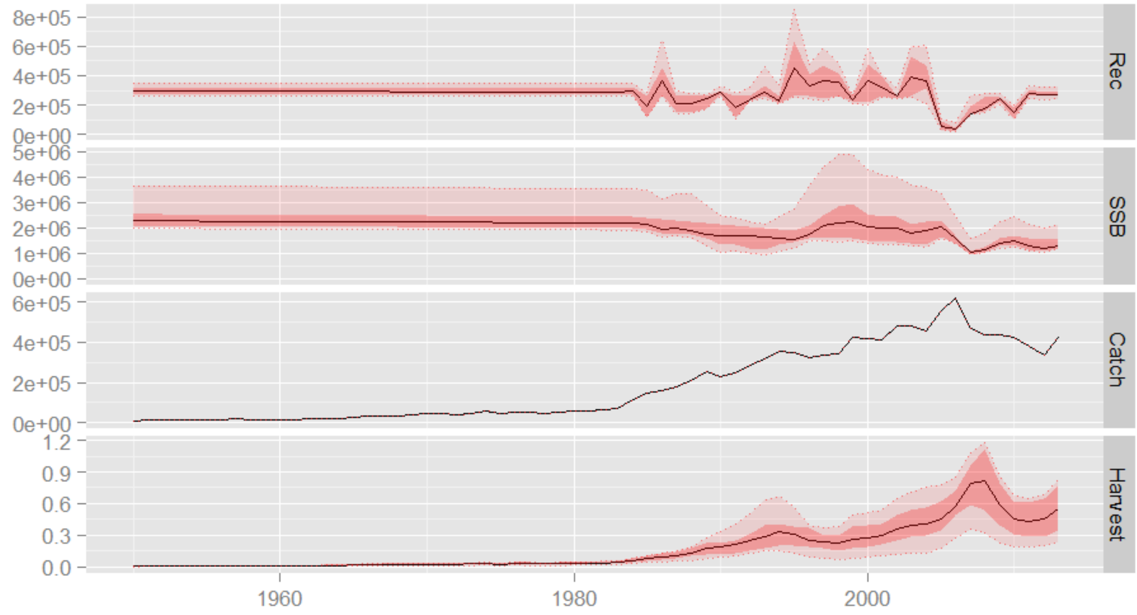

Figure 27: Overall uncertainty in Stock trajectories using equal weights on CPUE and length composition with no weight on tag data

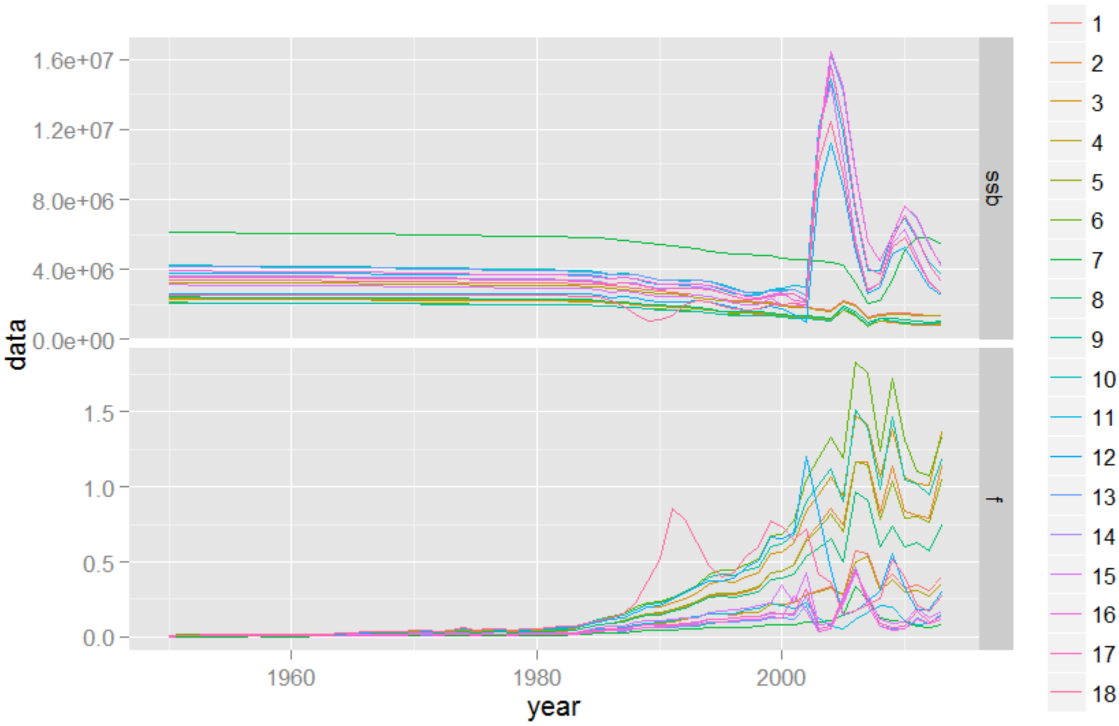

Figure 28: Stock trajectories using equal weights on CPUE and tag data, and no weights on length composition data

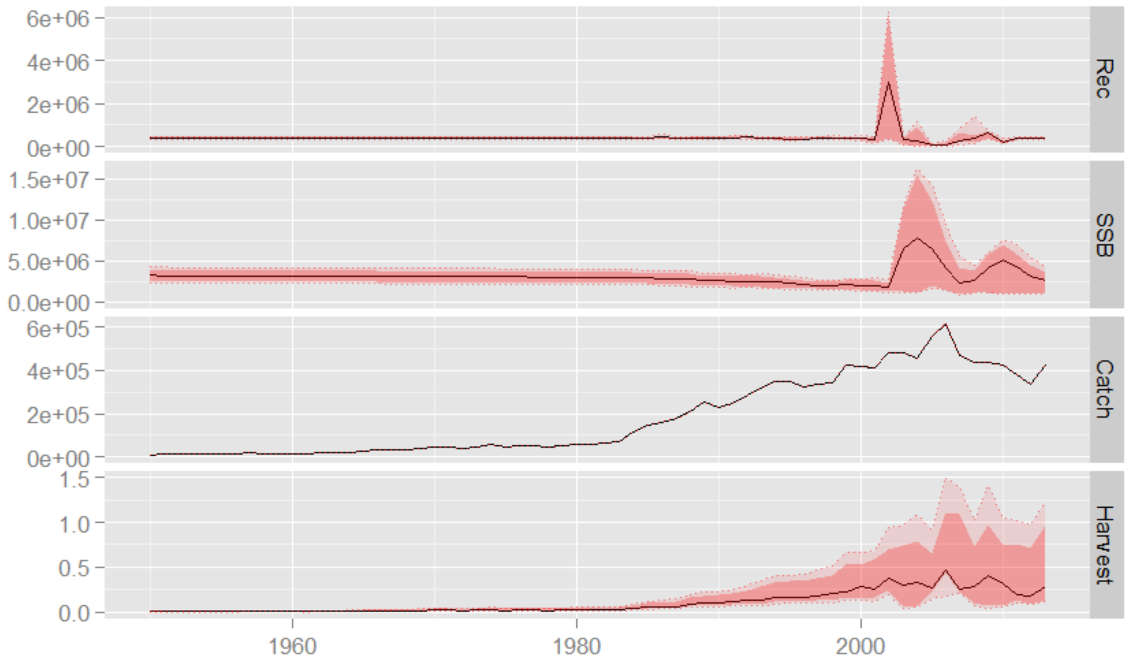

Figure 29: Overall uncertainty in Stock trajectories using higher weights on CPUE and tag data and no weight on the length composition data.

Table 8: Summary of all runs using the VB Growth Curve

Data Weight	Run	M	h	PS	SPB_1950	SSB_MSY	SPB_2013	F_2013	F_MSY	TotYield_MSY	LIKELIHOOD	FinalGradient	SB/SB0	SB/MSY	F/MSY
Equal Weight	1	0.7	0.7	0	3E+06	760609	1599390	0.21	0.59	649018	8757.1	1.29E-04	0.60	2.10	0.36
	2	0.8	0.7	0	2E+06	784678	1033110	0.30	0.48	545643	8600.21	1.74E-04	0.54	1.32	0.63
	3	0.9	0.7	0	2E+06	821828	869313	0.34	0.40	486689	8484.95	2.84E-04	0.53	1.06	0.84
	4	0.7	0.8	0	2E+06	798305	1511200	0.22	0.58	662327	8799.05	2.04E-04	0.62	1.89	0.39
	5	0.8	0.8	0	2E+06	813468	1045140	0.30	0.48	560998	8607.52	3.48E-05	0.56	1.28	0.62
	6	0.9	0.8	0	2E+06	831251	872645	0.34	0.40	487591	8491	9.90E-03	0.56	1.05	0.84
	7	0.7	0.9	0	2E+06	836695	1508200	0.22	0.58	691144	8803.34	2.47E-04	0.64	1.80	0.39
	8	0.8	0.9	0	2E+06	829885	1047700	0.30	0.48	569435	8612.21	9.61E-05	0.58	1.26	0.63
	9	0.9	0.9	0	2E+06	835993	871313	0.34	0.40	486525	8494.61	5.49E-05	0.57	1.04	0.85
	10	0.7	0.7	1	4E+06	960439	1879890	0.17	0.62	866463	8543.79	1.13E-04	0.53	1.96	0.28
	11	0.8	0.7	1	2E+06	937261	1164090	0.26	0.49	663229	8391.39	6.09E-05	0.50	1.24	0.54
	12	0.9	0.7	1	2E+06	924134	877643	0.33	0.39	527635	8261.12	1.95E-04	0.49	0.95	0.84
	13	0.7	0.8	1	3E+06	1E+06	1891090	0.17	0.61	955947	8543.65	4.62E-04	0.55	1.78	0.28
	14	0.8	0.8	1	2E+06	979135	1170720	0.26	0.49	690706	8390.97	4.17E-04	0.52	1.20	0.54
	15	0.9	0.8	1	2E+06	939477	883815	0.32	0.39	534700	8260.42	1.79E-03	0.51	0.94	0.83
	16	0.7	0.9	1	3E+06	1E+06	1898650	0.17	0.61	1E+06	8543.55	3.78E-05	0.56	1.68	0.28
	17	0.8	0.9	1	2E+06	1E+06	1175010	0.26	0.49	708386	8390.68	7.73E-05	0.53	1.17	0.53

	18	0.9	0.9	1	2E+06	948510	888114	0.32	0.39	538584	8259.95	7.36E-03	0.52	0.94	0.83
High weight CPUE vs Tags and LC	19	0.7	0.7	0	2E+06	649919	1149200	0.29	0.57	526079	7292.23	1.36E-04	0.53	1.77	0.51
	20	0.8	0.7	0	2E+06	653224	720418	0.42	0.48	449375	7140.25	2.51E-04	0.44	1.10	0.88
	21	0.9	0.7	0	1E+06	684019	635676	0.45	0.41	416320	7035.07	2.82E-04	0.45	0.93	1.08
	22	0.7	0.8	0	2E+06	706682	1161370	0.29	0.56	563086	7295.74	6.12E-04	0.55	1.64	0.51
	23	0.8	0.8	0	2E+06	689446	757793	0.40	0.47	464211	7144.12	8.62E-05	0.48	1.10	0.85
	24	0.9	0.8	0	1E+06	710628	667149	0.43	0.41	419142	7037.79	7.66E-03	0.49	0.94	1.06
	25	0.7	0.9	0	2E+06	741110	1162410	0.29	0.56	584842	7297.54	7.50E-03	0.57	1.57	0.51
	26	0.8	0.9	0	2E+06	707938	771784	0.40	0.47	471056	7145.74	6.09E-04	0.51	1.09	0.84
	27	0.9	0.9	0	1E+06	720491	677121	0.42	0.40	418947	7038.46	9.29E-04	0.51	0.94	1.06
	28	0.7	0.7	1	3E+06	1E+06	2668900	0.13	0.55	812762	7054.23	1.10E-03	0.80	2.56	0.24
	29	0.8	0.7	1	2E+06	929127	1263530	0.25	0.41	538025	6938.6	3.74E-04	0.63	1.36	0.62
	30	0.9	0.7	1	2E+06	927788	932463	0.32	0.31	404307	6823.7	3.84E-04	0.61	1.01	1.04
	31	0.7	0.8	1	3E+06	1E+06	2657480	0.13	0.55	887810	7053.77	2.87E-03	0.81	2.33	0.24
	32	0.8	0.8	1	2E+06	961909	1258050	0.26	0.41	556951	6937.89	8.77E-05	0.64	1.31	0.62
	33	0.9	0.8	1	2E+06	936646	928215	0.32	0.31	408210	6822.89	2.03E-03	0.62	0.99	1.04

	34	0.7	0.9	1	3E+06	1E+06	2649190	0.13	0.55	940394	7053.44	1.90E-04	0.81	2.20	0.24
	35	0.8	0.9	1	2E+06	984098	1253680	0.26	0.41	569840	6937.4	4.43E-04	0.65	1.27	0.62
	36	0.9	0.9	1	1E+06	942372	924843	0.33	0.31	410795	6822.33	1.15E-04	0.62	0.98	1.05
High weight CPUE& LC: No weight Tags	37	0.7	0.7	0	2E+06	721467	1298060	0.25	0.57	589389	8580.13	2.64E-03	0.54	1.80	0.45
	38	0.8	0.7	0	2E+06	756743	907264	0.34	0.47	515215	8432.29	3.67E-05	0.50	1.20	0.72
	39	0.9	0.7	0	2E+06	806712	809873	0.36	0.40	469997	8336.91	4.98E-04	0.51	1.00	0.90
	40	0.7	0.8	0	2E+06	749879	1225590	0.27	0.56	594353	8621.43	9.02E-05	0.56	1.63	0.48
	41	0.8	0.8	0	2E+06	781818	922710	0.33	0.47	526160	8440.36	1.88E-04	0.53	1.18	0.71
	42	0.9	0.8	0	2E+06	813823	815442	0.36	0.39	469659	8343.33	7.26E-05	0.54	1.00	0.90
	43	0.7	0.9	0	2E+06	782913	1239080	0.27	0.56	617943	8626.58	4.23E-05	0.59	1.58	0.48
	44	0.8	0.9	0	2E+06	797114	929124	0.33	0.46	531451	8445.59	1.96E-04	0.55	1.17	0.71
	45	0.9	0.9	0	1E+06	816975	815839	0.36	0.39	467832	8347.21	2.08E-05	0.56	1.00	0.91
	46	0.7	0.7	1	3E+06	905727	1616340	0.20	0.60	795576	8398.68	7.76E-05	0.50	1.78	0.33
	47	0.8	0.7	1	2E+06	852897	936559	0.32	0.47	577960	8247.27	2.32E-04	0.46	1.10	0.68
	48	0.9	0.7	1	2E+06	885506	785336	0.36	0.38	488691	8130.71	4.72E-03	0.47	0.89	0.95
	49	0.7	0.8	1	3E+06	993685	1626360	0.20	0.60	870120	8398.61	4.16E-04	0.52	1.64	0.33

	50	0.8	0.8	1	2E+06	882033	941102	0.32	0.47	595271	8246.77	1.07E-04	0.48	1.07	0.68
	51	0.9	0.8	1	2E+06	895683	791795	0.36	0.38	492585	8129.98	7.89E-04	0.49	0.88	0.94
	52	0.7	0.9	1	3E+06	1E+06	1633580	0.20	0.60	919302	8398.56	1.77E-04	0.53	1.55	0.33
	53	0.8	0.9	1	2E+06	900072	944227	0.32	0.47	605652	8246.43	1.00E-03	0.49	1.05	0.68
	54	0.9	0.9	1	2E+06	901350	796301	0.35	0.38	494468	8129.49	1.30E-03	0.50	0.88	0.94
High weight CPUE& LC: No weight Tags	55	0.7	0.7	0	3E+06	1E+06	1001600	0.31	0.18	330950	6560.67	7.12E+01	0.34	0.71	1.71
High weight CPUE& LC: No weight Tags	56	0.8	0.7	0	2E+06	1E+06	508140	0.54	0.21	300176	6445.38	8.46E+02	0.25	0.48	2.55
High weight CPUE& LC: No weight Tags	57	0.9	0.7	0	2E+06	998526	557804	0.48	0.22	314675	6353.17	4.86E+02	0.30	0.56	2.13
High weight CPUE& LC: No weight Tags	58	0.7	0.8	0	3E+06	1E+06	1005080	0.31	0.22	355169	6587.67	2.89E+02	0.36	0.80	1.43
High weight CPUE& LC: No weight Tags	59	0.8	0.8	0	2E+06	1E+06	563373	0.49	0.18	283610	6463.1	5.49E+02	0.28	0.48	2.66
High weight CPUE& LC: No weight Tags	60	0.9	0.8	0	2E+06	1E+06	610555	0.45	0.20	282956	6385.66	9.44E+02	0.36	0.59	2.25
High weight CPUE& LC: No weight Tags	61	0.7	0.9	0	5E+06	2E+06	4609840	0.08	0.19	578411	6477.46	1.36E+02	0.88	2.07	0.40
High weight CPUE& LC: No weight Tags	62	0.8	0.9	0	2E+06	1E+06	695967	0.41	0.21	314068	6461.46	3.92E+01	0.35	0.63	1.92
High weight CPUE& LC: No weight Tags	63	0.9	0.9	0	2E+06	1E+06	609316	0.44	0.19	277185	6363.35	2.68E+02	0.36	0.58	2.29
High weight CPUE& LC: No weight Tags	64	0.7	0.7	1	4E+06	1E+06	3693470	0.10	0.22	368098	5966.61	1.94E+01	1.02	2.93	0.46
High weight CPUE& LC: No weight Tags	65	0.8	0.7	1	3E+06	3E+06	3044310	0.11	0.07	237176	6113.13	9.52E-05	0.98	1.16	1.58

	66	0.9	0.7	1	2E+06	2E+06	1964730	0.17	0.13	279200	6053.36	1.03E-04	0.94	1.16	1.35
	67	0.7	0.8	1	4E+06	1E+06	3677120	0.10	0.22	396604	5965.78	3.54E+01	1.03	2.74	0.46
	68	0.8	0.8	1	3E+06	1E+06	2731950	0.13	0.19	361498	5992.74	2.71E+01	0.91	1.95	0.69
	69	0.9	0.8	1	2E+06	1E+06	1987830	0.16	0.17	322984	6008.84	6.50E+00	0.81	1.50	0.96
	70	0.7	0.9	1	3E+06	1E+06	3685320	0.10	0.22	402917	5970.05	1.09E-05	1.10	2.65	0.47
	71	0.8	0.9	1	3E+06	1E+06	2696550	0.13	0.18	366408	5993.79	3.83E+01	0.92	1.88	0.70
	72	0.9	0.9	1	2E+06	2E+06	2080240	0.16	0.12	257852	6058.95	1.17E-04	1.04	1.25	1.39

*PS is used and recruitment deviates are estimated back to 1985.

Results from the grid based approach by weight using the Richards Growth curve

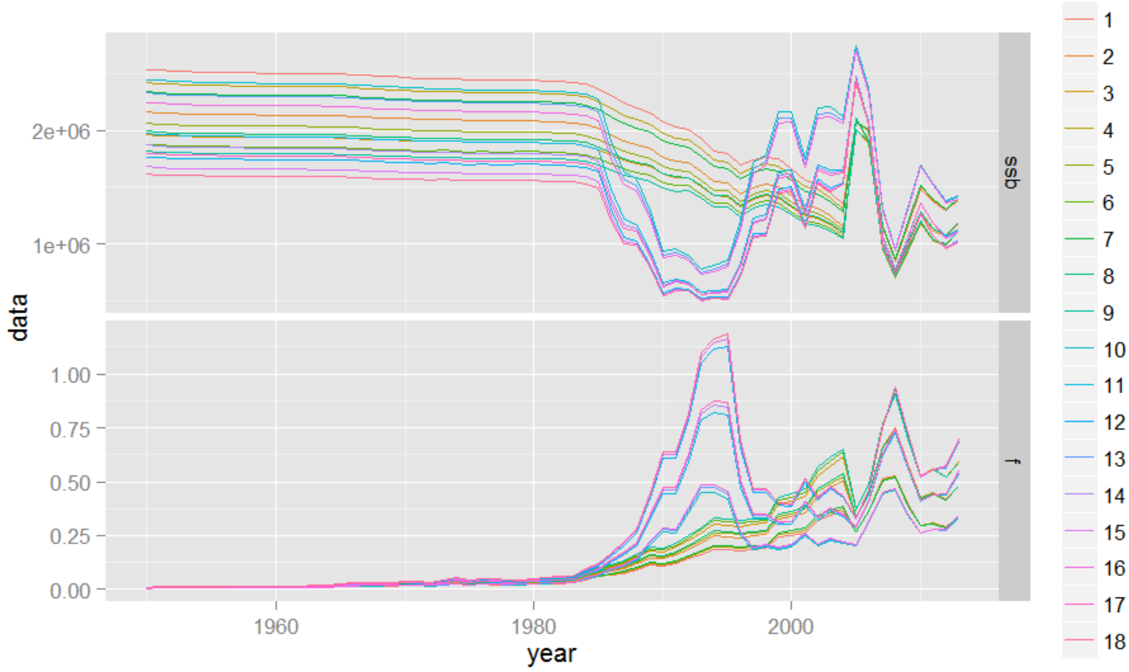

Figure 30: Stock trajectories using equal weights and either using the PL data only or both the PL and PS data

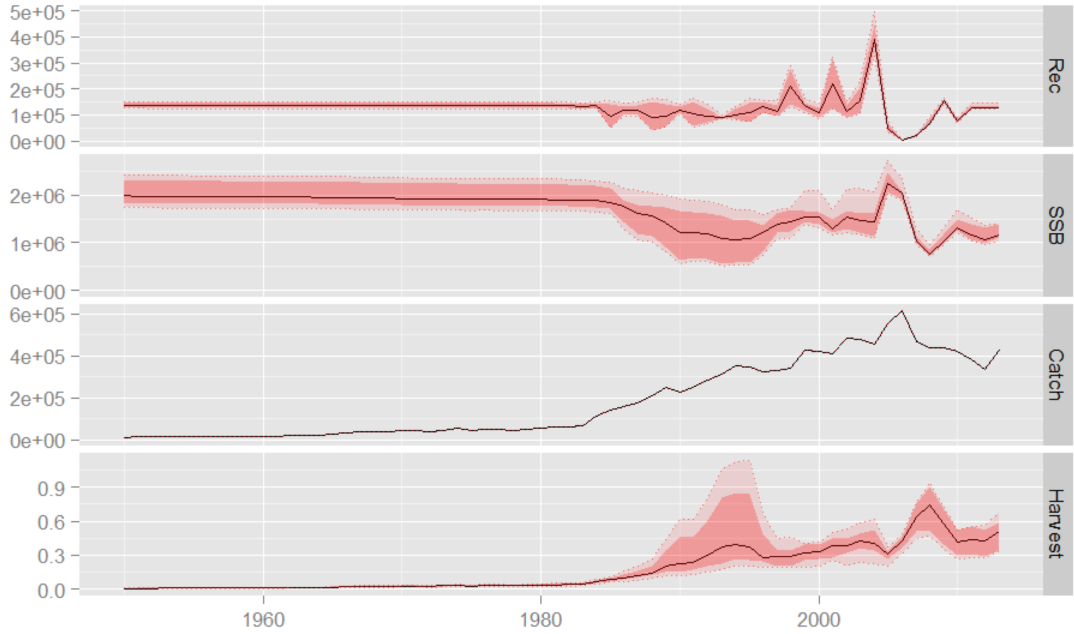

Figure 31: Overall uncertainty in Stock trajectories using equal weights and either using the PL data only or both the PL and PS data

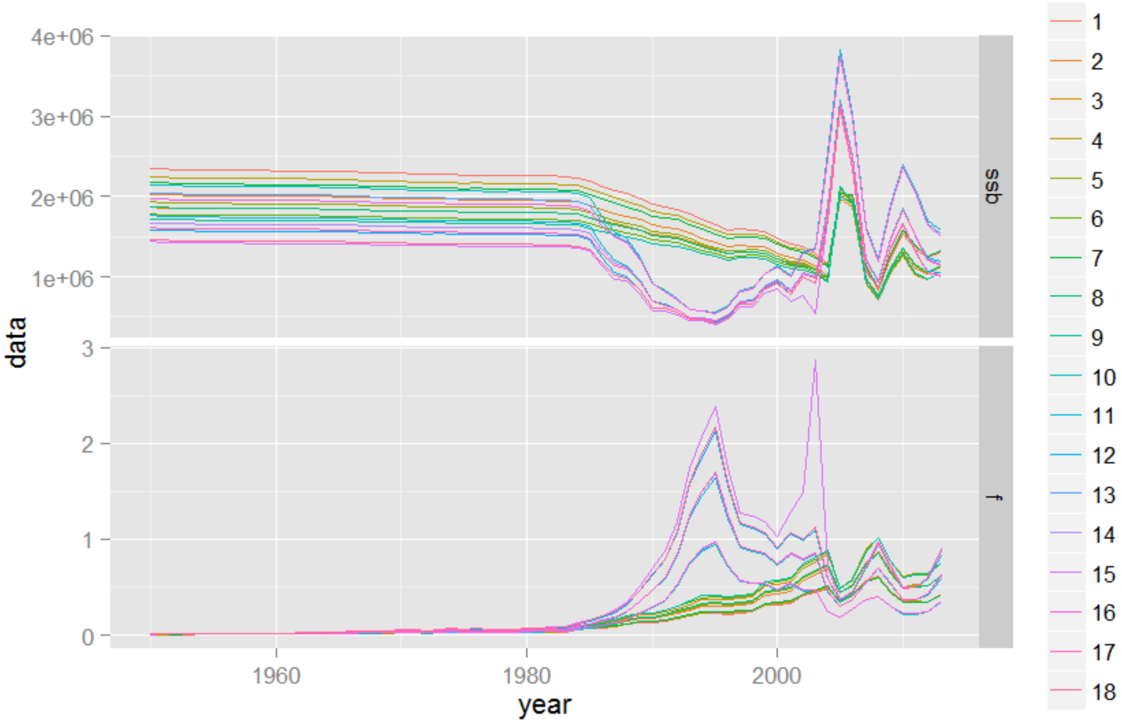

Figure 32: Stock trajectories using higher weights on CPUE vs length composition or tag data

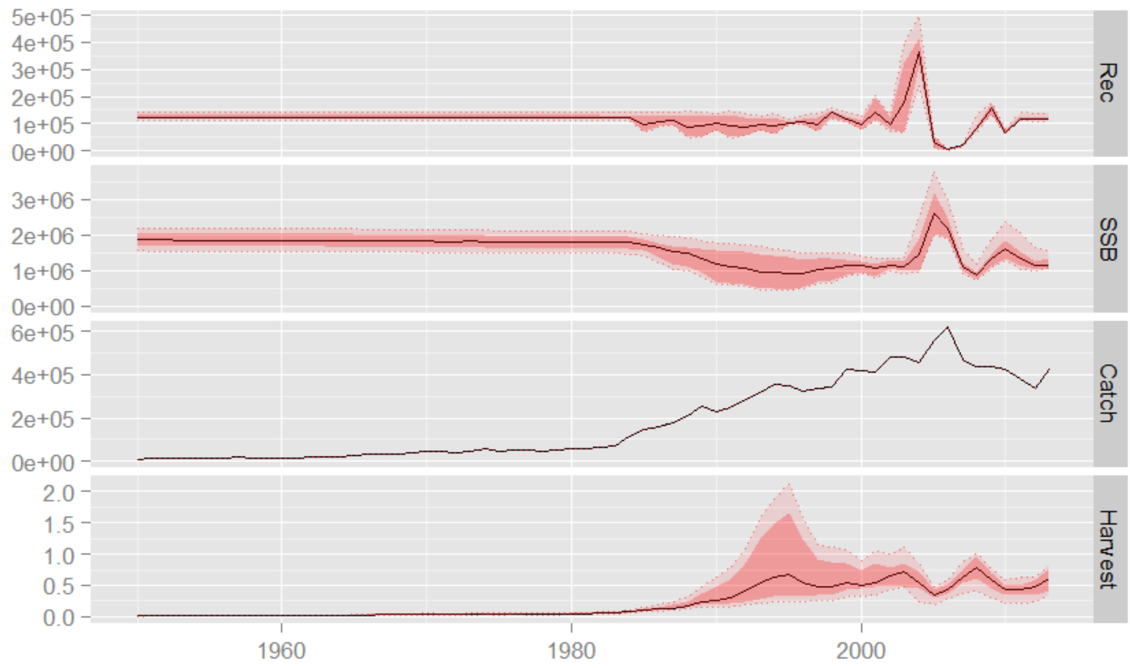

Figure 33: Overall uncertainty in Stock trajectories using higher weights on CPUE vs length composition or tag data

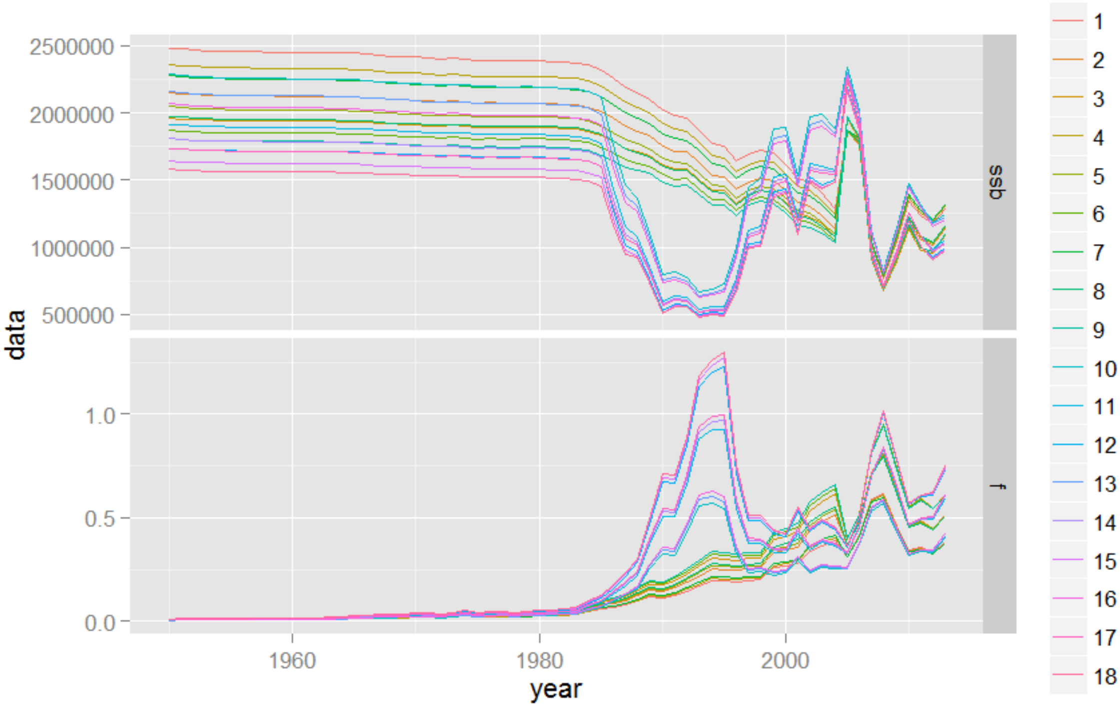

Figure 34: Stock trajectories using equal weights on CPUE and length composition and no tag data

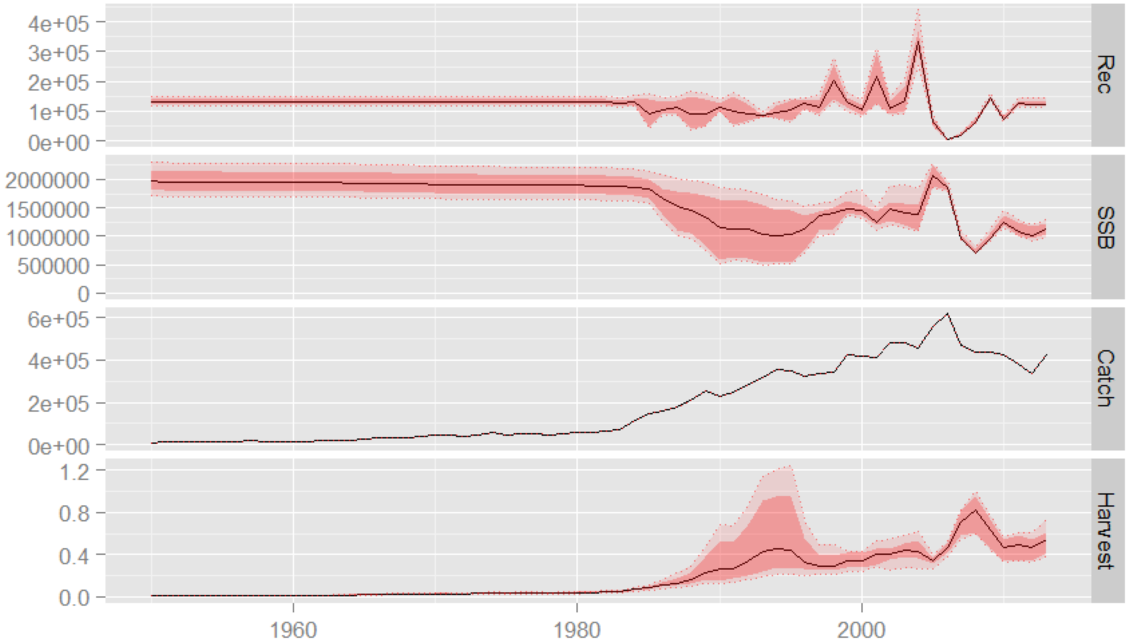

Figure 35: Overall uncertainty in Stock trajectories using equal weights on CPUE and length composition with no weight on tag data

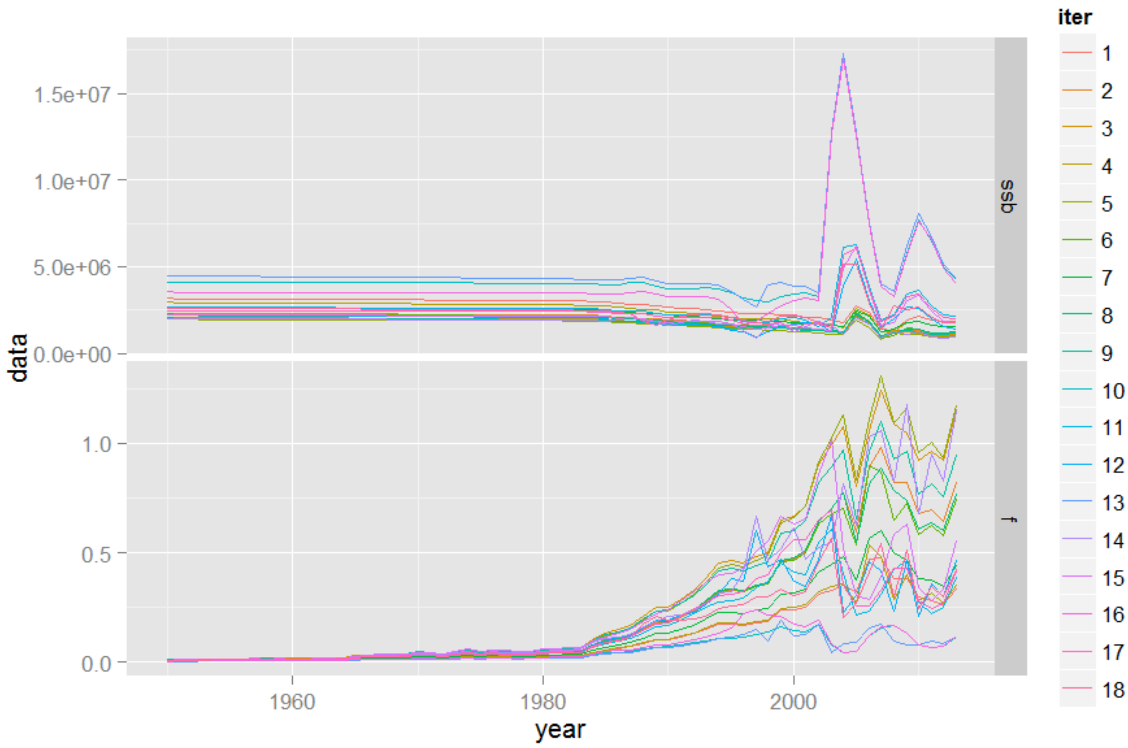

Figure 36: Stock trajectories using equal weights on CPUE and tag data, and no weights on length composition data

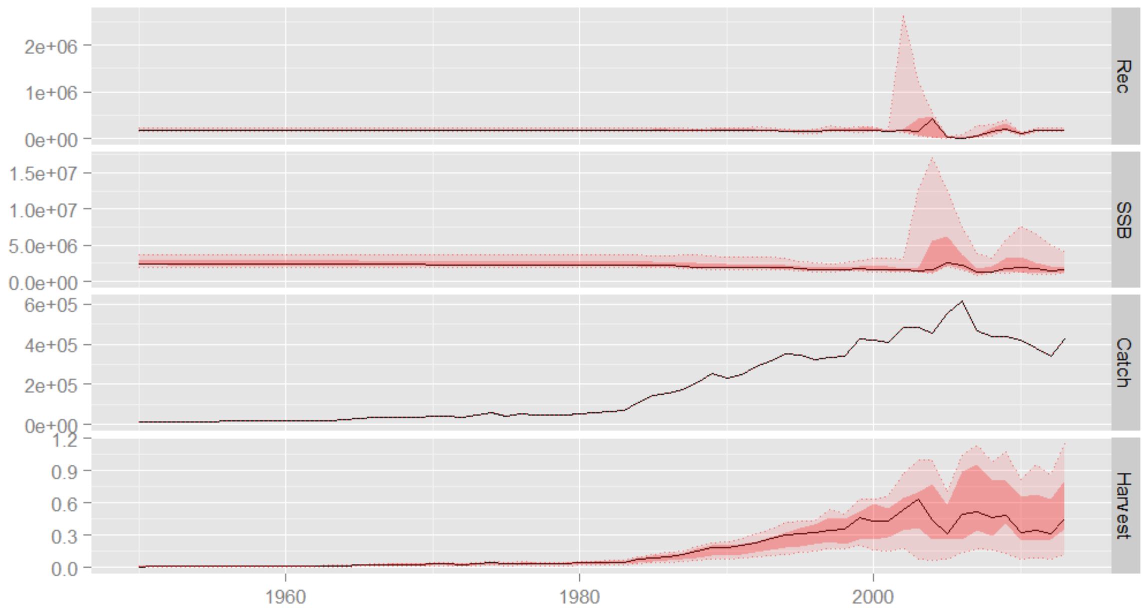

Figure 37: Overall uncertainty in Stock trajectories using higher weights on CPUE and tag data and no weight on the length composition data.

Table 9: Summary of all runs using the Richards Growth Curve

Data Weight	Run	M	h	PS	SPB_1950	SSB_MSY	SPB_2013	F_2013	F_MSY	TotYield_MSY	LIKELIHOOD	FinalGradient	SB/SB0	SB/SMSY	F/FMSY
Equal Weight	1	0.7	0.7	0	2E+06	708608	1234870	0.31	0.6	531957	9043	4.33E-03	0.52	1.74	0.49
	2	0.8	0.7	0	2E+06	635087	1018170	0.36	0.7	530813	8951	2.01E-04	0.51	1.60	0.53
	3	0.9	0.7	0	2E+06	698453	935380	0.38	0.6	528911	8905	1.49E-04	0.53	1.34	0.63
	4	0.7	0.8	0	2E+06	601581	1242240	0.3	0.8	581033	9046	8.44E-05	0.55	2.06	0.39
	5	0.8	0.8	0	2E+06	671806	1025680	0.36	0.7	557684	8953	3.32E-04	0.54	1.53	0.53
	6	0.9	0.8	0	2E+06	720766	941290	0.38	0.6	542379	8906	1.59E-02	0.56	1.31	0.63
	7	0.7	0.9	0	2E+06	641336	1243210	0.3	0.8	617083	9047	2.09E-03	0.57	1.94	0.39
	8	0.8	0.9	0	2E+06	694417	1027380	0.36	0.7	573639	8954	1.10E-04	0.56	1.48	0.53
	9	0.9	0.9	0	2E+06	734045	942836	0.38	0.6	549726	8907	6.80E-03	0.58	1.28	0.63
	10	0.7	0.7	1	2E+06	660990	1278790	0.3	0.7	515853	8897	1.03E-04	0.56	1.93	0.45
	11	0.8	0.7	1	2E+06	620372	978391	0.38	0.6	488091	8800	3.24E-04	0.54	1.58	0.58
	12	0.9	0.7	1	2E+06	686915	882467	0.41	0.6	471138	8750	2.97E-04	0.55	1.28	0.73
	13	0.7	0.8	1	2E+06	588148	1260850	0.3	0.8	561019	8895	9.60E-04	0.58	2.14	0.39
	14	0.8	0.8	1	2E+06	645272	965263	0.38	0.6	505102	8797	8.89E-05	0.56	1.50	0.59
	15	0.9	0.8	1	2E+06	695369	871618	0.41	0.6	475398	8748	1.84E-04	0.58	1.25	0.74
	16	0.7	0.9	1	2E+06	623873	1245820	0.3	0.8	593273	8894	6.78E-05	0.6	2.00	0.39
	17	0.8	0.9	1	2E+06	659592	953783	0.39	0.6	514607	8796	2.18E-05	0.58	1.45	0.60
	18	0.9	0.9	1	1E+06	699227	862006	0.42	0.6	477074	8746	3.38E-05	0.59	1.23	0.75
High weight CPUE vs Tags and LC	19	0.7	0.7	0	2E+06	671717	1164410	0.32	0.6	503559	7442	7.56E-05	0.53	1.73	0.51
	20	0.8	0.7	0	2E+06	776717	966959	0.38	0.5	478649	7337	3.31E-05	0.52	1.24	0.73
	21	0.9	0.7	0	2E+06	829530	896244	0.4	0.5	455915	7278	9.52E-05	0.53	1.08	0.87
	22	0.7	0.8	0	2E+06	719091	1174380	0.32	0.6	535612	7444	4.87E-05	0.56	1.63	0.51
	23	0.8	0.8	0	2E+06	798949	977732	0.38	0.5	489283	7339	8.45E-05	0.55	1.22	0.73
	24	0.9	0.8	0	2E+06	839146	903516	0.4	0.5	458178	7279	5.32E-05	0.56	1.08	0.87

	25	0.7	0.9	0	2E+06	748289	1175790	0.32	0.6	554984	7444	9.38E-05	0.58	1.57	0.51
	26	0.8	0.9	0	2E+06	811215	978640	0.38	0.5	494538	7339	3.72E-04	0.57	1.21	0.73
	27	0.9	0.9	0	2E+06	842523	902700	0.4	0.5	458115	7279	3.49E-04	0.58	1.07	0.87
	28	0.7	0.7	1	2E+06	632769	1440380	0.27	0.6	471047	7303	1.96E-04	0.72	2.28	0.43
	29	0.8	0.7	1	2E+06	757081	1050960	0.36	0.5	418649	7197	5.68E-05	0.65	1.39	0.76
	30	0.9	0.7	1	1E+06	803127	912337	0.4	0.4	377203	7136	9.28E-05	0.64	1.14	1.01
	31	0.7	0.8	1	2E+06	664531	1396970	0.28	0.6	494729	7302	2.95E-04	0.73	2.10	0.44
	32	0.8	0.8	1	2E+06	757442	1022460	0.37	0.5	419023	7195	8.10E-05	0.67	1.35	0.78
	33	0.9	0.8	1	1E+06	768969	864916	0.42	0.4	347512	7138	3.88E-04	0.67	1.12	1.10
	34	0.7	0.9	1	2E+06	684117	1366440	0.28	0.6	509383	7301	4.87E-05	0.74	2.00	0.45
	35	0.8	0.9	1	1E+06	756078	1000740	0.37	0.5	418511	7194	8.19E-05	0.68	1.32	0.79
	36	0.9	0.9	1	1E+06	784138	872779	0.42	0.4	368841	7133	8.84E-05	0.66	1.11	1.05
High weight CPUE& LC: No weight Tags	37	0.7	0.7	0	2E+06	543209	1134870	0.33	0.8	517239	8908	1.65E-05	0.49	2.09	0.43
	38	0.8	0.7	0	2E+06	643153	977186	0.37	0.7	528623	8832	1.31E-03	0.5	1.52	0.56
	39	0.9	0.7	0	2E+06	699244	911010	0.39	0.6	528865	8801	1.05E-04	0.52	1.30	0.64
	40	0.7	0.8	0	2E+06	600588	1151310	0.33	0.8	568894	8912	1.06E-03	0.52	1.92	0.42
	41	0.8	0.8	0	2E+06	676504	989011	0.37	0.7	552556	8835	2.32E-04	0.53	1.46	0.55
	42	0.9	0.8	0	2E+06	720295	919928	0.39	0.6	540699	8803	5.70E-05	0.55	1.28	0.64
	43	0.7	0.9	0	2E+06	637669	1159130	0.32	0.8	601278	8914	7.34E-05	0.55	1.82	0.42
	44	0.8	0.9	0	2E+06	697825	993966	0.37	0.7	566605	8837	2.20E-05	0.55	1.42	0.55
	45	0.9	0.9	0	2E+06	732794	923351	0.39	0.6	547295	8804	6.65E-04	0.57	1.26	0.64
	46	0.7	0.7	1	2E+06	526215	1108380	0.34	0.8	484737	8761	2.83E-05	0.52	2.11	0.45
	47	0.8	0.7	1	2E+06	622837	908010	0.4	0.6	475502	8677	2.64E-04	0.52	1.46	0.64
	48	0.9	0.7	1	2E+06	682145	840864	0.43	0.6	463034	8642	1.55E-04	0.54	1.23	0.77
	49	0.7	0.8	1	2E+06	572431	1088370	0.35	0.8	524247	8758	3.71E-04	0.54	1.90	0.46
	50	0.8	0.8	1	2E+06	642395	896114	0.41	0.6	487971	8674	9.56E-05	0.54	1.39	0.65
	51	0.9	0.8	1	1E+06	687544	830532	0.43	0.6	465185	8640	4.45E-05	0.56	1.21	0.78
	52	0.7	0.9	1	2E+06	600122	1071650	0.35	0.7	547444	8756	6.77E-05	0.56	1.79	0.47
	53	0.8	0.9	1	2E+06	652849	885284	0.41	0.6	494287	8672	5.44E-04	0.56	1.36	0.66

	54	0.9	0.9	1	1E+06	689179	821125	0.44	0.6	465347	8638	2.08E-04	0.58	1.19	0.79
High weight CPUE& LC: No weight Tags	55	0.7	0.7	0	3E+06	2E+06	1673070	0.23	0.1	302937	6643	1.99E+02	0.57	0.81	1.70
	56	0.8	0.7	0	2E+06	2E+06	1031460	0.36	0.2	262135	6608	4.21E+03	0.48	0.66	2.37
	57	0.9	0.7	0	2E+06	1E+06	964477	0.38	0.1	241829	6512	2.53E+03	0.51	0.66	2.55
	58	0.7	0.8	0	3E+06	2E+06	1393770	0.27	0.2	322172	6635	1.46E+02	0.51	0.82	1.58
	59	0.8	0.8	0	2E+06	1E+06	882116	0.43	0.2	261982	6637	2.81E+03	0.48	0.66	2.37
	60	0.9	0.8	0	2E+06	1E+06	1011680	0.35	0.2	261615	6379	1.50E+02	0.5	0.69	2.26
	61	0.7	0.9	0	2E+06	2E+06	1420100	0.27	0.2	293529	6731	1.07E-03	0.57	0.81	1.76
	62	0.8	0.9	0	2E+06	2E+06	1063020	0.35	0.1	246831	6582	2.63E+01	0.52	0.69	2.41
	63	0.9	0.9	0	2E+06	1E+06	1014280	0.36	0.2	246308	6473	3.71E+01	0.54	0.71	2.33
	64	0.7	0.7	1	4E+06	3E+06	3976310	0.1	0.1	221399	6327	7.95E-04	1.04	1.16	1.66
	65	0.8	0.7	1	2E+06	2E+06	1962620	0.2	0.1	305994	6379	7.89E-05	0.8	0.96	1.44
	66	0.9	0.7	1	2E+06	1E+06	1193220	0.3	0.1	223162	6190	1.31E+02	0.6	0.86	2.16
	67	0.7	0.8	1	4E+06	3E+06	4035860	0.1	0.1	206086	6334	3.18E+01	0.97	1.18	1.77
	68	0.8	0.8	1	2E+06	1E+06	819084	0.45	0.2	266926	6522	1.67E+03	0.44	0.63	2.42
	69	0.9	0.8	1	2E+06	2E+06	1579050	0.24	0.1	228162	6199	2.54E-05	0.79	0.91	2.02
	70	0.7	0.9	1	3E+06	3E+06	3758260	0.11	0.1	407498	6331	2.71E-03	1.14	1.46	0.73
	71	0.8	0.9	1	2E+06	2E+06	1804530	0.21	0.1	186108	6380	4.37E+01	0.79	0.89	2.53
	72	0.9	0.9	1	2E+06	2E+06	1544900	0.24	0.1	219129	6334	3.49E+02	0.65	0.81	2.34

Effect of data weighting

Francis (2011) indicates that often in complex integrated models there is conflicting sources of information, stemming from fitting to either the length composition data, or abundance index data. In our case, the abundance index data developed from the Maldivian PL or PSLS has problems with it, but may still be more reliable than the length-composition data. In addition, we have tagging data that provides information on movement and possible natural mortality and F's for the PS and PL fisheries. We thus have 3 sources of information that could be weighted in the likelihood function (objective function that is used for minimization), and we subjectively weigh the different sources as shown in Figures 22 to 37, seeing the influence of the different approaches.

Weighting tags and no length composition

The common belief is that if tag data exists it should be more informative than the length composition or abundance index data. However, in this case, we may have a few problems with the tagging study:

1) The tagging study was not done proportional to the abundance of skipjack in the eastern and western IO and as such much data was only available in the western IO. The data is thus not very informative of what is happening on the entire IO especially given that a bulk of the catch comes from the *Other* fishery category (Figure 1).
2) It is useful to get estimates of growth and natural mortality estimates, and possible fishing mortality estimates, but because of unknown reporting rates for the PL and OT, category we may be getting misleading results in the overall survival rates of the different groups.
3) A lot more time and effort needs to be spent understanding the tagging data, and its effects on the assessment. While growth and natural mortality estimates can be estimated from the tagging data, and put into the model externally, it has a large influence on the overall fit and dynamics as is evident from Figures 28,29, 36 and 37 (Table 8 and 9).

In all cases, the model is indicating very high fishing mortalities in 2006-2009 which is not evident in the other cases examined. So, if the tagging data is highly influential and informative, skipjack were overfished, and being subject to overfishing. Based on this the stock is not currently subjected to overfishing but still depressed. Alternatively, we can use the tagging data for growth and natural mortality estimates as was done in the base case, and we can discount the information in how they are used in the assessment, and use them along with the length composition data, and CPUE data with equal weights which seems to give reasonable results as shown in Figures 22,23, 30 and 31.

Weighting length composition and no tags

The length composition data is possibly giving us information on recruitment or is basically the noise over time. In Figures 34, 35 and Figures 26,27 (Tables 8 and 9) we notice that when fitting back to the mid-1980's recruitment levels may have declined as in recent years 2006-2009, causing the fishing mortality levels to increase. However, we still are below the rates of optimal fishing and the stocks are still healthy or not depressed in most cases (Tables 8 and 9).

Down-weighting length composition data and tagging data as compared to the CPUE data

When we give more weight to the CPUE data and less to the length composition and tagging data, the declines (Figures 24&25, 32 &33) and fluctuations are less pronounced (than when we use all the data with equal weight (Figures 22 and 23, Figures 30 and 31). While recruitment declines following the CPUE series, it's neither as variable nor as steep a decline as seen when we provide more weight to the length composition or more weight to the tagging data.

Effect of using PSLS series along with PL series

Note in all cases shown above the recruitment declines in the mid 1980's in response to the recruitment deviates being estimated prior to 2000's using the PSLS data and the length composition data. With the advent of industrial fisheries in the early 1980's we start tracking a decline in skipjack spawning biomass that is both a function of increased effort of the PS fisheries and the recruitment levels that declined in that period. These trajectories although a lot more variable maybe more representative rather than fitting to only the PL series from 2004. However, when fitting to these series back to the early recruitment deviates, we get estimates of target yields that seem quite low for the Indian Ocean (between 350-380K t, Table 10 below)

Effect of using PSFS (Marsac) series along with PL series

A different series based primarily on the French PS fisheries that operate on the FS was generated (Marsace and Floch 2014). This series when used for fitting gave results shown in Table 10, Figure 38. Although the fits don't change a whole lot between the PSLS and PSFS, the overall catchability estimate is different, and the overall effect on target management parameters changes as well. Unfortunately, these series are not stable and can change ddrastically if some assumption on how we measure effort changes. The added difficulty is quantifying the effect that FADs have on both FS and FAS based fisheries, and until this is properly understood, we recommend not using either of this series at this time. Another sensitivity run was conducted estimating the recruitment deviates back to 1979 (PSLS series starts in 1983 and age structured data back to 1982), to test how it might affect the derived management parameters . The effects were negligible at best.

Table 10: Effect on derived management parameters using PS CPUE series and estimating recruitment to 1985.

Management Quantity	Base case	PL + PSLS	PL +PSFS
LIKELIHOOD	9351	9121	9123
Most recent catch estimate	424,581 t	424,581 t	424,581 t
Mean catch over last 5 years	401,132 t	401,132 t	401,132 t
MSY (1000t)	529K (495K-562K)t	382K (367K-397K)t	363 (348.6K-377.7K)t
Current Data Period	1950-2013	1950-2013	1950-2013
F(Current)/F(MSY)	0.77 (0.74-0.79)	1.12(1.07-1.17)	1.23 (1.18-1.28)
B(Current)/B(MSY)	na	Na	na
SB(Current)/SB(MSY)	1.06 (1.02-1.10)	0.99 (0.95-1.04)	0.94 (0.89-0.98)
B(Current)/B(0)	na	Na	na
SB(Current)/SB(0)	0.5 (0.48-0.52)	0.52 (0,5-0.54)	0.53 (0.51-0.55)

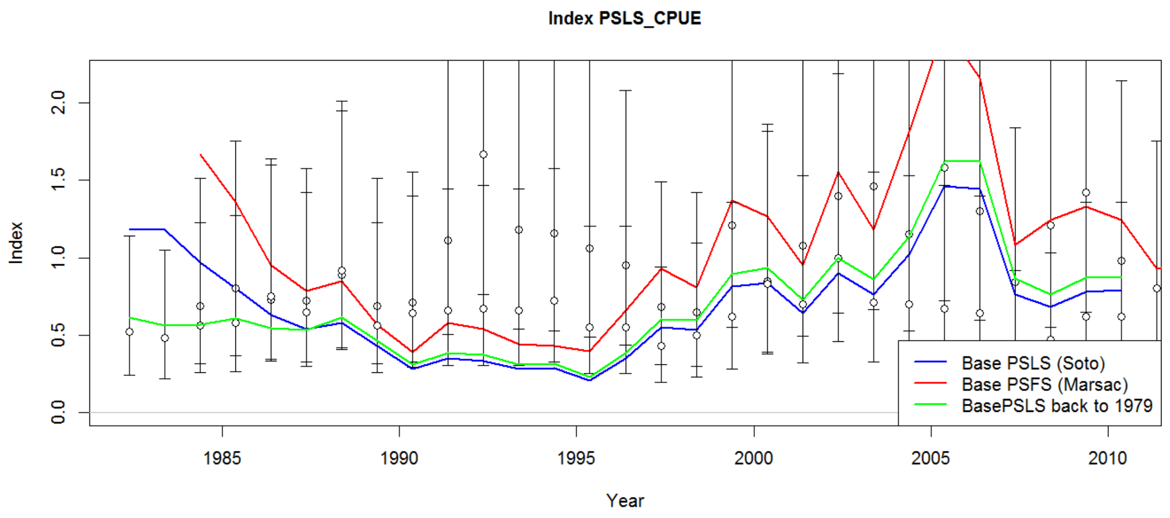

Figure 38: Fits to the PS series (Soto fit to PSLS, and Marsac to PSFS, back to 1979 series fit to PSLS series derived from Soto).

Projections

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Table 11: Projections based on catch levels in 2013 and the projected catches, and the chance of exceeding the limit and target reference points for IO Skipjack

Reference point and projection timeframe	**Alternative catch projections (relative to the average catch level from 2013, 424.58 Kt) and probability (%) of violating MSY-based limit reference points** ($SB_{target} = SB_{MSY}$; $F_{target} = F_{MSY}$)				
	60%	**80%**	**100%**	**120%**	140%
$SB_{2016} < SB_{MSY}$	17%	19%	26%	43%	55%
$F_{2016} > F_{MSY}$	18%	19%	26%	47%	65%
$SB_{2023} < SB_{MSY}$	5%	17%	28%	56%	80%
$F_{2023} > F_{MSY}$	7%	18%	31%	56%	81%
Reference point and projection timeframe	**Alternative catch projections (relative to the average catch level from 2013, 424.58 Kt) and probability (%) of violating MSY-based limit reference points** ($SB_{lim} = 0.4\ B_{MSY}$; $F_{Lim} = 1.5\ F_{MSY}$)				
	60%	**80%**	**100%**	**120%**	140%
$SB_{2016} < SB_{LIM}$	0%	0%	1%	2%	5%
$F_{2016} > F_{LIM}$	1%	13%	19%	22%	34%
$SB_{2023} < SB_{LIM}$	0%	0%	1%	6%	17%
$F_{2023} > F_{LIM}$	0%	7%	19%	29%	58%

Stock Status results

While all models presented are equally plausible (Table 8 & 9 likelihood values), it depends on the hypothesis that is presented and evaluated. Contradictory data sources present alternative hypothesis as to the current state of nature of the stock (Schnute and Hilborn 1993), and how we evaluate these contradictory sources of information and hypothesis are examined in Table 8 & 9, and through alternative assessments.

The attempt made here was to illustrate the key structural uncertainties in the stock assessment regarding key assumptions about growth, recruitment, natural mortality and data weighting***. Any of the presented models are plausible, and the authors recommend using the base case one area assessment. This is primarily based on the fact that this run included the natural mortality vector from the Eveson et. al. (2012) paper, and also used a growth curve that mimics the rapid growth of skipjack in the early part of its lifecycle.***

As Schnute and Richards (2001) pointed out, it is extremely important that these models are illustrated with the underlying assumptions, the structural uncertainty in the dynamics can give us te uncertainty grid around the base case. Based on this, we present the base case assessment with a 80% confidence interval based on the uncertainty grid below in Table 12, Figure 39.

Table 12: Stock Status Advice for Skipjack (2014)

Management Quantity	Base Case Assessment
Most recent catch estimate	424,581 t
Mean catch over last 5 years	401,132 t
MSY (1000t)	529K (377-1129K)t
Current Data Period	1950-2013
F(Current)/F(MSY)	0.77(0.12-1.70)
B(Current)/B(MSY)	na
SB(Current)/SB(MSY)	1.06 (0.72-1.97)
B(Current)/B(0)	na
SB(Current)/SB(0)	0.5 (0.39-0.79)

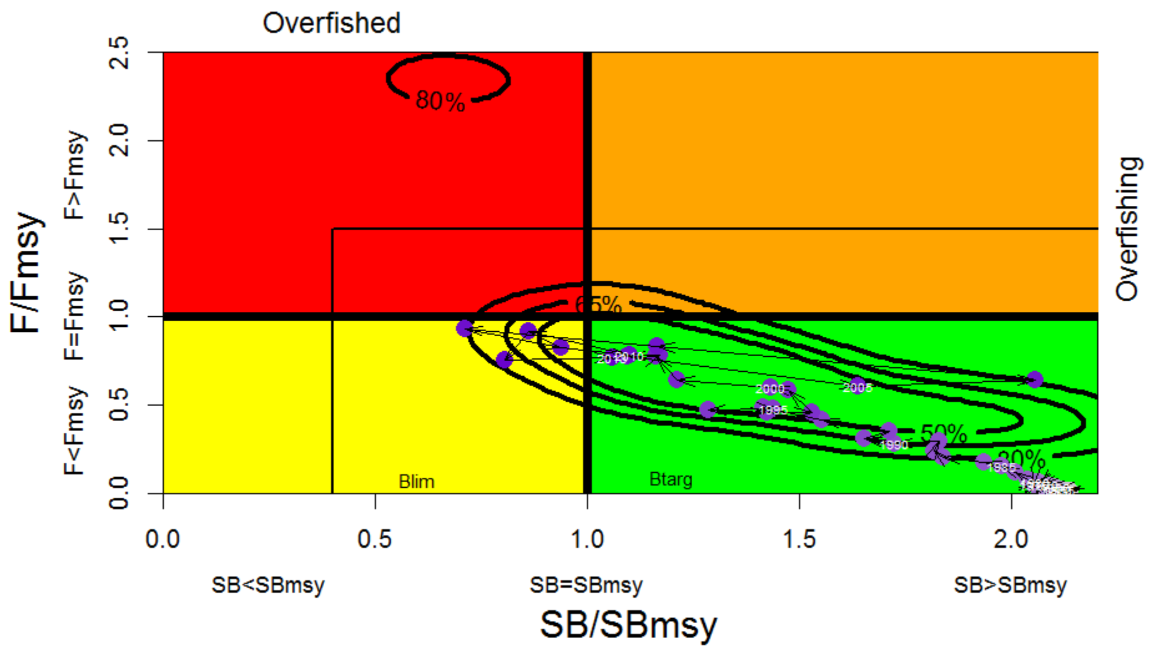

Figure 39: Kobe plot showing the base case run (Table 11) and the uncertainty grid based on Tables 8 and 9.

Conclusions

This analysis represents a third attempt to integrate the major fisheries, life history and tagging data into a single Indian Ocean skipjack tuna assessment. However, as identified in Kolody *et al.* (2011) and Sharma et. al. (2012) there are still serious concerns about important sources of data, and the lack of a suitable CPUE index. Most notably:

- It is unclear whether either the PL or PSFS CPUE series are proportional to abundance. It would be desirable to have a relative abundance index that spans the period of industrialization beginning in the 1980s.
- The quality of the catch data and size sampling from some important fleets is uncertain. This is particularly true for the *Other* fleet, which accounts for a large and increasing proportion of the catch in recent years.

The assessment results tend to suggest that the SKJ population has high natural mortality, limited selectivity of the youngest spawners, and high recruitment compensation with declining spawning biomass. As a consequence, there may be a reserve of young spawners that are largely invulnerable to the fishery. If this is true, even large increases in effort might not have much effect on the recruitment output and sustainable yield of the population. This possibility is encouraging from the perspective of the resilience of the stock, but it is not yet conclusive. And it should be emphasized that large increases in effort would still be expected to cause a serious decline in catch rates.

While we do not have a lot of confidence in the estimated population abundance trends, the evidence that is available (and the SKJ life history strategy) suggests that large fluctuations in abundance should be expected due to high recruitment variability. It is likely that 2005-2006 were exceptional years, and declining catches and catch rates since then are probably partially attributable to the fisheries, and partially attributable to poor year class recruitment following 2005. Once normal levels are again prevalent, the stock will recover as it is highly fecund and has lower selectivity for smaller year class fish which are still recruiting to the population. This maybe evident in the CPUE series seen in the Maldives for 2012.

The aggregated Indian Ocean population appears to be moderately depleted, with a low probability that MSY reference points are currently being exceeded. Based on the one area Model, base case (Table 11) :

- SB_{2013}/SB_{MSY} = 1.06 (0.72-1.97)
- F_{2013}/ F_{MSY}= 0.77 (0.12-1.70)
- MSY 529 (377-1129) thousand t (C_{2013}= 425 thousand t)
- Kobe plot is provided in Figure 38, reference point summary in Table 8.

Suggested priorities for improving the assessment:

- Further analysis of the tagging data:
    - Further investigate M and F and mixing period estimators using external tagging analyses.
    - The general assumption of very low tag-induced mortality might need to be revisited.
- Explore the standardization of PS CPUE series dating back to 1983. While this has been a priority since 2012, not much has really been done to examine this. In 2014, a new series was presented (Marsac et. a. 2014) but further research and new series should be presented at future meetings based on results of CECOFAD (Daniel Gaertner pers. comm.), and hopefully conducive to assessments.
- While the Maldivian CPUE can be estimated back to 1985 using some covariates, not much faith remains in its validity (as there are no ways to ground truth this signal), and hence we may be forced to rely on the series from 2004. A further effort should be taken by the Maldivian Government to see if we could reconstruct the series back to the early 1990's at least.
- Other improvements to the Maldivian PL CPUE series are also suggested below:
    - The WPTT suggested that it may be possible to develop a series based on the pre-mechanization period. However, since mechanization began in 1974, and observations from individual vessel data are not available until 2004, this may not be very helpful.
    - The large number of months with positive PL effort and zero SKJ catch requires further investigation. This is still an issue, and hasn't been resolved
    - The FAD effect maybe spurious as boast maybe landing fish in the North, but maybe fishing far in the south. Even large scale aggregated effects as demonstrated in WPTT 2014 may not be representative.
- In the absence of reliable abundance indices spanning the industrialization of the fishery, it may not be possible to do much more than modelling speculative scenarios that bound 'worst case' and 'best case' interpretations of how abundance changed during the development of the fishery. For e.g. this could involve imposing

effort creep scenarios on the CPUE series, or constraining recruitment dynamics prior to 2004.

- Finally, the two area assessment pursued before had some interesting results and further work could be conducted that may improve this assessment (Sharma et. al. 2012). Due to limited time available not much analysis could be pursued in 2014, but in subsequent years using a 2/3 area model maybe possible. In those instances, maybe using a 3rd CPUE for the eastern Indian Ocean based on the Japanese research vessel *Nippon Maru* may give us a possible approach to develop a 3 area model based assessment.

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Appendix 1. Template for the SS3 Control.SS file.

Different model options are flagged with '*# xxx*' followed by the option identifier from **Error! Reference source not found.** (*e.g.* '# xxx h75' corresponds to steepness 0.75). Individual model specifications are generated by removing the flags corresponding to the desired options.

```
1 #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern
# 1 #_Morph_between/within_stdev_ratio (no read if N_morphs=1)
# 1 #vector_Morphdist_(-1_in_first_val_gives_normal_approx)
# 1 #   number of recruitment designs
4 #  number of recruitment designs
0 # recruitment interaction requested
#GP seas pop
 1 1 1
 1 2 1
 1 3 1
 1 4 1
# 1 2 1
# 1 3 1
# 1 4 1
# 0 # N_movement_definitions goes here if pop > 1
# 1.0 # first age that moves (real age at begin of season, not integer)
# 1 1 1 2 4 10 # example move definition for seas=1, morph=1, source=1 dest=2, age1=4, age2=10
2 #_Nblock_Designs
5 5 # N_Blocks_per design
1960 1988 1989 1993 1994 1998 1999 2003 2004 2009
1960 1976 1977 1984 1985 1992 1993 2000 2001 2009
0.5 #_fracfemale
1 #_natM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
#5 #_N_breakpoints
#.75  1.25  1.75 2.25 3.75  # age(real) at M breakpoints

# xxx MAt 5 #_N_breakpoints
# xxx MAt 0 1 2 3 4 # age(real) at M breakpoints
# xxx MeA1 4 #_N_breakpoints
# xxx MeA1 1 2 3 4 # age(real) at M breakpoints
# xxx MeAs 5 #_N_breakpoints
# xxx MeAs 0 1 2 3 4 # age(real) at M breakpoints
# xxx MB 6 #_N_breakpoints
# xxx MB 1.99 2 2.99 3 3.99 4 # age(real) at M breakpoints

1 # GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=not implemented; 4=not implemented

0 #_Growth_Age_for_L1 #mid-season used for calculations
999 #_Growth_Age_for_L2 (999 to use as Linf)
0.1 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
#Should see if alternate t0 0 is better to admit growth effects of younger ages inflating CV
0 #_CV_Growth_Pattern:  0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A)
1 #_maturity_option:  1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern
#_placeholder for empirical age-maturity by growth pattern
1 #_First_Mature_Age
1 #_fecundity option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b
0 ### Hermaphroditism season ###
3 #_parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3=like SS2 V1.x)
1 #_env/block/dev_adjust_method (1=standard; 2=with logistic trans to keep within base parm bounds)
#_growth_parms
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn

# WCPFC fixed
# xxx MPa 0.075 4 2.5 2.5  0 1 -5 0 0 0 0 0 0.5 0 0 # NatM_p_1_Fem_GP:1_
# xxx MPa -3 3 -0.36 -0.36 0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MPa -3 3 -0.55 -0.55 0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MPa -3 3  0.4   0.4  0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MPa -3 3  0.28  0.28 0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_

# ICCAT flat M
# xxx MAt 0.075 2 0.8 0.8 0 1 -5 0 0 0 0 0 0.5 0 0 # NatM_p_1_Fem_GP:1_
# xxx MAt -3 3 -0.0 -0.0  0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MAt -3 3 -0.0 -0.0  0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MAt -3 3 -0.  -0.   0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MAt -3 3 -0.  -0.   0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_


# ICCAT flat M initial
# RTTP only
# xxx MeA1 0.075 2 0.8  0.8  0 1 5 0 0 0 0 0 0.5 0 0 # NatM_p_1_Fem_GP:1_
# xxx MeA1 -5    3 -0. -0.   0 1 7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MeA1 -5    3 -0. -0.   0 1 7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MeA1 -5    3 -0. -0.   0 1 6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# small-scale
# xxx MeAs 0.075 2 0.8  0.8  0 1 5 0 0 0 0 0 0.5 0 0 # NatM_p_1_Fem_GP:1_
# xxx MeAs -5    3 -0. -0.   0 1 7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MeAs -5    3 -0. -0.   0 1 7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
```

```
# xxx MeAs -5    3 -0. -0.   0 1 6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MeAs -5    3 -0. -0.   0 1 6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_


# Brownie (but not BP) L83 alt fixed
# Linf=83, Brownie: a(1:4)=   0.68      0.50      0.13      0.82
# xxx MB  0.075 2 0.68  0.68  0 1 -5 0 0 0 0 0 0.5 0 0 # NatM_p_1_Fem_GP:1_
# xxx MB  -5    3 -0.2926 -0.2926   0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MB  -5    3 -0. -0.   0 1 -7 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MB  -5    3 -1.347 -1.347   0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MB  -5    3 -0. -0.   0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_
# xxx MB  -5    3 1.8417 1.8417   0 1 -6 0 0 0 0 0 0.5 0 0 # NatM_p_2_Fem_GP:1_

  -30 30   20  20 0 100 -5 0 0 0 0 0 0.5 0 0 # L_at_Amin_Fem_GP_1
# xxx L83  50 100  83   83 0 100 -5 0 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
# xxx L83  -3 3  0.22 0.22 0 100 -1 0 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1
# xxx L70  50 100  70.2   70.2 0 100 -5 0 0 0 0 0 0.5 0 0 # L_at_Amax_Fem_GP_1
# xxx L70  -3 3  0.373 0.373 0 100 -1 0 0 0 0 0 0.5 0 0 # VonBert_K_Fem_GP_1

# start with CV20%, decrease to 10% at older ages
   0.01 60 0.2 0.2 0 100 -5 0 0 0 0 0 0.5 0 0 # CV_young_Fem_GP_1_ #try alternates to account for growth
   -3 3 -0.69 -0.69 0 100 -5 0 0 0 0 0 0.5 0 0  # CV_old_Fem_GP_1_ #try alternates to account for growth

 -3 3 5.32e-006 5.32e-006 0 100 -1 0 0 0 0 0 0.5 0 0 # Wtlen1_Fem
 2 4 3.34958 3.34958 0 100 -1 0 0 0 0 0 0.5 0 0 # Wtlen2_Fem

 1 150 38 38 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MAtm58 1 150 58 58 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MAtm38 1 150 38 38 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MeA1m58 1 150 58 58 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MeA1m38 1 150 38 38 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MeA.1m58 1 150 58 58 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MeA.1m38 1 150 38 38 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MBm58 1 150 58 58 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem
## xxx MBm38 1 150 38 38 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat50_Fem


# xxx check maturity slope sensible...
 -8 1 -1.25 -1.25 0 100 -1 0 0 0 0 0 0.5 0 0 # Mat_slope_Fem
 0 2 1 1 0 100 -1 0 0 0 0 0 0.5 0 0 # Eggs1_Fem
 -1 1 0 0 0 100 -1 0 0 0 0 0 0.5 0 0 # Eggs2_Fem
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0.5 0 0 # RecrDist_GP_1_
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0.5 0 0 # RecrDist_Area_1_
 -4 4 0 0 -1 99 -3 0 0 0 0 0 0.5 0 0 # RecrDist_Seas_1_
 -4 4 0 0 0 0.1 5 0 1 1983 2008 0.3 0 0 # RecrDist_Seas_2_
 -4 4 0 0 0 0.1 5 0 1 1983 2008 0.3 0 0 # RecrDist_Seas_3_
 -4 4 0 0 0 0.1 5 0 1 1983 2008 0.3 0 0 # RecrDist_Seas_4_
 1 1 1 1 -1 99 -3 0 0 0 0 0 0.5 0 0 # CohortGrowDev
# 0  #custom_MG-env_setup (0/1)
# -2 2 0 0 -1 99 -2 #_placeholder for no MG-environ parameters
# 0  #custom_MG-block_setup (0/1)
# -2 2 0 0 -1 99 -2 #_placeholder for no MG-block parameters
#_seasonal_effects_on_biology_parms
 0 0 0 0 0 0 0 0 0 0 #_femwtlen1,femwtlen2,mat1,mat2,fec1,fec2,Malewtlen1,malewtlen2,L1,K
# -2 2 0 0 -1 99 -2 #_placeholder for no seasonal MG parameters
# -2 2 0 0 -1 99 -2 #_placeholder for no MG dev parameters
5 # placeholder for #_MGparm_Dev_Phase
#_Spawner-Recruitment
6 #_SR_function: 1=null; 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=Survival_3Parm
#_LO HI INIT PRIOR PR_type SD PHASE
 0 35 20 20 0 10 1 # SR_R0 ##
# xxx h55 0.201 0.99 0.55 0.55 0 10 -2 # SR_steepness
# xxx h65 0.201 0.99 0.65 0.65 0 10 -2 # SR_steepness
# xxx h75 0.201 0.99 0.75 0.75 0 10 -2 # SR_steepness
# xxx h85 0.201 0.99 0.85 0.85 0 10 -2 # SR_steepness
# xxx h95 0.201 0.99 0.95 0.95 0 10 -2 # SR_steepness
  0 10 0.6 0.6 0 10 6 # SR_sigmaR
 -5 5 0 0 0 1 -3 # SR_envlink
 -5 5 0 0 0 1 -4 # SR_R1_offset ## changed from -4 (fixed) to 1 (estimated) ##
 0 0.5 0 0 -1 99 -2 # SR_autocorr
0 #_SR_env_link
0 #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
# xxx r0   0 #do_recdev:  0=none; 1=devvector; 2=simple deviations
# xxx rqs  1 #do_recdev:  0=none; 1=devvector; 2=simple deviations
1983 # first year of main recr_devs; early devs can preceed this era
2008 # last year of main recr_devs; forecast devs start in following year
4 #_recdev phase
1 #0 # (0/1) to read 11 advanced options
0 #_recdev_early_start (0=none; neg value makes relative to recdev_start)
-4 #_recdev_early_phase
-10 #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
1 #_lambda for prior_fore_recr occurring before endyr+1
960 #_last_early_yr_nobias_adj_in_MPD
1983 #_first_yr_fullbias_adj_in_MPD
2008 #_last_yr_fullbias_adj_in_MPD
2009 #_first_recent_yr_nobias_adj_in_MPD
1 #_max_bias_adj_in_MPD
0 # period of cycle in recruitment
```

```
-15 #min rec_dev
15 #max rec_dev
0 #_read_recdevs
#_end of advanced SR options
#Fishing Mortality info
0.15 # F ballpark for tuning early phases
2000 # F ballpark year(neg value to disable)
3 # F_Method:  1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
7 # max F or harvest rate, depends on F_Method ## We can changed from 0.99 to 4 if F_method is hyblid(3) ##
# no additional F input needed for Fmethod 1
# read overall start F value; overall phase; N detailed inputs to read for Fmethod 2
5 # read N iterations for tuning for Fmethod 3 (recommend 3 to 7)
# Fleet Year Seas F_value se phase (for detailed setup of F_Method=2)
#_initial_F_parms
#_LO HI INIT PRIOR PR_type SD PHASE ## changed the following maximum values from 0.9 to 3.99 ##

 0 3.99 0.0 0.0   0 100  -1 # InitF_1_LL (longline)
 0 3.99 0.0 0.0   0 100  -1 # InitF_2_PSFS
 0 3.99 0.0 0.0   0 100  -1 # InitF_3_PSLS
 0 3.99 0.0 0.0   0 100  -1 # InitF_4_Other

#_Q_setup
 # A=do power, B=env-var, C=extra SD, D=devtype(<0=mirror, 0/1=none, 2=cons, 3=rand, 4=randwalk); E=0=num/1=bio, F=err_type
 #_A  B  C  D  E  F ## change the following values of error-type from 0 to 30 for the future ##
 0 0 0 0
 0 0 0 0
 0 0 0 0
 0 0 0 0
 0 0 0 0
 0 0 0 0
 # 0 #_0=read one parm for each fleet with random q; 1=read a parm for each year of index
#_Q_parms(if_any)
# # Double normal size selectivity option
# # Start Size Sel Block
# #_size_selex_types
# #_Pattern Discard Male Special
# 24 0 0 0 # 1
# 24 0 0 0 # 2
# 24 0 0 0 # 3
# 24 0 0 0 # 4
# 5  0 0 1 # 1

#_size_selex_types
#_Pattern Discard Male Special
# piecewise size selex
# 6 0 0 9 # 1
# 6 0 0 7 # 2
# 6 0 0 7 # 3
# 6 0 0 7 # 4
# 5 0 0 1 # 5

# cubic spline size selex
 27 0 0 7 # 1
 27 0 0 5 # 2
 27 0 0 5 # 3
 27 0 0 5 # 4
 5 0 0 1 # CPUE mirror 1
 5 0 0 3 # CPUE mirror 3
#_age_selex_types = none
10 0 0 0 # f1
10 0 0 0 # f2
10 0 0 0 # f3
10 0 0 0 # f4
10 0 0 0 # cpue1
10 0 0 0 # cpue FSLS
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
## 1. LL (longline)
#
# fishery 1 #max age 15
# LO HI INIT PRIOR PR_type SD PHASE
#len bounds
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
 0 0 0 0 -1 0 -99 0 0 0 0 0.5 0 0 # SizeSpline_Code_PL_1
 -0.001 1 0.247221 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradLo_PL_1
 -1 0.001 -0.658209 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradHi_PL_1
 1 1 22.6447 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_1_PL_1
 1 1 37.5977 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_2_PL_1
 1 1 42.0377 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_3_PL_1
 1 1 45.702 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_4_PL_1
 1 1 51.7386 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_5_PL_1
 1 1 59.9904 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_6_PL_1
 1 1 71.3145 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_7_PL_1
 -9 7 -4.42509 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_1_PL_1
 -9 7 -2.2233 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_2_PL_1
 -9 7 -1.56912 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_3_PL_1
 -9 7 -1 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_4_PL_1
 -9 7 -1.26099 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_5_PL_1
 -9 7 -0.55179 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_6_PL_1
```

```
 -9 7 -0.579285 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_7_PL_1
 0 0 0 0 -1 0 -99 0 0 0 0 0.5 0 0 # SizeSpline_Code_PSLS_2
 -0.001 1 0.622317 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradLo_PSLS_2
 -1 0.001 -0.110388 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradHi_PSLS_2
 1 1 23.125 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_1_PSLS_2
 1 1 41.9035 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_2_PSLS_2
 1 1 45.6322 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_3_PSLS_2
 1 1 50.2975 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_4_PSLS_2
 1 1 70.9228 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_5_PSLS_2
 -9 7 -8.9974 0 1 0.001 -2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_1_PSLS_2
 -9 7 -2.05844 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_2_PSLS_2
 -9 7 -1 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_3_PSLS_2
 -9 7 -0.954789 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_4_PSLS_2
 -9 7 -2.24451 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_5_PSLS_2
 0 0 0 0 -1 0 -99 0 0 0 0 0.5 0 0 # SizeSpline_Code_PSFS_3
 -0.001 1 0.0149309 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradLo_PSFS_3
 -1 0.001 -0.245826 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradHi_PSFS_3
 1 1 23.1313 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_1_PSFS_3
 1 1 44.1442 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_2_PSFS_3
 1 1 48.4634 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_3_PSFS_3
 1 1 54.7779 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_4_PSFS_3
 1 1 71.2972 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_5_PSFS_3
 -9 7 -8.99994 0 1 0.001 -2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_1_PSFS_3
 -9 7 -2.04755 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_2_PSFS_3
 -9 7 -1 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_3_PSFS_3
 -9 7 -1.02858 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_4_PSFS_3
 -9 7 -1.20735 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_5_PSFS_3
 0 0 0 0 -1 0 -99 0 0 0 0 0.5 0 0 # SizeSpline_Code_Other_4
 -0.001 1 0.0655165 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradLo_Other_4
 -1 0.001 -0.202624 0 1 0.001 3 0 0 0 0 0.5 0 0 # SizeSpline_GradHi_Other_4
 1 1 22.5552 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_1_Other_4
 1 1 44.2844 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_2_Other_4
 1 1 51.4468 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_3_Other_4
 1 1 58.8149 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_4_Other_4
 1 1 72.4351 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Knot_5_Other_4
 -9 7 -4.41096 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_1_Other_4
 -9 7 -1.92167 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_2_Other_4
 -9 7 -1 0 -1 0 -99 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_3_Other_4
 -9 7 -0.364211 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_4_Other_4
 -9 7 0.286711 0 1 0.001 2 0 1 2004 2008 0.05 0 0 # SizeSpline_Val_5_Other_4
 1 1 1 1 1 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_1_PL_CPUE
 22 22 22 22 1 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_PL_CPUE
 3 3 3 3 3 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_1_PSFS_CPUE
 22 22 22 22 1 99 -3 0 0 0 0 0.5 0 0 # SizeSel_5P_2_PSFS_CPUE

# xxx sa 4 # selparm_Dev_Phase
# xxx sa 1 # selparm_adjust_method 1=direct, 2=logistic transform

# xxx ss -4 # selparm_Dev_Phase
# xxx ss 1 # selparm_adjust_method 1=direct, 2=logistic transform




1 # TG_custom:  0=no read; 1=read
#tag loss parameter - for each tag grp
# -10 10 9 9 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_
# chronic tag loss - for each tag group
# -10 10 9 9 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_chronic_1_
# Overdispersion  for the negative binomial for each tag group
# 1 10 200 200 1 0.001 -4 0 0 0 0 0 0 0 # TG_overdispersion_1_
#tag loss parameter - for each tag grp
# -10 10 9 9 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_
#set to negligible value

*****************    Repeated release group parameters are omitted below here ****************************

# xxx rttp # xxx L83 -15 10 -10 -10 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_ by release group what is the parameter definition; what is 1,2,3 ?!
# xxx rtss # xxx L83 -15 10 -10 -10 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_ by release group what is the parameter definition; what is 1,2,3 ?!
# xxx rttp # xxx L70 -15 10 -10 -10 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_ by release group what is the parameter definition; what is 1,2,3 ?!
# xxx rtss # xxx L70 -15 10 -10 -10 1 0.001 -4 0 0 0 0 0 0 0 # TG_loss_init_1_ by release group what is the parameter definition; what is 1,2,3 ?!

# chronic tag loss - for each tag group
# xxx rttp # xxx L83  -15 10 -4.185 -4.185 1 0.001 -4 0 0 0 0 0 0 0  # chronic tag loss
# xxx rtss # xxx L83  -15 10 -4.185 -4.185 1 0.001 -4 0 0 0 0 0 0 0  # chronic tag loss
# xxx rttp # xxx L70  -15 10 -4.185 -4.185 1 0.001 -4 0 0 0 0 0 0 0  # chronic tag loss
# xxx rtss # xxx L70  -15 10 -4.185 -4.185 1 0.001 -4 0 0 0 0 0 0 0  # chronic tag loss

# Overdispersion  for the negative binomial for each tag group
# xxx rttp # xxx L83 # xxx od02 1 150   2 2 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rtss # xxx L83 # xxx od02 1 150   2 2 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rttp # xxx L70 # xxx od02 1 150   2 2 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rtss # xxx L70 # xxx od02 1 150   2 2 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion

# Overdispersion  for the negative binomial for each tag group
# xxx rttp # xxx L83 # xxx od20 1 150   20 20 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rtss # xxx L83 # xxx od20 1 150   20 20 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rttp # xxx L70 # xxx od20 1 150   20 20 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
```

```
# xxx rtss # xxx L70 # xxx od20 1 150   20 20 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion

# Overdispersion  for the negative binomial for each tag group
# xxx rttp # xxx L83 # xxx od70 1 150   70 70 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rtss # xxx L83 # xxx od70 1 150   70 70 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rttp # xxx L70 # xxx od70 1 150   70 70 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion
# xxx rtss # xxx L70 # xxx od70 1 150   70 70 1 0.001 -4 0 0 0 0 0 0 0 # tag overdispersion

*****************    Repeated release group parameters are omitted above here ****************************

#PS recoveries already inflated by RR (PSLS and PSFS), estimate PL, force zero for others
#_LO HI INIT PRIOR PR_type SD PHASE env-var use_dev dev_minyr dev_maxyr dev_stddev Block Block_Fxn
-20  20  0  0  1  99  1  0  0  0  0  0  0  0  #  TG_report_fleet:_1_
-20  20  10  10  1  0.2  -4  0  0  0  0  0  0  0  #  TG_report_fleet:_2_
-20  20  10  10  1  0.2  -4  0  0  0  0  0  0  0  #  TG_report_fleet:_2_
-20  20  -10.  -10.  1  2.  -4  0  0  0  0  0  0  0  #  TG_report_fleet:_1_
# LO HI INIT PRIOR PR_type SD PHASE
# Exponential decay rate in reporting rate for each fleet (default=0, negative value to get decay)
 -4 0 0 0 0 2 -4 0 0 0 0 0 0 0 # TG_rpt_decay_fleet:_1_
 -4 0 0 0 0 2 -4 0 0 0 0 0 0 0 # TG_rpt_decay_fleet:_2_
 -4 0 0 0 0 2 -4 0 0 0 0 0 0 0 # TG_rpt_decay_fleet:_1_
 -4 0 0 0 0 2 -4 0 0 0 0 0 0 0 # TG_rpt_decay_fleet:_2_
1 #_Variance_adjustments_to_input_values
#_1 2 3
  0 0 0 0 0 0 #_add_to_survey_CV
  0 0 0 0 0 0 #_add_to_discard_CV
  0 0 0 0 0 0 #_add_to_bodywt_CV
# xxx CL1   1.0 1.0 1.0 1.0 1 1 #_mult_by_lencomp_N
# xxx CL5   0.5 0.5 0.5 0.5 1 1 #_mult_by_lencomp_N
# xxx CL2   0.2 0.2 0.2 0.2 1 1 #_mult_by_lencomp_N
# xxx CL04   0.04 0.04 0.04 0.04 1 1 #_mult_by_lencomp_N
  1 1 1 1 1 1 #_mult_by_agecomp_N
  1 1 1 1 1 1 #_mult_by_size-at-age_N
# 30 #_DF_for_discard_like
# 30 #_DF_for_meanbodywt_like
4 #_maxlambdaphase
1 #_sd_offset
10 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes:  1=survey; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin
#like_comp fleet/survey  phase  value  sizefreq_method

#CPUE
#keep or drop PSFS coupled with PL series
# xxx U0 1 6 1 0.  1
# xxx U1 1 6 1 1.  1

#size
  4 1 1 1. 1
  4 2 1 1. 1
  4 3 1 1. 1
  4 4 1 1. 1
# tags...not clear on assignment definitions
# 15 tag-comp does not seem to do anything?
#
 15 2 2 1.  1
 15 3 2 1.  1
#seems to do something
 16 1 2 1.  1
 16 2 2 1.  1
 16 3 2 1.  1
# lambdas (for info only; columns are phases)
#  0 #_CPUE/survey:_1
#  0 #_CPUE/survey:_2
#  1 #_CPUE/survey:_3
#  1 #_lencomp:_1
#  1 #_lencomp:_2
#  0 #_lencomp:_3
#  1 #_init_equ_catch
#  1 #_recruitments
#  1 #_parameter-priors
#  0 #_parameter-dev-vectors
#  100 #_crashPenLambda
0 # (0/1) read specs for extra stddev reporting
 # 0 1 -1 5 1 5 1 -1 5 # placeholder for selex type, len/age, year, N selex bins, Growth pattern, N growth ages, NatAge_area(-1 for all), NatAge_yr, N Natages
 # -1 1 1 1 1 # placeholder for vector of selex bins to be reported
 # -1 1 1 1 1 # placeholder for vector of growth ages to be reported
 # -1 1 1 1 1 # placeholder for vector of NatAges ages to be reported
999
```

Appendix 2. Additional Diagnostics for the One Area Model (selectivity, recruitment deviates and Tag fits by group and time)

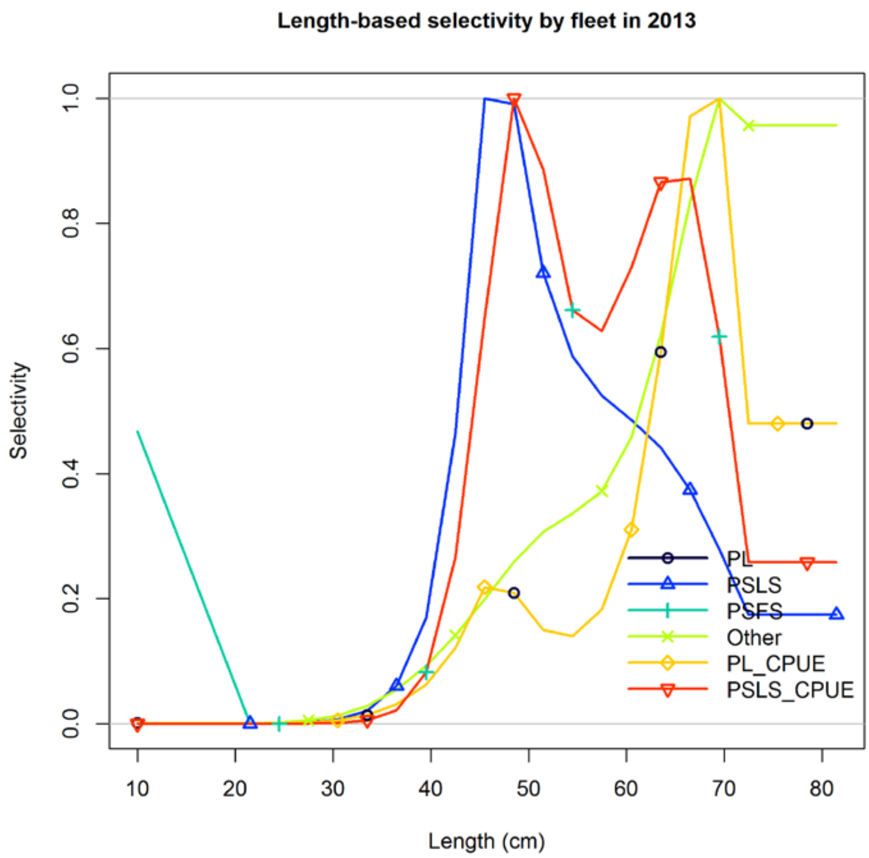


Figure 1: Selectivity curves by length and gear for the model with M fixed (M1, Table 4)

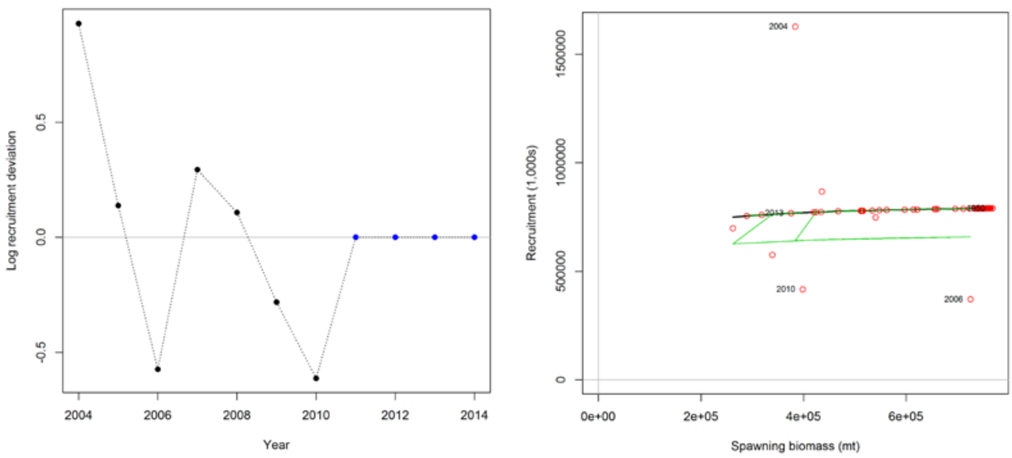


Figure 2: Recruitment deviates and fits to Spawning Biomass data

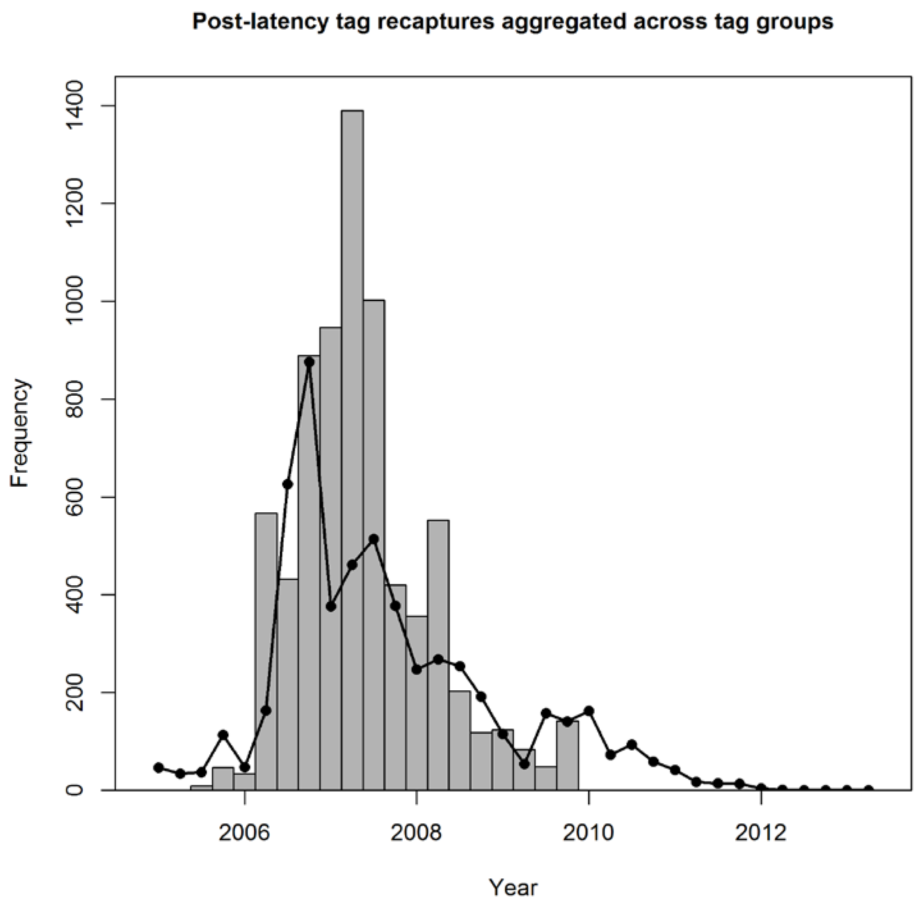
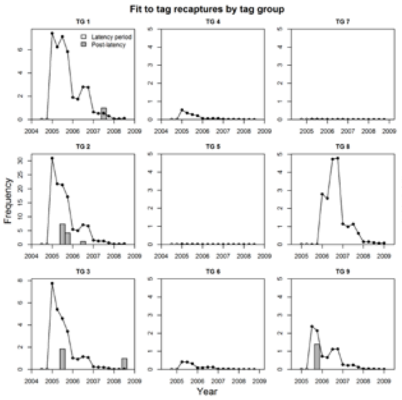
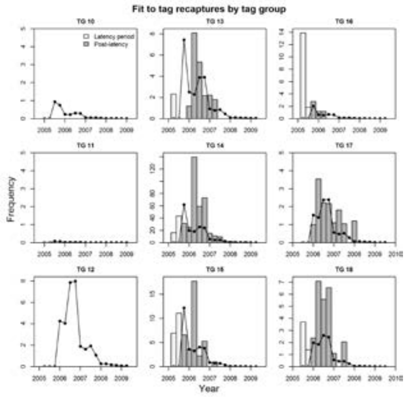
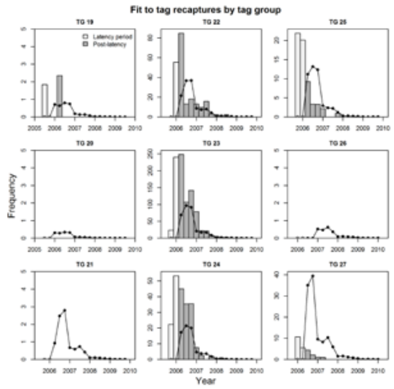
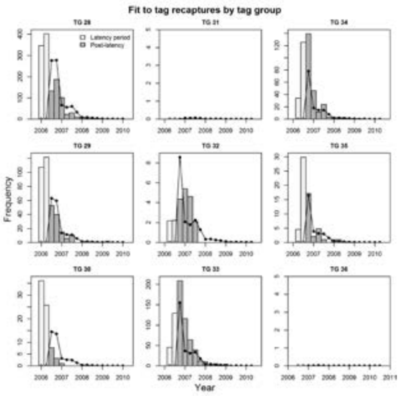


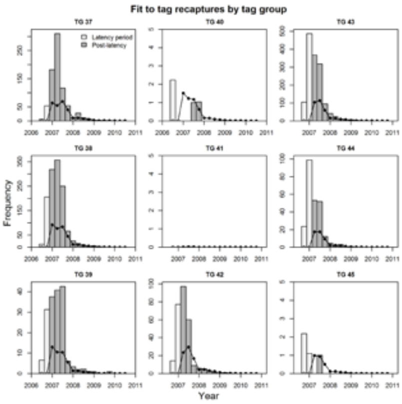
Figure 3: Fit to Tag data across all years

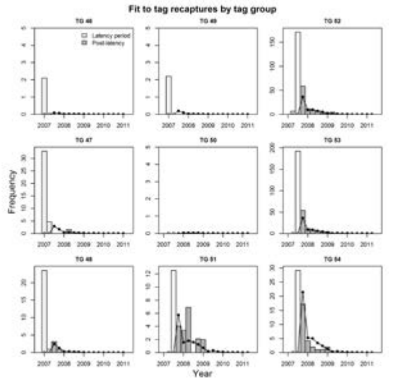

Fit to tag recaptures by tag group

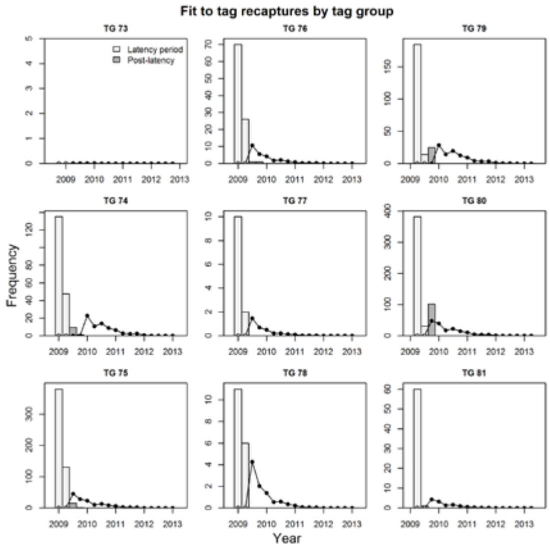

Fit to tag recaptures by tag group

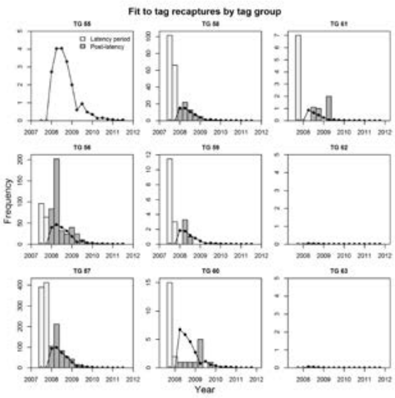

Fit to tag recaptures by tag group

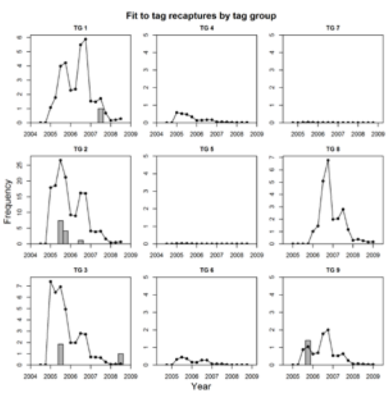

Fit to tag recaptures by tag group

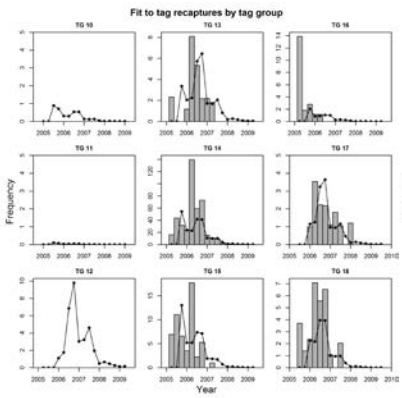

Fit to tag recaptures by tag group

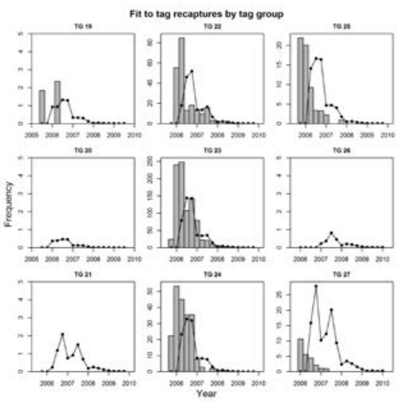

Fit to tag recaptures by tag group


Fit to tag recaptures by tag group
Latency period
Post-latency


Fit to tag recaptures by tag group


Fit to tag recaptures by tag group


Fit to tag recaptures by tag group


Fit to tag recaptures by tag group

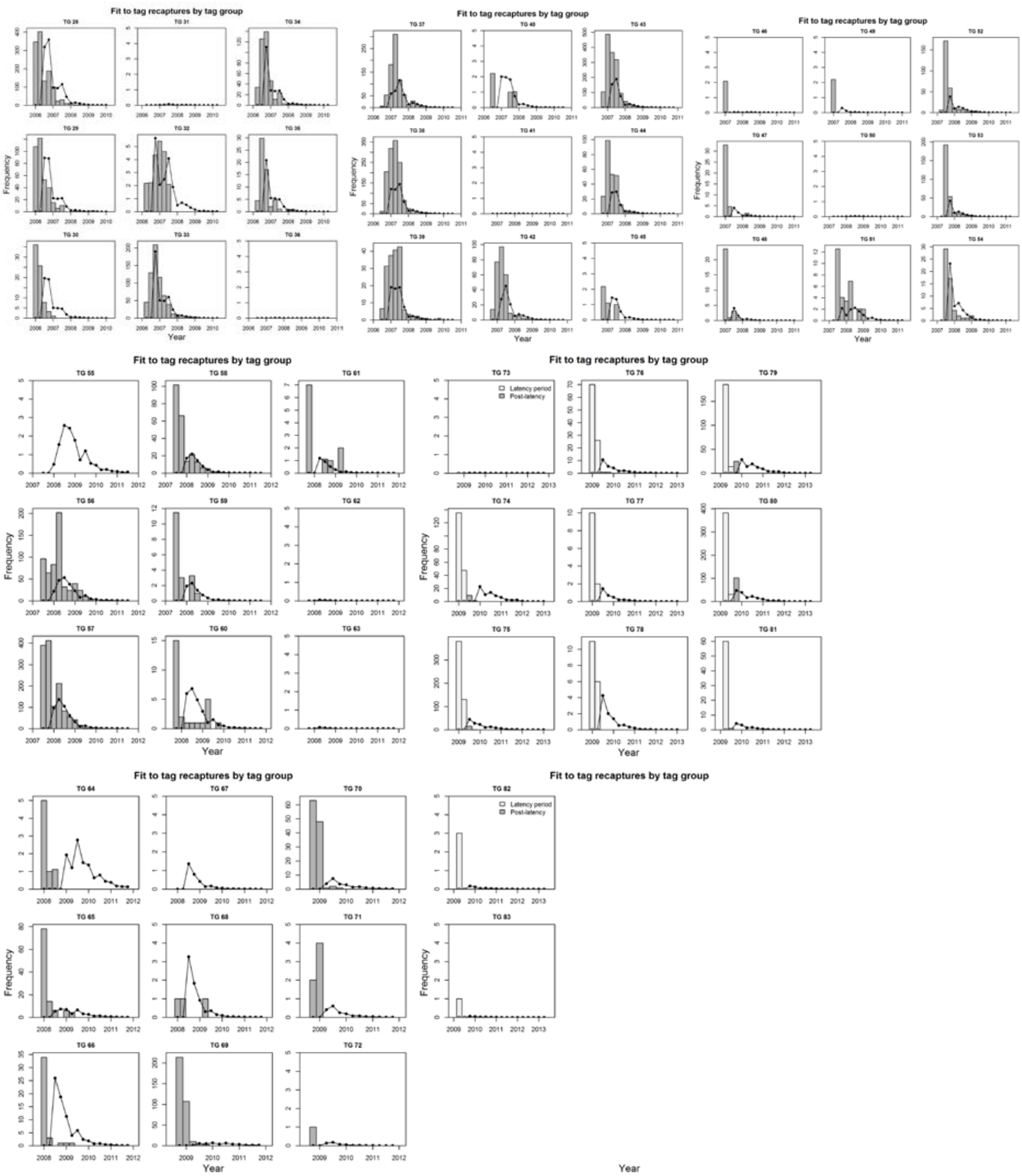


Figure 4: Fit to Tag data by Tag group

Appendix 3. Final Model Results from revised grid proposed by WPTT

Table 1: Grid examined for the new grid

Assumption	Option
Spatial domain	***io;*** Indian Ocean with one area
Beverton-Holt SR Steepness (h)	h=0.7 h=0.8 **h=0.90 (Base case)**
Growth, and Maturity	***Richards (base case);***
Natural Mortality	*0.7, 0.8 & 0.9*
CPUE* σ=SD lognormal errors	***PL;*** σ=0.1; ***PSLS;*** σ=0.1; (2 series for PS, one with effort creep 3%, other no change)
Recruitment σ=SD(log(devs))	**σ=0.6 deviates estimated for PL series 2004-10** (**base case**) σ=0.6 deviates estimated for PL series and PSLS series 1985-2010.
Catch-at-Length (SS=assumed sample)	***CL1000;*** *SS* = $N_{PL,PS\ input}$ = min(N_{obs} /10, 1000) and $N_{OTHER\ input}$= min(N_{obs} /10, 100), lambda=1, **base case (note when we use these values ESS is corrected by another multiplier of 0.04, making the ESS 40 for PL&PS and 4 for the other fisheries components)** ***Downweighted option LC and Tags (***lambda=0.5 Tags, 0.25 LC, ESS=10 PL/PS and 1 for OT) No Tage Option
Tag Data	τ = 2, implying the negative binomial component close to a Poisson in the likelihood of the tag data, mixing period=2 quarters

Results of the revised Grid:

Due to te model poorly estimating F_{MSY} the model results reported were relative to Bo and a proxy f was reported relative to C_{MSY}. Final results of the grid are shown in Table 2 and the results of the Stock status is shown in Figure 2 (a set of runs is shown in Figure).

Table 2: Key results of the revised grid using updated PS CPUE data (Sote et. al. 2014), and not using the case where the tag data was weighed equalyy with CPUE data and no length composition data was used.

Management Quantity	Indian Ocean
2013 catch estimate	424,580
Mean catch from 2009–2013	401,100
MSY (1000 t) (80% CI)	684 (550–849)
Data period used in assessment	1950–2013
F_{MSY} (80% CI)*	0.65 (0.51–0.79)
SB_{MSY} (1000 t) (80% CI)	875 (708.5–1,075)
F_{2013}/F_{MSY} (80% CI)*	0.42 (0.25–0.62)
C_{2013}/C_{MSY} (80% CI)*	0.62 (0.49-0.75)
B_{2013}/B_{MSY} (80% CI)	n.a.
SB_{2013}/SB_{MSY} (80% CI)	1.59 (1.13–2.14)
B_{2013}/B_{1950} (80% CI)	n.a.
SB_{2013}/SB_{1950} (80% CI)	0.5 (0.53–0.62)
$B_{2013}/B_{1950,\ F=0}$ (80% CI)	n.a.
$SB_{2013}/SB_{1950,\ F=0}$ (80% CI)	n.a.

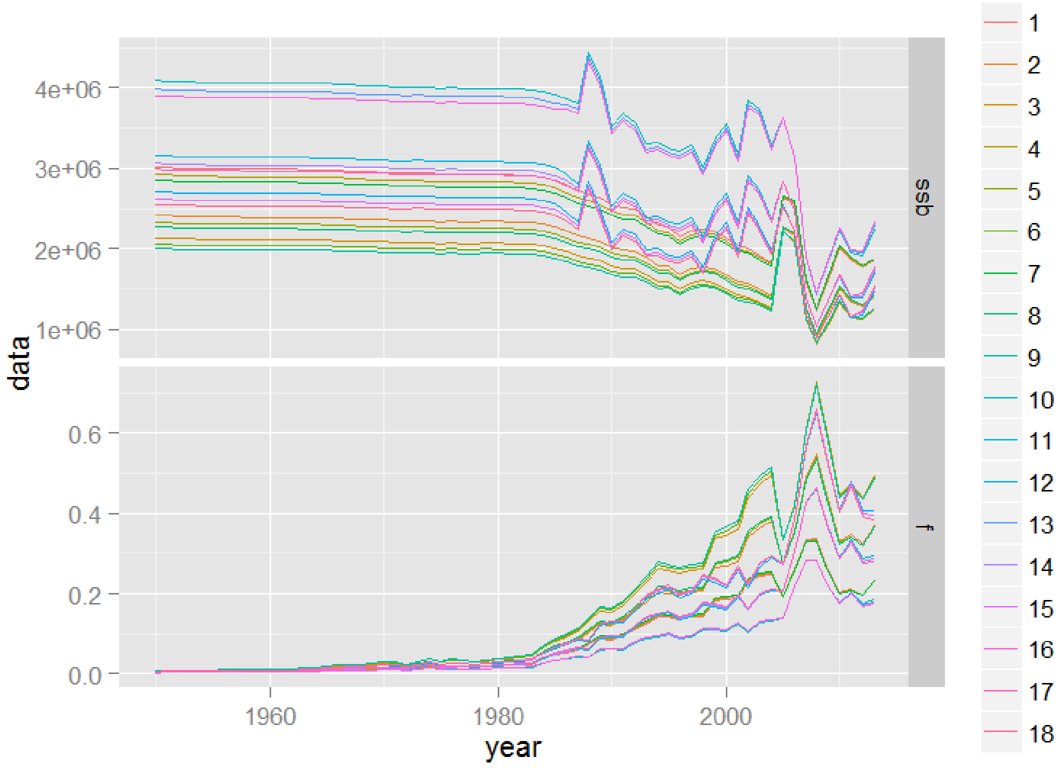


Figure 1: Runs showing equal weight to tag data, length composition and CPUE data, assuming no changes to PS catchability.

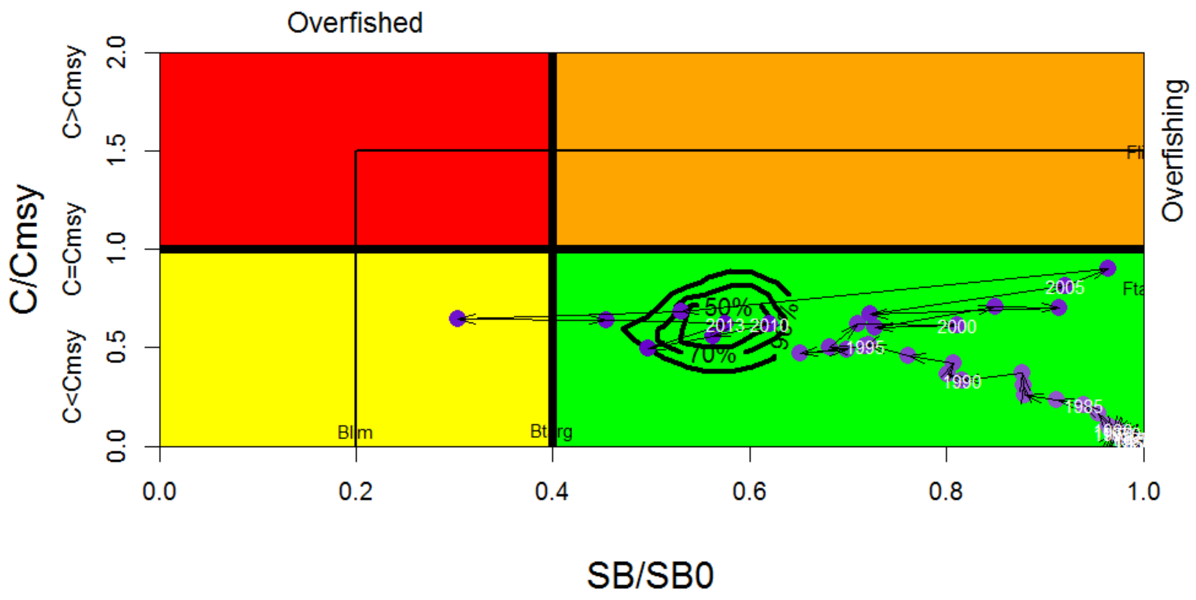


Figure. 2. Skipjack tuna: SS3 Aggregated Indian Ocean assessment Kobe plot (contours are the 50, 70 and 90 percentiles of the 2013 estimate). Blue circles indicate the trajectory of the point estimates for the SB/SB0 ratio and F proxy ratio for each year 1950–2013 estimated as C/C_{MSY}. Interim target (Ftarg and SBtarg) and limit (Flim and SBlim) reference points, are based on 0.4 (0.2) B_0 and C/C_{MSY}=1 (1.5) as suggested by WPTT and used by SPC.