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STOCK ASSESSMENT OF YELLOWFIN TUNA IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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Nick Davies, Shelton Harley, John Hampton,

and Sam McKechnie

Oceanic Fisheries Programme

Secretariat of the Pacific Community, Noumea, New Caledonia

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EXECUTIVE SUMMARY

This paper presents the 2014 assessment of yellowfin tuna in the western and central Pacific Ocean. This assessment is supported by several other analyses which are documented separately, but should be considered as part of this assessment as they underpin many of the fundamental inputs to the models. The updated assessment addresses many of the recommendations provided in the report of the "Independent Review of the 2011 bigeye tuna stock assessment" (Ianelli et al., 2012), which apply equally to yellowfin tuna. Other key papers document: the methods used in producing the purse seine size data (Abascal et al. 2014), longline size data (McKechnie 2014), longline CPUE data (McKechnie et al. 2014b), and tagging data (Berger et al. 2014); revisions to the fisheries and spatial definitions (McKechnie et al. 2014a); the guidance of the Pre-Assessment Workshop (PAW) held in April, 2014 (OFP 2014).

Some of the main improvements in the 2014 assessment are:

- Increases in the number of spatial regions to better model the tagging and size data;
- Inclusion of catch estimates from Vietnam and some Japanese coastal longline data previously not included;
- The use of operational longline data for multiple fleets to better address the contraction of the Japanese fleet and general changes over time in targeting practices;
- Improved modelling of recruitment to ensure that uncertain estimates do not influence key stock status outcomes; and
- A large amount of new tagging data corrected for differential post-release mortality and other tag loss.

The large number of changes since the 2011 assessment (some of which are described above), and the nature of some of these changes, means that full consideration of the impacts of individual changes is not possible. Nevertheless, the report details some of the steps from the 2011 reference case (LLcpueOP_TWcpueR6_PTTP) to the 2014 reference case (run37 – Ref.Case). Distinguishing features of the 2014 reference case model include:

- The steepness parameter of the stock recruitment relationship is fixed at 0.8.
- Long-term average recruitment is defined for the period 1965-2011.
- Natural mortality at age is fixed according to an external analysis in which it is assumed that the natural mortality rate of females increases with the onset of reproductive maturity.
- The likelihood function weighting of the size data is determined using an effective sample size for each fishing observation of one-twentieth of the actual sample size, with a maximum effective sample size of 50.
- For modelling the tagging data, a mixing period of 2 quarters (including the quarter of release) is applied.
- The last four quarterly recruitments aggregated over regions are assumed to lie on the stock-recruitment curve.

The rationale for these choices, which comprise the key areas of uncertainty for the assessment, is described in detail in the report. We report the results of "one-off" sensitivity models to explore the impact of these choices for the reference case model on the stock assessment results. A sub-set of key, plausible model runs was taken from these sensitivities to include in a structural uncertainty analysis (grid) for consideration in developing management advice.

The main conclusions of the current assessment are consistent with recent assessments presented in 2009 and 2011. The main conclusions are as follows.

1. The new regional structure appears to work well for yellowfin, and in combination with other modelling and data improvements, provides a more informative assessment than in the past.
2. Spatially-aggregated recruitment is estimated to decline in the early part of the assessment, but there is no persistent trend post-1965.
3. There appears to be confounding between the estimates of regional recruitment distribution and movement such that certain regions have very low recruitments. While adding

complexity to the recruitment process of age 1 fish, this did not add to the uncertainty over the range of runs considered in this assessment.

4. Latest catches marginally exceed the maximum sustainable yield (MSY).
5. Recent levels of fishing mortality are most likely below the level that will support the MSY.
6. Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the level which will support the MSY.
7. Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the limit reference point of 20%$SB_{F=0}$ agreed by WCPFC.
8. Recent levels of spawning potential are most likely higher (by 1%, based on 2008-11 average) and lower than (by 2% based on 2012) the candidate biomass-related target reference points currently under consideration for skipjack tuna, i.e., 40-60%$SB_{F=0}$.
9. Stock status conclusions were most sensitive to alternative assumptions regarding the modelling of tagging data, assumed steepness and natural mortality. However the main conclusions of the assessment are robust to the range of uncertainty that was explored.

The report also includes recommendations for future stock assessments of yellowfin tuna, including research activities to improve model inputs.

1 INTRODUCTION

This paper presents the current stock assessment of yellowfin tuna (*Thunnus albacares*) in the western and central Pacific Ocean (WCPO, west of 150°W). The first assessment was conducted in 1999 and assessments were conducted annually until 2007. The most recent assessments are documented in Hampton and Kleiber (2003), Hampton et al. (2004, 2005 and 2006) and Langley et al. (2007, 2009, 2011). The current assessment incorporates the most recent data from the yellowfin fishery and maintains the model structure of the recent assessments. The sensitivity of the key results of assessment to a range of model assumptions, principally related to uncertainty in the various input data sets, is also examined.

This assessment is supported by several other analyses which are documented separately, but should be considered in reviewing this assessment. These include: improved purse seine catch estimates (Lawson 2011; Lawson & Sharples 2011), reviews of the catch statistics of the component fisheries (Williams 2014; Williams & Terawasi 2014), standardised CPUE analyses of operational level catch and effort data (McKechnie et al. 2014b, Pilling et al. 2014, Bigelow et al. 2014), size data inputs from the purse seine (Abascal et al., 2014) and longline fisheries (McKechnie 2014), revised regional structures and fisheries definitions (McKechnie et al., 2014a), preparation of tagging data and reporting rate information (Berger et al., 2014). Finally, many of these issues were discussed in detail at Pre-Assessment Workshop held in Noumea in April, 2014 (SPC-OFP 2014). Further the 2011 assessment of bigeye tuna in the WCPO was the focus of a detailed independent review (Ianelli et al., 2012) and some of the recommendations from the review have been incorporated in the current yellowfin assessment.

The overall objectives of the assessment are to estimate population parameters, such as time series of recruitment, biomass and fishing mortality, which indicate the status of the stock and impacts of fishing. We also summarise stock status in terms of well-known reference points, such as the ratios of recent stock biomass to the biomass at maximum sustainable yield (SB_{latest}/SB_{MSY} but also $SB_{current}/SB_{MSY}$) and recent fishing mortality to the fishing mortality at MSY ($F_{current}/F_{MSY}$).

The methodology used for the assessment is that commonly known as MULTIFAN-CL (Fournier et al. 1998; Hampton and Fournier 2001; Kleiber et al. 2003; http://www.multifan-cl.org), which is software that implements a size-based, age- and spatially-structured population model. Parameters of the model are estimated by maximizing an objective function consisting both of likelihood (data) and prior information components. Structural uncertainty was described over a range of the key model assumptions that produced a "grid" of all combinations of each option, and the distribution of reference point ratios is presented to describe their uncertainty.

As in previous years, a Pre-assessment Workshop (PAW) was held prior to the commencement of the current stock assessment (SPC-OFP 2014). The PAW reviewed the main input data sets and provided recommendations regarding the range of assessment model options and sensitivities to be included within the stock assessment. These recommendations provided the main direction for the current assessment.

2 BACKGROUND

2.1 Stock structure

For the purpose of yellowfin assessments, the stock within the domain of the model area (essentially the WCPO, west of 150°W, Figure 1) has been considered as a discrete stock unit (Langley 2007, 2009, 2011). This area has been disaggregated into model regions so as to describe to some effect spatial processes (such as recruitment and movement) and fishing mortality within regions. Information about stock structure includes a large amount of tagging data (1989-2012), from which the movement of tagged fish among regions can be used to infer movement coefficients. This information indicates extensive latitudinal movements among the equatorial regions but also a level of longitudinal movements to and from the sub-tropical latitudes (Figure 2). For the current assessment, the model domain is disaggregated further, into 9 regions (Figure 1), and this is described further in section 3.1.

2.2 Biological characteristics

Yellowfin tuna are distributed throughout the tropical and sub-tropical waters of the Pacific Ocean. However, there is some indication of restricted mixing between the western and eastern Pacific based on analysis of genetic samples (Ward et al. 1994) and tagging data. Adults (larger than about 100 cm) spawn, probably opportunistically, in waters warmer than 26°C (Itano 2000), while juvenile yellowfin are first encountered in commercial fisheries (mainly surface fisheries in Philippines and eastern Indonesia) at several months of age.

Yellowfin tuna are relatively fast growing, and have a maximum fork length (FL) of about 180 cm. The growth of juveniles departs from von Bertalanffy type growth with the growth rate slowing between about 40 and 70 cm FL (Lehodey and Leroy 1999). The first age-class has a mean fork length of around 25 cm and is approximately three months of age according to analysis of daily structures on otoliths (Lehodey and Leroy 1999).

It is recognised there are possibly regional differences in growth rate for yellowfin tuna. There is some indication that young yellowfin may grow more slowly in the waters of Indonesia and the Philippines than in the wider area of the WCPO (Yamanaka 1990). This is further supported by the comparison between the growth rates derived from WCPO yellowfin stock assessment (Hampton et al. 2006) and the growth rates derived from a MFCL model that included only the single western, equatorial region (region 3) (Langley et al. 2007, Figure 1). The growth rates from the western equatorial region alone were considerably lower than from the WCPO, with the former growth rates more consistent with the growth of yellowfin in the southern Philippines waters (Yamanaka 1990) and growth increments from tag release/recovery data. On the other hand, the growth rates from the WCPO MFCL model are more consistent with the growth rates determined from daily growth increments from a collection of otoliths collected from a broad area of the equatorial WCPO (Lehodey and Leroy 1999). However, an examination of region-specific growth was beyond the scope of this assessment and the importance of this feature upon the stock assessment results is unknown.

The natural mortality rate is strongly variable with size, with the lowest rate of around 0.6–0.8 yr^{-1} being for pre-adult yellowfin 50–80 cm FL (Hampton 2000). Tag recapture data indicate that significant numbers of yellowfin reach four years of age. The longest period at liberty for a recaptured yellowfin, tagged in the western Pacific at about 1 year of age, is currently 6 years.

For the purpose of computing the spawning biomass, we assume a fixed maturity schedule consistent with the observations of Itano (2000).

2.3 Fisheries

Yellowfin tuna, an important component of tuna fisheries throughout the WCPO, are harvested with a wide variety of gear types, from small-scale artisanal fisheries in Pacific Island and southeast Asian waters to large, distant-water longliners and purse seiners that operate widely in equatorial and tropical waters. Purse seiners catch a wide size range of yellowfin tuna, whereas the longline fishery takes mostly adult fish.

The industrial purse-seine fishery accounts for a large proportion of the total yellowfin tuna catch (Figure 3). However, there is uncertainty regarding the accuracy of the reported purse-seine catch as catches may significantly under-estimate actual catch levels (Lawson 2009 and 2010, Lawson & Sharples 2011), the purse seine catch history has been corrected for the over-reporting of skipjack and under-reporting of yellowfin+bigeye on logsheets (Hampton and Williams 2011, Abascal et al. 2014) and for the selection bias in grab samples (spill-sample corrected purse seine estimates). These corrected catches represent the primary catch data incorporated in the stock assessment and are the basis of quoted catch estimates in this paper. The corrected annual catch estimates are substantially higher than the uncorrected catch.

The annual yellowfin tuna catch in the WCPO increased from 100,000 mt in 1970 to about 550,000 mt in recent years, with the exception of a record catch of 650,000 mt in 2008 (Figure 3). Purse seiners harvest the majority of the yellowfin tuna catch (61% in 2012), while the longline fleet accounted for 16-20% of the catch in recent years, primarily in the equatorial regions (Figure 4). The remainder of the catch is dominated by the domestic fisheries of the Philippines and Indonesia, principally catching smaller fish using a variety of small-scale gear types (e.g. pole-and-line, ringnet, gillnet, handline and seine net) but also including small to medium sized purse seiners based in those countries and catching fish of sizes more typical of purse seine fisheries elsewhere.

Yellowfin tuna usually represent 20–25% of the overall purse-seine catch and may contribute higher percentages of the catch in individual sets. Yellowfin tuna is often directly targeted by purse seiners, especially as unassociated schools which accounted for 48% of the recent (2005–09) yellowfin purse-seine catch.

Since the mid 1980s, annual catches by longline have remained relatively stable, at about 70,000–80,000 mt. This is well below the level of catch in the late 1970s – early 1980s (which peaked at about 110,000 mt), presumably partly related to changes in targeting practices by some of the larger fleets (Figure 3). Annual catches from the domestic fisheries of the Philippines and eastern Indonesia are highly uncertain, particularly prior to 1990. Catches from these fisheries increased steadily from the 1970s, reaching approximately 100,000 mt in 2000 (Figure 4) and remaining at that level in subsequent years (excluding the catches from the purse seine fleets operating beyond archipelagic waters).

Figure 5 shows the spatial distribution of yellowfin tuna catch in the WCPO for the past 10 years. Most of the catch is taken in western equatorial areas, with declines in both purse-seine and longline catch towards the east. The east-west distribution of catch is strongly influenced by ENSO events, with larger catches taken east of 160°E during *El Niño* episodes. Catches from outside the equatorial region are relatively minor (5%) and are dominated by longline catches south of the equator and purse-seine and pole-and-line catches in the north-western area of the WCPO (Figure 4 and Figure 5).

3 DATA COMPILATION

The data used in the yellowfin tuna assessment consist of catch, effort, length-frequency and weight-frequency data for the fisheries defined in the analysis, and tag release-recapture data (Figure 6). The details of these data and their stratification are described below. There have been significant improvement to these data inputs since the 2011 assessments based on implementation of recommendations from the independent review (Ianelli et al., 2012) and the 2014 Pre-assessment workshop (SPC-OFP, 2014). These analyses are the subject of detailed working and information papers. We will not repeat the full details of these analyses here, rather we will provide a brief overview of the key features and direct interested readers to the relevant papers which are referenced throughout this section.

3.1 Spatial stratification

The spatial stratification for the assessment was modified for the current assessment (Figure 1), in particular the western equatorial region. The western boundary for this region was moved to 110°E to include additional catch from several fleets. This new area was then divided into three regions, the far western subregion was created to reduce the impact of uncertainty in the catch time series from Indonesia, Philippines, and Vietnam (region 7). A new region was added covering the area best described as the Bismarck and Solomon Seas (region 8). Considerable tagging has occurred here and analyses of skipjack tuna showed slower mixing compared to wider western equatorial region. Finally, a new region was added covering the specific region of the Coral Sea in south-western region of the model where specific tagging of bigeye and yellowfin tuna occurred (region 9).

The eastern boundary for the assessment regions was 150°W and as such excludes the WCPFC Convention area component that overlaps with the IATTC area.

3.2 Temporal stratification

The primary time period covered by the assessment is 1952-2012, thus including all significant post-war tuna fishing in the WCPO. Within this period, data were compiled into quarters (January–March, April–June, July–September, October–December). As agreed at SC9, the assessment did not include data from the most recent calendar year. This is because these data are only finalized very late and often subject to significant revision post-SC. This year the 2013 data was not finalized until the end of the first week of July – far too late to be included in assessments due only two weeks later. In the discussion section we consider potential mechanisms to address this matter.

3.3 Definition of fisheries

MULTIFAN-CL requires the definition of "fisheries" that consist of relatively homogeneous fishing units. Ideally, the fisheries so defined will have selectivity and catchability characteristics that do not vary greatly over time (although in the case of catchability, some allowance can be made for time-series variation). The creation of new subregions in the current assessment required the definition of new fisheries and these were discussed in detail during the Pre-Assessment workshop. An important consideration in whether multiple fisheries were included in a region was the availability of CPUE and size data (discussed below). The 33 fisheries defined for the bigeye and yellowfin assessments are provided in Table 1. A graphical summary of the availability of data for each fishery is provided in Figure 6.

A major change was the addition of a new offshore fishery in region 7. New purse seine and pole and line fisheries were added for regions 7 and 8. For regions 5 and 6 the previous LL-ALL and LL_PICT fisheries were combined as it was found that neither had full temporal coverage of size data. Region 9 also received two longline fisheries (LL-AU) and LL-ALL, though the later had very low catches and no catches in recent years. The previous LL-ALL(BMS)-3 and LL-PNG-3 fisheries have been merged into the L-All-8 fishery.

A full summary of the basis for the spatial and fishery definitions is provided in McKechnie et al. (2014a) and there is also discussion of these matters within the Pre-Assessment Workshop report (OFP 2014) and the independent review mentioned previously (Ianelli et al. 2012).

3.4 Catch and effort data

Catch and effort data were compiled according to the fisheries defined above. Catches by the longline fisheries were expressed in numbers of fish, and catches for all other fisheries expressed in weight. This is consistent with the form in which the catch data are recorded for these fisheries.

Total annual catches by major gear categories for the WCPO are shown in Figure 3 and a regional breakdown is provided in Figure 4. The spatial distribution of catches over the past ten years in provided in Figure 5. Most of the catch occurs in the tropical regions (3, 4, 7, and 8).

As noted above, only data through 2012 was used in the current assessment to overcome the delays and data issues that commonly occur, e.g., in the 2011 assessment data for the main longline fisheries were incomplete as indicated by atypical catch proportions among quarters in the final year.

Within the model, effort for each fishery was normalised to an average of 1.0 to assist numerical stability. Some longline fisheries were grouped to share common catchability parameters in the various analyses. For such grouped fisheries, the normalisation occurred over the group rather than for the individual fisheries so as to preserve the relative levels of effort between the fisheries. No effort is used for some fisheries - this is typically in cases where effort data are either considered unreliable or the fishery aggregates different 'other' fishing gears such that effort units are not compatible.

3.4.1 Purse seine

Previous assessments have considered two sets of purse-seine input catch data, but the problems surrounding logbook reports of skipjack catches and grab-sample bias have been clearly demonstrated and only a single set of purse seine catch estimates have been included in the current assessment. Details of the analyses, including the independent review and response are provided in Lawson (2013), Cordue (2013), Powers (2013) and McArdle (2013).

Briefly, catch data are estimated by 1° latitude, 1° longitude, month flag, and set-type. Though the exact algorithm depends on the year and data available, total catches are taken from the logsheet declared totals and then the grab samples are corrected for bias based on the estimates of the correction factors from the paired spill and grab sampling trials. For some fleets and time periods we use reported catch by species rather than estimating it, e.g., recent Japanese purse seine estimates which are based on detailed port sampling.

As in previous assessments, effort data units for purse seine fisheries are defined as days fishing and/or searching, and are allocated to set types based on the proportion of total sets attributed to a specified set type (associated or unassociated sets) in logbook data. Recently it has been discovered that some fleets have changed their reporting practices (SPC-OFP 2013) such that far fewer searching days are reported and these are instead reported as non-fishing transit days. This practice essentially represents effort creep and we have not yet specifically corrected recent data to ensure consistency of reporting. Therefore the impact of this is not known, but it will be minimized by the practice of estimating frequent time-based changes in catchability.

Catch-per-unit-effort for the Philippines domestic purse seine was analysed using a GLM for CPUE indices by Bigelow et al. (2014), (Figure 7). These indices were applied to the catches of the S-PH-7 fishery for the years 2005-2012 and lacked estimates of time-variant precision.

Catch-per-unit-effort for all fleets in the purse seine fishery operating largely within the PNG archipelagic waters was analysed for standardised indices using the GLM (Pilling et al. 2014a), (Figure 7). These indices were applied to the catches of the S-ASS-All-8 fishery for the years 1997-2012 and included estimates of time-variant precision.

3.4.2 Longline fisheries

The major change to longline catch data used in the current assessment was incorporation of some of the Japanese coastal fishery catches that were not previously associated with a location so they could not be assigned to a region (Williams 2014). Collaborative work between SPC and Japan confirmed that some of these catches were occurring in the waters of the Federated States of Micronesia and were already in the assessment, but some new catches were added to regions 1 and 7. Also included for the first time were some longline catches from Vietnam (Williams 2014).

The longline CPUE indices for the main longline fisheries in each region are one of the most important inputs to the assessment as they provide information on trends in abundance over time for each subregion.

For the current assessment, two sources of standardized CPUE series were used in various stages of the assessments. The first set of indices were derived from Japanese operational-level longline data using generalized linear models (GLM) and a delta-lognormal approach (Hoyle and Okamoto 2011). These were only available for the old regions 1-6 and through to 2009 and for some areas the indices for 2009 were very uncertain. In order to have time series that went through until 2012 it was necessary to use Japanese aggregate catch and effort data and then 'splice' these together. The procedures for this are described in McKechnie et al. (2014b).

As these indices were not available for the new regional structure, as an intermediate step, in the stepwise progression from the 2011 model, the CPUE indices for old region 3 was applied to new regions 3, 7, and 8.

The independent review of the bigeye assessment highlighted the spatial contraction of the Japanese fleet (and therefore the indices based on it) and accounting for targeting changes as the two major issues to address with longline CPUE (Ianelli et al. 2012). The new CPUE indices developed for the current assessment attempt to address these issues in two ways: 1) by using data across multiple fleets in order to minimize the spatial/temporal gaps in longline CPUE coverage; and 2) using operational data which allows us to consider vessel effects and other operational details to better account for targeting changes.

Accounting for targeting practices was achieved through the use of clustering analysis at the level of the trip based on the composition of albacore, bigeye, and yellowfin tunas in the catch. See McKechnie et al. (2014b) for further details of the how the clustering was undertaken and the GLM models used to create the standardized indices.

The operational CPUE data used for the analysis included all of the SPC data holdings, plus some data only held by Chinese Taipei which was integrated into the analyses undertaken for regions 4 and 6.

Unfortunately, for this year's assessment it was not possible to incorporate non-SPC data holdings from Korea and Japan which are the two historically dominant distant water longline fleets.

Coefficients of variation (CVs) for region-specific standardised effort were scaled to have a mean 0.2 over the period 1980-1990. This is different to the previous assessment which had much higher CVs for regions 5 and 6 due to the paucity of data. Using all flags indices led to CVs which were comparable across all regions (McKechnie et al. (2014) so it was decided that a similar mean CV would be used for all subregions.

Another important input for the standardized indices is regional scaling factors which are incorporated to estimate the relative level of exploitable longline biomass among regions (see Langley et al. 2005, and, Hoyle and Langley 2006). In an improvement from previous years Generalised Additive Models (GAMs) were used to model aggregate catch and effort data for the fleets from Japan, Korea, and Chinese-Taipei (McKechnie et al. 2014b). This approach allowed the estimation of regional scaling factors for all year-quarters, though of course years with better coverage (and therefore requiring less spatial interpolation) were more reliable. As some of the new CPUE series only started around 1980, the period 1980-1990 was used for the period to calculate the scalars to be applied to the standardized indices.

The final CPUE indices used in the reference case model comprised Japanese based indices for regions 1 and 2 (no other operational data was available), all flags operational for regions 3, 7, and 8, nominal for region 9 (very little fishing and only aggregate data was available. All indices for which catchability was shared and assumed constant, i.e., the L-All fisheries in each region, are presented in Figure 8. Due to conflicts with other data for region 8, particularly the tagging data (described later in Section 6.1), the CPUE index for L-All-8 was not used in the reference case model. Therefore, the nominal catch rates for this fishery is shown in Figure 8 as was input to the model, and the standardised index is presented by McKechnie et al. (2014b).

For the other longline fisheries, the effort units were defined as the total number of hooks set.

3.4.3 Other fisheries

There has been continual improvement in the catch estimates from Indonesia and the Philippines through the GEF-WPEA project and for the first time we include some catch data from the small-fish fisheries in Vietnam. For the Indonesian miscellaneous (small fish) fishery, including purse seine within archipelagic waters, catch data for 2012 were unavailable, therefore the data for 2011 were assumed as a proxy.

Effort for these other fisheries is either included in days fished, or more often set to 'missing'. Where effort data are absent, the model directly computes fishing mortality consistent with the observed catch using a Newton-Raphson procedure. Effort for the reference case model was set to missing for the three small-fish miscellaneous fisheries (Misc-PH-7, Misc-ID-7, Misc-VN-7). A nominal effort of one was added for the final year of the model to allow the estimation of a catchability coefficient to assist with projections which are reported in Pilling et al. (2014b).

Catch-per-unit-effort for the combined Indonesia and Philippines handline fishery was analysed using a GLM for CPUE indices by Bigelow et al. (2014). These indices were applied to the catches of the HL-PH-7 fishery for the years 2004-2012 and lacked estimates of time-variant precision.

3.5 Size data

Available length-frequency data for each of the defined fisheries were compiled into 95 2-cm size classes (10–12 cm to 198–200 cm). All weight data were recorded as processed weights (usually recorded to the nearest kg) and were compiled into 1–200 kg weight classes. Processing methods varied between fleets requiring the application of fishery-specific conversion factors to convert the available weight data to whole fish equivalents. Details of the conversion to whole weight are described in Langley et al. (2006). For each fishery, quarterly weight frequency data were compiled by 1 kg weight intervals over a range of 1-200 kg. Data were either collected onboard by fishers, through observer programmes, or through port sampling. Langley et al. (2011) provides more details on the source of the size data.

Each length-frequency record in the model consisted of the actual number of yellowfin tuna measured and Figure 9 provides details of the temporal availability of length and weight (for longline) frequency data and the relative sample sizes. Note that a maximum sample size of 1000 was implemented in the assessment.

3.5.1 Purse seine

Length-frequency samples from purse seiners have been collected from a variety of port sampling and observer programmes since the mid-1980s. Most of the early data are sourced from the U.S. National Marine Fisheries Service (NMFS) port sampling programme for U.S. purse seiners in Pago Pago, American Samoa and an observer programme conducted for the same fleet. Since the early 1990s, port sampling and observer programmes on other purse seine fleets have provided additional data. Only data that could be classified by set type were included in the final data set.

Only length frequency samples are used in the assessments and the previous assessment used only observer samples which had been corrected for grab sample bias. As observer coverage had been very low and unrepresentative in early years, there were many gaps and the time series of size data did not show evidence of model progression. Two major changes were made for the current assessment and are described in detail in Abascal et al. (2014), first the long time series of port sampling data from Pago Pago was included, and second all samples were weighted by the catch – both at the set and strata level, with thresholds put in to ensure that small samples from important catch strata did not get too much weight (as was done for the longline fishery). Unfortunately Pago Pago data are essentially unavailable since 2009 (only a limited number of samples are available for this year) as they have not been entered into electronic format.

The length frequency data collected by observers are susceptible to bias due to the grab sampling procedure (Lawson 2011). For the current assessment, a length-based correction factor was applied to the length frequency samples to correct for this source of bias. Details of these calculations and the adjustment for species composition are provided by Abascal et al. (2014).

3.5.2 Longline

A detailed review of all available length and weight frequency data for yellowfin tuna was undertaken and is described in McKechnie et al. (2014a) and McKechnie (2014) provides details of the analytical approaches for constructing this year's data inputs. The key principle used in constructing the data inputs were that weight and length data available for the same quarter would not be input together for a fishery, as it would either introduce conflict (if data were in disagreement), or dominate the model fit (if they were in agreement). Therefore, we considered the coverage and size of samples and typically chose to use weight frequency data when it was available. Japanese weight data was not available for regions 4, 5, and 6 in recent years and had to be supplemented by Japanese training vessel length data in region 4 and all flags length data in regions 5 and 6.

The general approach used by McKechnie (2014) was that Japanese size data were weighted spatially in respect of the spatial distribution of catch within the region, and the size data from all fleets data were weighted by levels of catch by flag for some fisheries. A moving 11 quarter time window was used to calculate the weighting of a stratum based upon catch.

3.5.3 Other fisheries

For the other fisheries, length data from each fishery/quarter were simply aggregated assuming that the collection of samples was broadly representative of the operation of the fishery in each quarter.

Philippines: Size composition data for the Philippines domestic fisheries derived from a sampling programme conducted in the Philippines in 1993–94 were augmented with data from 1995. In addition, data collected during 1997–2008 from the Philippines hand-line (PH HL 3) and surface fisheries (PH MISC 3) under the National Stock Assessment Project (NSAP) were included in the current assessment.

As for the 2010 assessment the length frequency samples from the small fish hook and line and large fish handline fisheries were adjusted to exclude all reported fish lengths greater than 90 cm for PH MISC 3 from the current assessment. This was done on the basis that it is suspected that the presence of these large fish may be due to mis-reporting of the fishing gear in some of the regional sampling programmes.

No fishery size data were available for the combined Philippines-Indonesian offshore purse seine fishery. For the purposes of the assessment, the S-PHID-7 fishery was assumed to have a selectivity equivalent to the S-ASS-All fisheries.

Indonesia and Vietnam: No fishery size data were available for the Indonesian and Vietnamese domestic fisheries. For the purposes of the assessment, the Misc-ID-7 and Misc-VN-7 fisheries were assumed to have a selectivity equivalent to the Misc- PH-7 fishery.

Japan coastal: Length data from the Japanese coastal purse-seine and pole-and-line fleets were provided by the National Research Institute of Far Seas Fisheries (NRIFSF).

Pole-and-line: For the equatorial pole-and-line fishery, length data were available from the Japanese distant-water fleet (sourced from NRIFSF) and from the domestic fleets (Solomon Islands and PNG). Since the late 1990s, most of the length data were collected by observers covering the Solomon Islands pole-and-line fleet.

3.6 Tagging data

A considerable amount of tagging data was available for incorporation into the current yellowfin stock assessment (Table 2). Previous assessments have incorporated yellowfin tuna tag releases and returns from the OFP's Regional Tuna Tagging Project conducted during 1989–1992, the Coral Sea tagging programme (1991–1995), and the 2011 assessment included, for the first time, the Pacific Tuna Tagging programme (PTTP) data. The tag release effort was spread throughout the tropical western Pacific, between approximately 120°E and 170°W (see Kaltongga 1998 for further details).

The largest tag data sets available for inclusion in the current assessment was that from the recent PTTP which was mainly undertaken in the western tropical Pacific from Indonesia to the Gilbert Islands of Kiribati over the last decade. This data set was expanded since the previous assessment from just over 10,000 recaptures to 13,500 recaptures, and from 21 to 40 release groups. (Table 2).

A moderate change was made to the tagging data used in the current assessment compared to the 2011 assessment. Whereas 30 release groups comprising 8,367 releases from the Hawaii tagging programme were included in the 2011 assessment, these data were excluded from the current assessment. Inclusion of these data in the model was problematic as all tags were released and recovered around the boundary of regions 2 and 4 (latitude 20° N). This results in large changes in the estimated movement coefficients between regions 2 and 4 and in other model parameters influenced by tagging data. On this basis, and due to a paucity of recaptures (total of 29) and no information for reporting rates, these data were not included in the current assessment.

For incorporation into the MULTIFAN-CL analyses, tag releases were stratified by release region, time period of release (quarter) and the same length classes used to stratify the length-frequency data. The complete data set includes a total of 82,581 releases which were classified into region/quarter that comprised 78 tag release groups. A total of 17,121 tag returns could be assigned to the fisheries included in the model. The returns from each length class of each tag release group were classified by recapture fishery and recapture time period (quarter). Because tag returns by purse seiners were often not accompanied by information concerning the set type, tag-return data were aggregated across set types for the purse seine fisheries in each region. The population dynamics model was in turn configured to predict equivalent estimated tag recaptures by these grouped fisheries.

A considerable number of tag returns from the PTTP have been recovered but have yet to be assigned to a fishery, particularly for the more recent release groups. The individual release groups were corrected to account for these additional tags recoveries. Briefly, unusable tags were accounted for by adjusting tag release numbers downward to preserve the release-recovery ratio. Similarly, tag-shedding and tagging-related mortality were corrected for by adjusting tag releases downwards to prevent the model from including fish that were tagged but either died or lost their tag soon after release. Further details of the correction procedure are provided by Berger et al. (2014).

4 MODEL DESCRIPTION – STRUCTURAL ASSUMPTIONS, PARAMETERISATION, AND PRIORS

The model can be considered to consist of several components, (i) the dynamics of the fish population; (ii) the dynamics of the fisheries; (iii) the dynamics of tagged fish; (iv) observation models for the data; (v) parameter estimation procedure; and (vi) stock assessment interpretations. Detailed technical descriptions of components (i) – (iv) in respect of the MULTIFAN-CL modelling software are given in Hampton and Fournier (2001) and Kleiber et al (2003), and are not repeated here. Brief descriptions of the various processes, including information on structural assumptions, estimated parameters, priors and other types of penalties used to constrain the parameterisation were provided in Langley et al. (2011 – Table 2) and only changes to these assumptions are reported here.

4.1 Population dynamics

The model partitions the population into spatial regions (see section 3.1) and quarterly age-classes (see section 3.2). The last age-class comprises a "plus group" in which mortality and other characteristics are assumed to be constant. The population is "monitored" in the model at quarterly time steps, extending through a time window of 1952–2012. The main population dynamics processes are described here for the **reference case model only** as applied in the current (2014) assessment as follows. Variations to the assumptions and structure that accommodate the developments since the 2011 assessment (Table 3) have been explored and are described for other model runs in Section 5.

4.1.1 Recruitment

Recruitment is defined as the appearance of age-class 1 fish in the population. Tropical tuna spawning does not follow a clear seasonal pattern but occurs sporadically when food supplies are plentiful (Itano 2000). It was assumed that recruitment occurs instantaneously at the beginning of each quarter. This is a discrete approximation to continuous recruitment, but provides sufficient flexibility to allow a range of variability to be incorporated into the estimates as appropriate.

The distribution of recruitment among the model regions was estimated within the model and allowed to vary over time in a relatively unconstrained fashion. The time-series variation in spatially-aggregated recruitment was somewhat constrained by a lognormal prior. The variance of the prior was set such that spatially aggregated recruitments of about three times and one third of the average recruitment would occur about once every 25 years on average.

Spatially-aggregated recruitment was assumed to have a weak relationship with the spawning biomass via a Beverton and Holt stock-recruitment relationship (SRR) with a fixed value of steepness (h). Steepness is defined as the ratio of the equilibrium recruitment produced by 20% of the equilibrium unexploited spawning biomass to that produced by the equilibrium unexploited spawning biomass (Francis 1992; Maunder and Watters 2001).

The SRR was incorporated mainly so that yield analysis could be undertaken for stock assessment purposes, particularly the determination of equilibrium based reference points. We therefore opted to apply a relatively weak penalty for deviation from the SRR so that it would have negligible effect on the recruitment and other model estimates (see Hampton and Fournier 2001, Appendix D).

Typically, fisheries data are not very informative about the steepness parameter of the SRR parameters; hence, the steepness parameter was fixed at a moderate value (0.80) and the sensitivity of the model results to the value of steepness was explored via a range of model sensitivities with lower (0.65) and higher (0.95) values of steepness. Model options that estimated the value of steepness internally in the model were also explored. In this case, an uninformative (uniform) prior was assumed on steepness of the SRR.

4.1.2 Initial population

The population age structure in the initial time period in each region was assumed to be in equilibrium and determined as a function of the average total mortality during the first 20 quarters. This assumption avoids having to treat the initial age structure, which is generally poorly determined, as independent parameters in the model. The initial age structure was applied to the initial recruitment estimates to obtain the initial populations in each region.

4.1.3 Growth

The standard assumptions made concerning age and growth are (i) the lengths-at-age are normally distributed for each age-class; (ii) the mean lengths-at-age follow a von Bertalanffy growth curve; (iii) the standard deviations of length for each age-class are a log-linear function of the mean lengths-at-age; and (iv) the probability distributions of weights-at-age are a deterministic function of the lengths-at-age and a specified weight-length relationship. These processes are assumed to be regionally invariant.

As noted above, the population is partitioned into quarterly age-classes with an aggregate class for the maximum age (plus-group). The aggregate age class makes possible the accumulation of old and large fish, which is likely in the early years of the fishery when exploitation rates were very low.

Based upon previous analyses assuming a standard von Bertalanffy growth pattern, substantial departures from the model may be indicated, particularly for fish of small sizes (up to about 80 cm for yellowfin). Similar observations have been made on yellowfin growth patterns determined from daily otolith increments and tagging data (Lehodey and Leroy 1999). We therefore modelled growth by allowing the mean lengths of the first eight quarterly age-classes to be independent parameters, with the remaining mean lengths following a von Bertalanffy growth curve. These deviations attract a small penalty to avoid over-fitting the size data.

4.1.4 Movement

Movement was assumed to occur instantaneously at the beginning of each quarter via movement coefficients that connect regions sharing a common boundary. Note that fish can move between non-contiguous regions in a single time step due to the “implicit transition” computational algorithm employed (see Hampton and Fournier 2001; Kleiber et al. 2003 for details). Movement is parameterised as the proportion of fish in a given region that move to the adjacent region. Across each inter-regional boundaries in the model, movement is possible in both directions for the four quarters, each with their own movement coefficients. Thus the number of movement parameters is 2×no.regions×4quarters. The seasonal pattern of movement persists from year to year with no allowance for longer-term variation in movement. Usually there are limited data available to estimate age-specific movement and the movement coefficients are normally invariant with respect to age.

A prior of 0.1 is assumed for all movement coefficients, inferring a relatively high mixing rate between regions. A small penalty is applied to deviations from the prior.

4.1.5 Natural mortality

Natural mortality (M) may be held fixed at pre-determined age-specific levels or estimated as age-specific parameters. Natural mortality at age was recalculated for previous assessments using an approach applied to other tunas (Watters and Maunder 2001; Harley and Maunder 2003, Hoyle 2008, Hoyle and Nicol 2008) in the WCPO and EPO. The generally increasing proportion of males in the catch with increasing size is assumed to be due to an increase in the natural mortality of females, associated with sexual maturity and the onset of reproduction. The externally-estimated M-at-age parameters used in the model assume the fixed values shown in Figure 10.

4.1.6 Sexual maturity

Reproductive output at age, which is used to derive spawning biomass, used the same values as were assumed for the previous assessment. The maturity-at-age was calculated based on data collected in the WCPO, and based on relative reproductive potential rather than the relative biomass of both sexes above the age of female maturity. This approach was previously applied to albacore (Hoyle 2008) and bigeye (Hoyle and Nicol 2008) tunas in the WCPO. The reproductive potential of each age class was assumed to be the product of the proportion of females at age, the proportion of females mature at age, the spawning frequency at age of mature females, and the fecundity at age per spawning of mature females (Figure 10). Overall, this results in a slight shift in the age of first maturity and a substantial reduction in the reproductive potential for older age classes.

4.2 Fishery dynamics

The interaction of the fisheries with the population occurs through fishing mortality. Fishing mortality is assumed to be a composite of several separable processes – selectivity, which describes the age-specific pattern of fishing mortality; catchability, which scales fishing effort to fishing mortality; and effort deviations, which are a random effect in the fishing effort – fishing mortality relationship.

4.2.1 Selectivity

In many stock assessment models, selectivity is modelled as a functional relationship with age, e.g. using a logistic curve to model monotonically increasing selectivity and various dome-shaped curves to model fisheries that select neither the youngest nor oldest fish. Modelling selectivity with separate age-specific coefficients (with a range of 0–1), constrained with smoothing penalties, has the disadvantage of requiring a large number of parameters. Instead, we have used a method based on a cubic spline interpolation. This is a form of smoothing, but the number of parameters for each fishery is the number of cubic spline "nodes" that are deemed to be sufficient to characterise selectivity over the age range. We chose five nodes, which seems to be sufficient to allow for reasonably complex selectivity patterns. For particular fisheries alternative functions were employed, including logistic and non-decreasing. In all cases, selectivity was assumed to be fishery-specific and time-invariant. However, it is possible for a single selectivity function to be "shared" among a group of fisheries that have similar operational characteristics and/or exist in similar areas and with similar size compositions, in other words they were constrained to have equal selectivity parameters. This grouping facilitates a reduction in the number parameters being estimated and permits including fisheries without size data.

Selectivity coefficients for the longline fisheries L-All-1 and L-All-2 (northern fisheries) were constrained to be equal, as were L-All-3–6 (equatorial and southern fisheries). The associated Purse seine fisheries S-ASS-All in regions 3, 4, 7 and 8 were constrained to be equal, and similarly the unassociated Purse seine fisheries S-UNS-All in those regions were constrained to be equal. The miscellaneous fisheries for Philippines, Indonesia and Vietnam (Misc-PH-7, Misc-ID-7, Misc-VN-7) were constrained to be equal. In all fisheries, the selectivity for the last four age-classes, for which the mean lengths are very similar, was constrained to be equal.

The offshore longline fishery (L-OS-W-7) has caught consistently larger fish than the other longline fleets in a comparable time period. There are operational differences between the longline fleets that may account for a higher selectivity of larger fish by the Chinese/Taiwanese fleet. These differences in size composition, which were consistent across length- and weight-frequency data, implied that the selectivity of older yellowfin by the L-All fisheries was less than 100%. On this basis, the selectivity of the Chinese/Taiwanese longline fisheries was constrained to have full selectivity for the oldest age classes, while the selectivity of the other longline fisheries (including the principal LL ALL fisheries) was allowed to have declining selectivity for the older age classes. Therefore, the selectivity for the L-OS-W-7 fishery was parameterised using a logistic functional form rather than the cubic spline method. Non-decreasing selectivities were estimated for the L-US-2, L-All-7 and L-All-8 fisheries.

4.2.2 Catchability

Constant catchability (time-invariant) was estimated for all fisheries for which standardised indices of relative abundance were available. As noted earlier, this assumption is similar to assuming that the CPUE for these fisheries indexes the exploitable abundance both among areas and over time. The "main" longline fisheries were grouped for the purpose of initial catchability, and to maintain the relativity of catch rates among regions. Other fisheries for which standardised CPUE were available were not grouped.

For all other fisheries, catchability was allowed to vary slowly over time (akin to a random walk) using a structural time-series approach. Random walk steps were taken every two years, and the deviations were constrained by prior distributions of mean zero and variance specified for the different fisheries according to our prior belief regarding the extent to which catchability may have changed. For fisheries having no available effort estimates (e.g. the Philippines and Indonesian surface fisheries), partial fishing mortalities were estimated consistent with the observed catches using a Newton-Raphson procedure. Therefore, catchability deviations (and effort deviations) are not estimated for these fisheries.

For the other fisheries with time-series variability in catchability, the catchability deviation priors were assigned a variance approximating a CV of 0.10.

Apart from those fisheries for which the data were based on annual estimates, the catchabilities of all other fisheries were allowed to vary seasonally.

4.2.3 Effort deviations

Effort deviations were used to model the random variation in the effort – fishing mortality relationship, and may be constrained by pre-specified prior distributions. For the main longline and other fisheries for which standardized effort were available, the CV of the prior was set to 0.7, but for all other fisheries, the variance was set at a moderate level proportional to the amount of effort expended.

The region-specific CPUE indices represent the principal indices of stock abundance, and the extent to which the model can deviate from the indices is moderated by the penalty weights assigned to the standardised effort series. The precision of the CPUE indices varies temporally and among regions and, therefore, a relative weighting on the individual effort observations in each time period was implemented according to the canonical variance estimates derived from the GLM. CPUE indices from region 3 were considered to be the more reliable than the indices from the other regions and, given the high proportion of the total biomass within this region are the most influential in the assessment model. Consequently, variance estimates among regions were scaled relative to this region in the follow way.

The CPUE indices were assumed to have an average coefficient of variation (CV) of 0.2 for the period 1979-86. A CV was then calculated for each effort observation by scaling the actual CV of the individual CPUE indices (obtained from the GLM) relative to the mean of 0.2. The resulting scaled CVs were transformed to an effort deviate penalty for each CPUE observation. Penalties were inversely related to variance, such that lower effort penalties were associated with indices having high variance, consequently these indices were less influential in fitting the model.

4.3 Dynamics of tagged fish

4.3.1 Initial mixing

The population dynamics of the fully recruited tagged and untagged populations are governed by the same model structures and parameters. The populations differ in respect of the recruitment process, which for the tagged population is the release of tagged fish, i.e. an individual tag and release event is the recruitment for that tagged population. Implicitly, we assume that the probability of recapturing a given tagged fish is the same as the probability of catching any given untagged fish in the same region and time period. For this assumption to be valid either the distribution of fishing effort must be random with respect to tagged and untagged fish and/or the tagged fish must be randomly mixed with the untagged fish. The former condition is unlikely to be met because fishing effort is almost never randomly distributed in space. The second condition is also unlikely to be met soon after release because of insufficient time for mixing to take place. Depending on the disposition of fishing effort in relation to tag release sites, the probability of capture of tagged fish soon after release may be different to that for the untagged fish. It is therefore desirable to designate one or more time periods after release as “pre-mixed” and compute fishing mortality for the tagged fish based on the actual recaptures, corrected for tag reporting (see below), rather than use fishing mortalities based on the general population parameters. This in effect de-sensitises the likelihood function to tag recaptures in the pre-mixed periods while correctly discounting the tagged population for the recaptures that occurred.

We assumed that tagged yellowfin mix fairly quickly with the untagged population at the region level and that this mixing process is complete by the end of the second quarter after release.

4.3.2 Tag reporting

In principle, tag-reporting rates can be estimated internally within the model. In practice, experience has shown that independent information on tag-reporting rates for at least some fisheries tends to be required for reasonably precise estimates to be obtained. We provided reporting rate priors for all fisheries that reflect our prior opinion regarding the reporting rate and the confidence we have in that opinion.

Previous assessments have assumed fishery specific reporting rates are constant over time. This assumption was reasonable when most of the tag data were associated with a single tagging programme. However, tag reporting rates may vary considerably between tagging programmes due to changes in the composition and operation of individual fisheries, and different levels of publicity and follow-up. Consequently, fishery-specific tag reporting rates were estimated that were also specific to individual tagging programmes, i.e. a reporting rate matrix.

Within this matrix, reporting rates may be grouped for each tagging programme, and for each of the fisheries that account for most of the tag recoveries, most notably the equatorial purse seine fisheries, the domestic fisheries of Philippines, Indonesia and Vietnam, the equatorial pole-and-line fishery, Australian and Hawaiian domestic longline fisheries and the domestic Japanese fisheries (Table 4). Limited numbers of tags have been recovered from the broad-scale longline fisheries (L-All-1-4,6-8, L-OS-W-7, and L-OS-E-7), and a single tag reporting rate, independent of tagging programme, was estimated for these fisheries. The longline fisheries L-All-5 and L-All-9 were not grouped given the unique nature of the tag returns from these regions.

The estimation of the reporting rates included penalty terms in respect of pre-determined priors. These were derived from analyses of tag seeding experiments and other information (Hampton 1997) and were modified by the estimates of tagger-specific mortality of tagged fish (Berger et al. 2014). For the PTTP, relatively informative priors were formulated for the two equatorial purse seine fisheries given the larger extent of information available.

Relatively informative priors were also applied to the tag recoveries from tagging programmes directed towards the Hawaiian and Australian longline fisheries. For the remainder of the fisheries, we have no auxiliary information with which to estimate reporting rates, so relatively uninformative priors were used for those fisheries.

All reporting rates were assumed to be constant over time.

4.4 Likelihood components

There were four data components that contribute to the log-likelihood function — the total catch data, the length-frequency data, the weight-frequency data and the tagging data. The observed total catch data were assumed to be unbiased and relatively precise, with the SD of residuals on the log scale being 0.007.

The probability distributions for the length-frequency proportions were assumed to be approximated by robust normal distributions, with the variance determined by the effective sample size and the observed length-frequency proportion. A similar likelihood function was used for the weight-frequency data.

The size frequency data was assigned an effective sample size lower than the number of fish sampled. Reduction of the effective sample size recognises that (i) length- and weight-frequency samples are not truly random (because of clumping in the population with respect to size) and would have higher variance as a result; and (ii) the model does not include all possible process error, resulting in further under-estimation of variances.

The size compositions from particular fisheries with certain sampling protocols may be considered more reliable or representative than those from other fisheries. The protocols described in Section **Error! Reference source not found.** for rescaling the longline fisheries size data provides for more reliable indicators of the trends in the size composition of the population over time. On this basis, the size data were considered to be moderately informative and were assigned moderate weight in the likelihood function such that individual length and weight frequency distributions were assigned an effective sample size of 0.2 times the actual sample size, with a maximum effective sample size of 50.

The relative weighting of the longline size frequency was comparable to the approach used in the 2009 assessment (n/20). However, the larger number of length and weight samples included in the current data set meant that these data were likely to be more influential than in previous assessments. The influence of the longline size data was explored by halving the relative weight by assigning lower (n/40) effective sample sizes within the suite of model sensitivities.

A log-likelihood component for the tag data was computed using a negative binomial distribution. The negative binomial is preferred over the more commonly used Poisson distribution because tagging data often exhibit more variability than can be attributed by the Poisson. We have employed a parameterisation of the variance parameters such that as they approach infinity, the negative binomial approaches the Poisson. Therefore, if the tag return data show high variability (for example, due to contagion or non-independence of tags), then the negative binomial is able to recognise this. This should then provide a more realistic weighting of the tag return data in the overall log-likelihood and allow the variability to impact the confidence intervals of estimated parameters. However, early attempts at estimating fishery-specific variance parameters from the data yielded values at either bound, suggesting insufficient information was available. A fixed value at the midpoint of the variance range was therefore assumed for all fisheries. A complete derivation and description of the negative binomial likelihood function for tagging data is provided in Hampton and Fournier (2001) (Appendix C).

4.5 Parameter estimation and uncertainty

The parameters of the model were estimated by maximizing the log-likelihoods of the data plus the log of the probability density functions of the priors and smoothing penalties specified in the model. The maximization to a point of model convergence was performed by an efficient optimization using exact derivatives with respect to the model parameters (auto-differentiation, Fournier et al. 2012). Estimation was conducted in a series of phases, the first of which used arbitrary starting values for most parameters. A bash shell script, *doitall*, (Annex 10.5) implements the phased procedure for fitting the model. Some parameters were assigned specified starting values consistent with available biological information. The values of these parameters are provided in the *yft.ini* file (Annex 10.4)[1].

In this assessment two approaches were used to describe the uncertainty in key model outputs. The first estimated the statistical variation **within** a given assessment run, while the second focused on the structural uncertainty in the assessment by considering the variation **among** model runs. For the first approach, the Hessian matrix was calculated for the reference case model run to obtain estimates of the covariance matrix, which is used in combination with the Delta method to compute approximate confidence intervals for parameters of interest (the biomass and recruitment trajectories). For the second approach, a crosswise grid of model runs was undertaken which incorporated many of the options of uncertainty explored by the key model runs and one-off sensitivity analyses. This procedure attempts to describe the main sources of structural and data uncertainty in the assessment.

For highly complex population models fitted to large amounts of often conflicting data, it is common for there to be difficulties in estimating absolute abundance (Lee et al. 2014). Therefore, a profile likelihood analysis was done of the marginal posterior likelihood in respect of the total population scaling parameter. Reasonable contrast in the profile was taken as indicating sufficient information existed in the data for estimating absolute abundance, and also offered confirmation of the global minimum obtained by the maximum likelihood estimate.

Due to the low number of observations for recent cohorts, recruitment estimates in the terminal model time periods may be poorly estimated. This was investigated using retrospective analysis where data from the terminal time periods (the last three years) were successively removed and the model fitted to each case. The terminal recruitments and biomass estimates were compared among the retrospective models for their robustness to the loss of data. Whether to estimate the terminal recruitments or not was based upon the outcome of this analysis.

4.6 Stock assessment interpretation methods

Several ancillary analyses using the converged model were conducted in order to interpret the results for stock assessment purposes. The methods involved are summarized below and the details can be found in Kleiber et al. (2003). Note that, in each case, these ancillary analyses are completely

[1] Details of elements of the *doitall* and *.ini* files as well as other input files that structure a MULTIFAN-CL run are given in Kleiber et al. (2013).

integrated into the model, and therefore confidence intervals for quantities of interest are available using the Hessian-Delta approach.

4.6.1 Reference points

The unfished spawning biomass ($SB_{F=0}$) in each time period was calculated given the estimated recruitments and the Beverton-Holt spawner-recruit relationship. This offers a basis for comparing the exploited population relative to the population subject to natural mortality only. A useful reference point is the 20% level of $SB_{F=0}$ against which current absolute spawning biomass can be gauged.

4.6.2 Fishery impact

Many assessments estimate the ratio of recent to initial biomass as an index of fishery depletion. The problem with this approach is that recruitment may vary considerably throughout the time series, and if either the initial or recent biomass estimates (or both) are "non-representative" because of recruitment variability or uncertainty, then the ratio may not measure fishery depletion, but simply reflect recruitment variability.

We approach this problem by computing biomass time series (at the region level) using the estimated model parameters, but assuming that fishing mortality was zero. Because both the *real* biomass B_t and the *unexploited* biomass B_{0t} incorporate recruitment variability, their ratio at each time step of the analysis $\frac{B_t}{B_{0t}}$ can be interpreted as an index of fishery depletion. The computation of unexploited biomass includes an adjustment in recruitment to acknowledge the possibility of reduction of recruitment in exploited populations through stock-recruitment effects. This analysis was conducted in respect of groups of fisheries so as to describe the relative fishing impacts of each group on the population.

4.6.3 Yield analysis

The yield analysis consists of computing equilibrium catch (or yield) and biomass, conditional on a specified basal level of age-specific fishing mortality (F_a) for the entire model domain, a series of fishing mortality multipliers, *fmult*, the natural mortality-at-age (M_a), the mean weight-at-age (w_a) and the SRR parameters α and β. All of these parameters, apart from *fmult*, which is arbitrarily specified over a range of 0–50 in increments of 0.1, are available from the parameter estimates of the model. The maximum yield with respect to *fmult* can easily be determined and is equivalent to the *MSY*. Similarly the total ($\tilde{B}_{MSY}$) and adult ($S\tilde{B}_{MSY}$) biomass at *MSY* can also be determined. The ratios of the current (or recent average) levels of fishing mortality and biomass to their respective levels at MSY are of interest as reference points. These ratios were also determined for the principal assessment model with alternative values of steepness assumed for the SRR.

For the standard yield analysis, the F_a are determined as the average over some recent period of time. In this assessment, we use the average over the period 2008–2011. We do not include 2012 in the average as fishing mortality tends to have high uncertainty for the terminal data year of the analysis and the catch and effort data for this terminal year are usually incomplete.

The MSY-based reference points were also computed using the average annual F_a from each year included in the model (1952–2012). This enabled temporal trends in the reference points to be assessed and a consideration of the differences in MSY levels under historical patterns of age-specific exploitation.

The assessments indicated that recruitment over particular periods had higher uncertainty. Consequently, yield estimates based on the long-term equilibrium recruitment estimated from a Beverton and Holt SRR fitted to all estimated recruitments may substantially bias the yields currently available from the stock under current recruitment conditions. For this reason, a separate yield analysis was conducted based on the SRR estimated for the levels of recruitment and spawning potential that occurred in subsets of the model calculation period.

5 MODEL RUNS

5.1 Developments from the 2011 assessment

Following the recommendations of the PAW, a number of developments were made starting from the 2011 reference case model (Table 3). Aside from updating the input data (catch, effort, size frequencies, and standardised CPUE derived from aggregate and operational data), there are five main differences in the input data and structural assumptions of the current (2014) assessment compared to the 2011 assessment (run LLcpueOP_TWcpueR6_PTTP).

i. Spatial structure has been expanded from six to nine regions; with two new regions added to the western equatorial region and one to the south western region.

ii. Fishery structure has been expanded from 25 to 33 fisheries; and features the first inclusion of some Japanese and Vietnamese coastal fishery catches. The revised spatial structure necessitated redefining the WCPO fisheries. The changes include: for the western equatorial region (3, 7, 8) two longline fisheries have been merged, with two new longline fisheries, four new purse seine fisheries, two new pole-and-line fisheries, and a new Vietnamese domestic fishery; for the eastern equatorial region (4) two longline fisheries have been merged; for the south-western region (5 and 9) two new longline fisheries have been added; and, for the south-eastern region (6) two longline fisheries have been merged. Details of these changes can be found in OFP (2014, PAW report)

iii. Incorporation of CPUE indices derived from either Japanese logsheet data, or all operational data from all fleets (combined flags) available to SPC (McKechnie et al. 2014b).

iv. A revised protocol for deriving the length- and weight size compositions for the principal longline fisheries. This entailed using either weight or length data for particular fisheries depending upon the quality and coverage of each data type within the region and over time. Japanese size data was weighted spatially in respect of the spatial distribution of catch within the region, and the size data from all fleets data was weighted spatially or by flag for some fisheries, (see McKechnie 2014 for details).

v. The correction of the purse-seine length frequency data collected by observers to account for sampling bias and the inclusion of Pago Pago port sampling data, with all data weighted in respect of the set catch weight (Abascal et al. 2014).

As in the previous assessment, the purse-seine fishery catch estimates were corrected (for species composition), and this approach was considered to be the most reliable. Therefore no models were considered that used uncorrected catch estimates.

Details of the stepwise developments from the 2011 reference case model to that of the current assessment with the model run specifications are described in Annex 10.3, and two notable changes to the model assumptions are:

- Excluding the estimation of the terminal temporal recruitment deviates in the final year (2012); and,
- Fitting the BH-SRR to the estimated recruitments for the sub-set model period 1965 to 2011.

5.2 Sensitivity analyses

Based upon the recommendations of the PAW, the sensitivity of the reference case model was tested for a range of key assumptions in a series of "one-off" sensitivity analyses (Table 5). As the assessment developed and uncertainties in model aspects became apparent, further sensitivities were added to those recommended, making up a list of twelve runs. These can be divided in to six parts in respect of the assumptions being tested:

<u>Size data relative weighting</u>

A lower relative weight for length- and weight-frequency data (**SZ_dw**). The relative influence of the length and weight composition data for all fisheries was reduced by assigning an effective sample size of 0.025 times the individual samples, with a maximum sample size of 20. This explores the relative influence of size composition data upon the model estimates and illustrates data conflicts.

Standardised CPUE indices

Include the operational domestic Philippines handline CPUE time series: (**CP_all**). The standardised indices for the fishery HL-PH-7 were excluded for the reference case model fit because the trend appears in conflict with other indices for region 7. Including this time series explores the effects of this apparent data conflict.

An exploratory model ("excl.CP_curr") was run to examine the sensitivity of the model to reducing the relative weight of the CPUE indices in the western equatorial regions (3, 7, 8), such that more weight was assigned to the tagging data for these regions. The conflict among these data could therefore be examined. This was done by excluding for the most recent 5 years the CPUE indices for the fisheries L-All-3, L-All-7, and the nominal catch rates for L-All-8.

Tagging data

Reduce the tag mixing period to 1 quarter (**Mix_1**). The tagging data indicate high levels of mixing among the equatorial regions, and in combination with a larger number of regions, the possibility of more rapid mixing of tagged fish in the population was explored by reducing the mixing period to 1 quarter. This sensitivity also serves to explore an increased relative weight assigned to the tagging data as it increases the effective number of observed tag recaptures.

An exploratory model run ("Tag_var_est") examined the relative weight of the tagging data through estimating the variance parameters of the negative binomial likelihood term for these data.

Steepness

Fixed values of 0.65 (**h_0.65**) and 0.95 (**h_0.95**). Generally there is limited information available to define an appropriate value of steepness for tuna species and, consequently, lower (0.65) and higher (0.95) plausible values were examined.

In an exploratory model run ("h_est") steepness was also estimated, largely for purposes of comparison with previous assessments.

Natural mortality

Estimate age-specific natural mortality schedule (**M_est**). Given the large amount of tag-recapture data input to the model, it was considered feasible to estimate natural mortality. Although a thorough examination of this capability would entail considerable alterations to the reference case model, for the purposes of examining the sensitivity of the model to this parameter, the only change entailed activating its estimation.

Recruitments

Two exploratory models were run that tested the sensitivity to assumptions regarding the estimated recruitments. The model run "Rterm_est" included the estimation of the terminal temporal recruitment deviates (2012) so as to determine its effect on estimates of spawning biomass in the final model year. The model run "SRR_full" included the recruitments estimated over the full model calculation period in fitting the BH-SRR, so as to determine the relative effect of the high early recruitments on the estimates of equilibrium yields and biomass.

The six sensitivity runs in **bold** above were taken as the key model runs for examining the effects of the primary sources of uncertainty on management reference points in the current assessment.

5.3 Structural uncertainty

An examination of uncertainty in the model structure was integrated into a single analysis that explored the interactions of the assumptions tested in the one-off sensitivity runs, i.e. for the key model runs, and that test the alternative assumptions recommended by the PAW. These interactions were tested in a grid of 48 combinations of the following options:

- Tag mixing period [2 levels]: **Ref.Case** (2 quarters) and **Mix_1** (1 quarter)
- Steepness[3 levels]: **Ref.Case** (0.8), **h_0.65** (0.65), **h0.95** (0.95)
- CPUE [2 levels]: **Ref.Case** (exclude HL-PH-7 CPUE), **CP_all** (include HL-PH-7 CPUE))
- Size data weighting [2 levels]: **Ref.Case** (n/20), **SZ_dw** (n/40)
- Natural mortality [2 levels]: **Ref.Case** (fixed values), **M_est** (estimated)

A separate model was run for each of the combinations in the grid. The model results were screened to ensure model convergence and reasonable values of key parameters. From the distribution for each management quantity, the median and 90%iles were reported.

The Peer Review recommendation (Ianelli et al. 2012) to consider applying relative weighting of grid options for deriving probabilities in respect of exceeding reference point levels was not applied in deriving the grid median and confidence intervals. We recommend the SC consider this possibility.

6 RESULTS

6.1 Model diagnostics (reference case)

A brief review follows of the fit of the model to the four predicted data classes: the total catch data, the length frequency data, the weight frequency data and the tagging data. In addition, the estimated effort deviations provide an indication of the consistency of the model with the effort data. The following observations are made concerning the various fit diagnostics:

- A high penalty was applied to the catch deviations in the model likelihood and consequently the catch residuals were very small for all fisheries.
- The model estimates of longline exploitable biomass trends were generally consistent with the observed longline CPUE indices, in that predicted CPUE for these fisheries closely reflected the observed trends (Figure 11). Despite the shorter time series, the model predicted CPUE was also consistent with the observed indices for the purse seine fisheries in regions 7 and 8, (S-ID-PH-7 and S –ASS-All-8). In all cases the model predictions traced the temporal variation in observed CPUE, and most importantly, the long-term general declines observed especially in regions 3, 7, 4 and 6. The short-term declines in the purse seine CPUE were also adequately predicted by the model. Standardised CPUE for the L-All-8 fishery was not included in the model fit, and the comparison between the model predicted CPUE and the nominal catch rates are shown for the sake of completeness in Figure 11. A lower penalty was assumed for these data, and consequently the model predictions and the observations were not closely consistent; although both display a general decline throughout the model time period. An unstable pattern in the effort deviations exists for the L-All-8 fishery, particularly for the period 1995-2012, indicating that the trends in nominal catch rate were unable to be predicted by the model (Figure 12). This was due to the inability of the model to predict the increase in the observed nominal catch rates for L-All-8 fishery over this period. However, in the adjacent regions 3 and 7, the effort deviations are small and appear generally more stable. Similar stability was found for the L-All-4 and L-All-6 fisheries. Account must be taken of the high variability and intermittent observations in the time series for the L-All-9 and L-All-2 fisheries (Figure 11 and Figure 12). The effort deviations over the period 1990-2012 for the longline fishery in region 1 were negative with a systematic downward trend (Figure 12). This reflects the poor fit to the observed CPUE indices over this period in region 1, which were systematically lower than the preceding period.
- For most longline fisheries, there is a reasonable fit to the length data as revealed from a comparison of the observed and predicted proportions at length (Figure 13). The apparent lack of fit to a mode of small fish in the L-AU-9 fishery is contrasted by highly consistent predicted and observed weight-frequencies for this fishery (Figure 14) for which the sample size was substantially larger. Close consistency between the model and observed length frequencies was obtained for the relatively large samples from the purse seine fisheries in regions 3, 7, and 8, with the substantially smaller fish observed in region 7 being predicted well by the model. Generally the model adequately describes the variability in catch length frequencies observed among the regions (Figure 13).

- The model predicted weight frequencies were highly consistent with those observed for the longline fisheries (Figure 14). Some exceptions to this include an over-estimation of large fish in the L-All-8 fishery, and an under-estimation of a large mode of small fish in the L-AU-5 fishery despite the relatively large sample sizes from these fisheries. Some lack of fit to a relatively small sample for the L-All-6 fishery is evident.
- The generally good fit to the size data was also revealed from a comparison of the observed and predicted median lengths and weight over time (Figure 15 and Figure 16). Model predictions in median size through time were a reasonable reflection of the observed decreasing trends in size for the purse seine fisheries in regions 3, 4 and 8; and the longline fisheries in regions 1, 2 and 4. However, for the longline fishery in region 7 (L-All-7), model predictions are positively biased since 2003 – with the model under-estimating the proportion of fish in the smaller length classes evident in the observed declining trend in size.
- The fit of the model to the total numbers of observed recaptures of tagged fish by calendar time is shown in Figure 17 (recaptures plotted in log-space). The observed recaptures have relatively low variability through the recovery phase, and the model predictions were broadly consistent with the observations, including the high numbers obtained from the PTTP in 2008-12. Model predicted recaptures exceeded those observed for some of the later years of the CS and RTTP programs, but overall the model fit to these data was good.
- The consistently good fit to the tagging data is also reflected in the predicted recaptures in respect of time at liberty closely matching the observations (Figure 18), indicating that model estimates of tag attrition due to fishing and natural mortality adequately describe that observations over all tag release programmes. A steep decline in recaptures was observed in the first 4 quarters following release, but a sustained number of tagged fish were recaptured up to 13 quarters at liberty.
- Generally the model predictions of the movement of tagged fish among the regions reflected the observed recaptures of tagged fish by time period at liberty (quarter) from the region of release to the region of recapture (Figure 19). Region 8 has the majority of observed tag recaptures, and the recaptures of tagged fish remaining in this region was well described by the model predictions, and similarly for the lower number of recaptures remaining in regions 3, 4, 7 and 9. Reasonable estimates of the movement of tagged fish out of the release regions were obtained, but overestimated the movement from region 7 to region 3 for the long term recaptures only (Figure 19).

6.2 Model parameter estimates (reference case)

Tag Reporting Rates

Estimated tag-reporting rates by fishery are shown in Figure 20. As could be expected, tag reporting rates for individual fisheries differed both among fisheries and tagging programmes. The grouping of tag reporting rate estimates assumed among fisheries and programmes is shown in Table 4, The “main” longline fisheries (1,2,4:9,13) were grouped over all the tagging programs, while for other fisheries, the fishery-specific grouping was maintained, but a program-specific rate was estimated for each group. Informative priors for the tag reporting rates were available for a number of the main fisheries, most notably the tag recoveries by the purse-seine fisheries from the RTTP and PTTP programmes.

For all programmes, some of the reporting rate estimates were estimated to be higher than the mode of their prior distributions and tended to vary considerably between regions, particularly for groups for which the prior was relatively uninformative. The estimate for the largest longline fishery group (1) was below the prior, while for other longline fisheries the estimates were highly variable, ranging from near zero (region 5) to the upper limit allowed (0.9, region 9). However, the estimated reporting rates from the longline fisheries are based on very small numbers of tag recoveries and, consequently, the tag-recovery data from these fisheries are not very informative.

The RTTP and PTTP reporting rates for the equatorial pole-and-line fishery (P-All-3), were estimated at the upper bound on the reporting rate (0.9). However, this fishery accounted for a small percentage (<1%) of the total tag recoveries.

The reporting rate estimates for the S-ASS-All-8 and S-UNS-All-8 fisheries were at the upper bound (0.9) which is significant as these fisheries accounted for 74% of the PTTP recaptures (excluding recaptures during the mixing period). The estimates for the S-ASS-All and S-UNS-All fisheries in regions 3 and 4 were estimated at close to their prior modes and these fisheries accounted for a substantial amount of the PTTP recaptures (13%). While the estimate for the Misc-ID-7 fishery was also at the upper bound, this fishery accounted for only a moderate amount of the PTTP recaptures (5%).

Growth

The estimated growth curve is shown in Figure 21. For the Ref.Case model, growth in length is estimated to continue throughout the lifespan of the species, approaching a maximum level. The estimated mean length of the final age-class is 153.4 cm and L_{∞} is 156.64 cm. The non-von Bertalanffy growth of juvenile yellowfin is clearly evident, with irregular growth occurring in the 25–75 cm size range showing slower growth in the first 2 years than predicted by the von Bertalanffy function (Figure 21). The Ref.Case estimate predicts slower growth than the 2011 reference case estimate, although with a similar length at maximum age, and similar variability.

Selectivity

The estimated selectivity coefficients are generally consistent with expectations such that the longline and handline fisheries principally select larger, older fish and the associated purse-seine sets (FAD and log sets) select smaller yellowfin (Figure 22). Unassociated purse-seine sets generally catch substantially larger fish than associated sets with a moderate selectivity for the older age classes. The selectivity of the miscellaneous Philippines, Indonesia and Vietnamese fisheries have the highest coefficients for fish in quarterly age-class 1, decreasing to a low level by age-class 5. These estimates were based upon the length-frequency data available for the Philippines surface fishery (Misc-PH-7) and the model estimates that catches from this fishery are comprised of young fish (age classes 1-3).

The Japanese coastal pole-and-line fishery (P-JP-1) and the northern equatorial pole-and-line fisheries (P-All-3) are estimated to catch fish of larger sizes than western and southern equatorial pole-and-line fisheries (P-All-7, P-All-8) which principally catch small fish. However, there are also some observations of larger fish in the catch and higher variability observed, which result in the higher selectivities of larger yellowfin for the Japanese and northern pole-and-line fisheries (Figure 15).

For the Japanese purse-seine fishery (S-JP-1), there is an apparent shift in the size composition of the catch from large fish to small fish in the mid 1980s (Figure 15). The reference model assumes a single selectivity for the entire period and includes a high selectivity for older fish. This process may be mis-specified and would be improved by estimating separate selectivities for the two time periods, which may result in a considerable improvement in the fit to the length frequency data from this fishery.

For the principal longline fisheries: L-All-3-6 and L-OS-E-3, the selectivity is estimated to be highest for age-classes 7-10 with lower selectivity of older fish. This is consistent with the slightly smaller size of fish caught by these fisheries compared to the corresponding L-All-7, L-OS-W-7 and L-All-8 fisheries. The functional form of the selectivity of the latter fisheries was constrained to have full or non-decreasing selectivity for the oldest age classes.

Catchability

Catchability for the main longline fisheries and for the S-PH-7 and S-ASS-All-8 fisheries was assumed constant (not time-variant) as standardised CPUE for these fisheries was fitted in the model. Time-variant catchability was estimated for all other fisheries (Figure 23).

A consistent pattern estimated in the time-variant catchability coefficients among almost all the equatorial purse seine, all flags, fisheries (S-All), having a steady increase from the commencement of the fisheries in the 1970's to the current year (Figure 23). Exceptions to this pattern were for the associated purse seine fisheries in region 7, (S-ASS-All-7), where catchability decreases since 1992 following the initial increase, and the unassociated fishery (S-UNS-All-7) that is highly variable with a recent steep decline since 2005. Given similarities in the operational characteristics of these fisheries, this result suggests a different abundance trends for region 7 compared to the other equatorial regions.

Movement

Two representations of movement estimates are shown in Figure 24 and Figure 25. The estimated movement coefficients for adjacent model regions are shown in Figure 24. The model estimates very large movements of fish northward and southward from regions 1 and 3 in the second and third quarters of the year. Southward movement from region 8 to region 5 is estimated in the first quarter, with reciprocal movement from region 5 to 8 in the third quarter, and large reciprocal movements in the fourth quarter. There are estimated reciprocal movements of fish between regions 3 and 4 in the first and third quarters, and a further movement of fish from region 4 to region 3 in the fourth quarter. Movement rates between all other adjacent regions are low or negligible. However, it is important to note that even low movement rates from regions of high abundance can result in considerable stock mixing in the recipient region.

The estimated movement coefficients are generally consistent with the observed distribution of recaptured tagged fish among regions over the main recovery period (Figure 19). There were limited or no tag releases and recoveries to inform the model regarding the movement of fish among combinations of regions 1 and 2. Most tag releases within regions 3, 7 and 8 were recovered within the region of release, although there was also a transfer of tags among these regions. The predicted tag movements among regions 3, 4, 5, and 7 into and out of region 8 were generally consistent with the observed tag recoveries, and these observations are most likely strongly informative for the estimation of the movement coefficients which predict large movements among these regions in all quarters.

The distribution of regional biomass by source region derived from a simulation using the movement coefficients is presented in Figure 25. The simulation indicates the proportion of biomass within a region that is sourced from recruitment within that region and from other regions. For regions 1, 2, 5, 6, 7, and 9, a relatively high proportion of the biomass is predicted to be sourced from within each respective region. However, the high movement rates predicted among regions 3, 4, 7, and 8 results in substantial proportions, and in some cases (e.g. regions 3 and 4) all of biomass originating from recruitment in other regions. Recruitment in region 1 is estimated to contribute to the biomass in regions 3, 4, 7, and 8 via the high movement rates among the equatorial regions. This high level of mixing between the equatorial regions results in a significant proportion of biomass in regions 3, 4 and 8 being sourced from recruitment in the western region (region 7) and region 1 (Figure 25).

6.3 Stock assessment results

Symbols used in the following discussion are defined in Table 6 and the key results are provided in Table 7. As a general introduction, previous yellowfin assessments in the WCPO have featured very strong non-stationary behaviour such as consistent declining recruitment trends, and large mismatches between equilibrium unfished and non-equilibrium unfished biomass. These features are greatly reduced in the current assessment. This is driven by reduced data conflict achieved through better model inputs and structural model assumptions, and increased tag release and recapture data available to the model.

6.3.1 Recruitment

The reference case recruitment estimates (aggregated by year for ease of display) for each region and the WCPO are shown in Figure 26. Overall average annual recruitment as a proportion of the total across regions is highest within region 7 (0.42), followed by region 1 (0.25), while moderate levels of recruitment also occur within regions 5 and 6. Very low recruitments were estimated for the other regions. The regional estimates display large interannual variability and variation on longer time scales. Recruitment is estimated to be high in most regions up to 1965, and these estimates are highly uncertain (Figure 26). This uncertainty in the early recruitments underpinned the decision to assume the period 1965-2011 as the basis for the **long-term average recruitment**, and was used when estimating the BH-SRR. Over this period, recruitment on average displays very little trend, and the uncertainty decreases substantially since the late 1980's.

The declining trend in recruitment estimated in previous assessments is reduced in the current assessment. Whereas in the 2011 reference case model, the ratio of average recruitment in the second half of the model calculation period to that in the first half was 0.75, for the current reference case this has increased to 0.83. The lower recruitments since 1990 account almost entirely for this dichotomy in the current assessment, being 15% lower than the average over the full model period, a similar result to that in the 2011 reference case. Therefore, between 1965 and 1990, the current assessment estimates no strong trend in recruitments.

The low recruitments since 1990 represents only a 6% reduction relative to the long-term average (1965-2011), and appears to be determined largely by declines in regions 1, 2 and 5. In contrast, a moderate increase is estimated over this period in region 7, and the trend in total recruitment since the mid-1990s appears flat (Figure 26).

The last four recruitment deviates were not estimated and instead set to zero. This was because the retrospective analysis showed that these were poorly estimated (Annex 10.2.2). It was demonstrated that this has no impact upon the spawning potential reference points as these cohorts do not contribute to SB_{latest} or $SB_{current}$, and have minimal impact on $F_{current}/F_{msy}$ as F in the terminal year was ignored.

The estimated distribution of recruitment across regions should be interpreted with caution as MULTIFAN-CL can use a combination of movement and regional recruitment to move fish. Large movement coefficients were estimated for the reference case (c.f. Section 6.2), particularly among the equatorial regions, and therefore juvenile fish are predicted to be well dispersed among these regions within the first 2 quarters of life.

6.3.2 Biomass

The estimated biomass for each region are represented using the estimated spawning potential presented in Figure 27. Apart from some variability early in the calculation period, biomass is estimated to have declined steadily over the model period, with most of the decline occurring within regions 3, 4, and 7, with declines to lesser magnitude in regions 5 and 8 (Figure 28). The other regions account for a small proportion of the WCPO biomass throughout the model period. Over the last decade (2001-10), the western equatorial regions 3, 7 and 8 in combination accounted for 61% of the total biomass, and region 4 accounted for 10%.

The trends in biomass are more variable among regions 1, 2, 5, 6 and 9 (Figure 27), generally reflecting the differences in the CPUE trends from the main longline fisheries (Figure 8). There are some discrepancies between the catch rate trends in adjacent regions, e.g. where steady declines occur in regions 3 and 7, an increase occurs in region 8 since 2000. The steady decline in biomass in region 8 conflicts with the catch rate trend, and is evident in the lack of fit of the longline exploitable biomass for this region to the CPUE indices (Figure 11).

Uncertainty in the biomass estimates is substantially higher in the early part of the calculation period, consistent with the uncertainty in the recruitments. This decreases after 1965, and uncertainty is relatively low after 1990 (Figure 27). Consistent with the recruitment patterns, spawning potential at the start of the model is estimated to be substantially higher than that estimated for period 1965-75. This feature was also present in previous assessments. This substantial decline occurs despite the low and relatively similar catch levels in the periods 1952 – 1965 and 1965-75 (Figure 3). Therefore the high early biomass and subsequent decline around 1965 can be attributed to the uncertain and high recruitment estimates preceding 1965.

6.3.3 Fishing mortality

Average fishing mortality rates for juvenile and adult age-classes increase strongly from 1970 and are at the highest level in the most recent years (Figure 29). Estimates are comparable for juvenile and adult age-classes throughout the model period, although the juvenile rates are generally slightly higher, except for the most recent three years.

Changes in fishing mortality-at-age and population age structure are shown for decadal time intervals in Figure 30. Since the 1970's exploitation rates are high on the youngest age classes and this is associated with increased catches by the purse-seine fishery in region 3 and the Philippines, Indonesian and Vietnamese fisheries in region 7 (Figure 4). There is also a high exploitation rate on the older age classes (6–16 age classes), which coincides with the peak in the selectivity of the unassociated purse-seine fisheries. Overall, there has been a substantial decline in the proportion of old (greater than age class 15) fish in the population since the mid 1970s (Figure 30).

6.3.4 Fishery impact

We measure fishery impact at each time step as the ratio of the estimated biomass to the biomass that would have occurred in the historical absence of fishing. This is a useful variable to monitor, as it can be computed both at the region level and for the WCPO as a whole. This information is plotted in two ways, first the fished and unfished spawning potential trajectories (Figure 31) and second as the depletion ratios themselves (Figure 32). The latter is relevant for the agreed limit reference point and discussed in more detail in Section 6.4.1.

It is evident from the fished and unfished spawning potential trajectories that the impact has been substantial in the western equatorial regions (3, 7, and 8) and considerable in regions 4 and 5, with the impact increasing steadily from the early 1980s (Figure 32). The impacts are relatively low in regions 2 and 9, and moderate in regions 1 and 6.

Overall, the impact of fishing has reduced the current spawning biomass in regions 3, 7, and 8 to about 36%, 40% and 24% of the unexploited level respectively (Figure 32), and has reduced the spawning biomass in region 4 to about 31% of unexploited levels. The current total WCPO biomass is at about 40% of unexploited levels (Figure 33).

The trends in unfished biomass should illustrate the impact of regional recruitment on local biomass, but again must be considered in context of the potential confounding between regional recruitment and movement. However, with the lack of consistent trends in recruitment since 1965 for equatorial regions (3, 4, 7, and 8, Figure 26), the analysis suggests that the declines in spawning potential in these regions are being driven primarily by the fishing impacts.

It is possible to classify the fishery impact on the spawning biomass ($1 - SB_t / SB_{0t}$) to specific fishery components in order to see which types of fishing activity have the largest impact on spawning biomass (Figure 34 and Figure 35). Within each region, the relative impacts of specific fisheries on spawning biomass are vary depending upon the scale of each fishery’s operation. In region 7, the Philippines/Indonesian/Vietnamese miscellaneous fisheries have the greatest impact, whereas the associated purse seine fishery has the largest impact in regions 3, 4 and 8. The impact of the unassociated purse seine fishery has increased in recent years in region 8 (Figure 34). In region 4, the purse seine fishery is responsible for most of the impact.

It is noteworthy that apart from regions 6, the longline fishery has a relatively small impact. In the sub-equatorial regions, the longline fishery tends to have a larger share of the impact, but overall impacts are much smaller.

In areas where they operate, fisheries that catch small fish have a significant impact, and the impact of these fisheries can also be seen in areas that they do not operate, but at a much lower level. While the Philippines/Indonesian/Vietnamese fisheries operate in region 7, they account for an appreciable level of the total impact in regions 3, 4, and 8. This is due to the direct movement of fish originating from region 7.

The recent overall fishery-specific impacts on total biomass in the WCPO indicate relatively low impacts from the longline and pole-and-line fisheries, moderate but increasing impacts from the unassociated purse-seine fishery and the highest impacts from the associated purse-seine and the Philippines/Indonesian/Vietnamese domestic fisheries (Figure 35). It is notable that the impacts from the associated purse-seine fishery have decreased since 2007.

6.3.5 Yield (MSY, MSY time series, SB_{MSY})

Symbols used in the following discussion are defined in Table 6. The yield analyses conducted in this assessment incorporate the estimated Beverton-Holt spawning stock-recruitment relationship (BH-SRR), (Figure 36) into the equilibrium biomass and yield computations. The uncertain recruitments for the early years (pre-1965) and the terminal recruitments (2012) were excluded from fitting the BH-SRR. For the reference model, the steepness coefficient was fixed at a value of 0.80 which implies a moderate relationship between spawning stock biomass and recruitment; average recruitment is assumed to decline to 80% of the equilibrium unexploited recruitment when the level of spawning biomass is reduced to 20% of the unexploited level. Consequently, only the scaling parameter was estimated.

The equilibrium unfished spawning potential was estimated at 2,467,000 mt, and the spawning potential that would support the MSY was estimated to be 728,300 or 29.5% of SB_0. The total equilibrium unfished biomass was estimated to be 4,319,000 mt.

The yield analysis also enables an assessment of the *MSY* level that would be theoretically achievable under the different patterns of age-specific fishing mortality observed through the history of the fishery (Figure 37). Prior to 1970, the WCPO yellowfin fishery was almost exclusively conducted using longlines, with a low exploitation of small yellowfin. The associated age-specific selectivity resulted in a substantially higher level of *MSY* (>900,000 mt per annum) compared to that estimated for the fishery based on the recent age-specific fishing mortality pattern (about 586,000 mt). The dramatic decline in the *MSY* in the 1970's follows the increased development of those fisheries that catch younger yellowfin, principally the small-fish fisheries in the west equatorial regions (Figure 37). Based on these analyses, we conclude that MSY levels would increase if mortality of small fish were reduced which would allow greater overall yields to be sustainably obtained.

Equilibrium yield and biomass (spawning) were computed as a function of multiples of the 2008–2011 average fishing mortality-at-age (Figure 38). For the reference case, a maximum yield (*MSY*) of 586,400 mt per annum is achieved at *fmult* = 1.38; i.e. the current level of fishing mortality relative to F_{MSY} (the ratio of $F_{current}/\tilde{F}_{MSY}$) is 72% (approximately 1/1.38). On this basis, current exploitation rates are approximately 72% of the exploitation rates to produce the *MSY*. Increasing the exploitation rates to the MSY level is predicted to result in only a marginal increase in the long-term, equilibrium yield from of 559,600 mt ($Y_{Fcurrent}$) to 586,400 mt (*MSY*).

However, the form of the yield curve is highly uncertain as it is derived from estimates of fishing mortality at levels lower than the F_{MSY} level and is highly dependent on the assumed value of steepness in the SRR. Further, the *MSY* computation assumes recruitment at the level of the long-term average, mediated by the BH-SRR. For the reference model, low recruitments since 1990 represents a 6% reduction relative to the long-term average (1965-2011), and if future recruitments remain at about the current level, lower yields can be anticipated from the stock.

6.4 Stock status

6.4.1 Stock status based on the traditional Kobe plot

For continuity with previous practice, and while the SC and WCPFC consider the use of target and limit reference points, we have included the traditional Kobe plot for spawning potential versus fishing mortality (Figure 39). We have included both $SB_{current}$ and SB_{latest} for reference on this figure. $SB_{current}$ (2008-11 average) and SB_{latest} (2012) are estimated to be 137% and 124%, respectively, of SB_{MSY} (Table 7).

As noted in Section 6.3.3, fishing mortality has been increasing through time, but $F_{current}$ (2008-11 average) is estimated to be 0.72 times the fishing mortality that will support the *MSY*.

6.4.2 Spawning biomass in relation to limit reference point

The $SB_{F=0}$ calculated based on the period 2002-11 is the basis for the limit reference point and this is a spawning potential of 2,368,557 which 4% lower than SB_0 (Table 7). This indicates that recruitment has been generally slightly lower than that estimated by spawner recruitment curve during this period. The limit reference point is 20%$SB_{F=0}$ and this is a spawning potential of 473,711. $SB_{current}$ (2008-11 average) and SB_{latest} (2012) are estimated to be 42% and 38%, respectively, of $SB_{F=0}$, (Figure 40).

6.4.3 Spawning biomass in relation to potential target reference points

There are currently no agreed biomass-related target reference points for any species, but the WCPFC has requested investigation of spawning potential in the range of 40-60% $SB_{F=0}$ for skipjack for potential biomass-related target reference points. As $SB_{current}$ (2008-11 average) was estimated to be 42% of $SB_{F=0}$, this level falls within the range of the candidate biomass-related target reference points currently under consideration for skipjack tuna, i.e., 40-60%$SB_{F=0}$. However, the SB_{latest} (2012) was estimated to be 38% of $SB_{F=0}$, and this levels falls outside the range of the candidate biomass-related target reference points.

6.5 Results for other model runs

6.5.1 Impact of key model developments (stepwise)

In order to examine the impacts of the stepwise developments from the 2011 yellowfin assessment (run LLcpueOP_TWcpueR6_PTTP) to the reference case of the current assessment (Ref.case), estimates of key reference points, (symbols for which are defined in Table 6), and total biomass trajectories for each of the runs are provided in the Annex 10.3.

2011_newMFCL

Using the latest release version 1.1.5.6 of the MULTIFAN-CL software produced a noticeable effect despite identical input data and model structure. There was an overall decrease in absolute abundance (24% downward shift in $SB_{current}$) and a change from an increasing trend to a flat-to-decreasing trend in abundance since 2000 (Figure 10.3.1). Since the version used for the 2011 assessment, there have been at least four significant improvements in MULTIFAN-CL to the: tagging catch calculations; tagging likelihood; Newton-Raphson catch calculation; and, the penalty calculation in respect of priors on fishery-specific tag reporting rates. It is the latter improvement that most likely accounts for the difference in this stepwise model due to the change in the penalty term and hence the fit to the tagging data. The differences noted above are because these data strongly influence estimates of absolute abundance and the biomass trend.

2011_upd

The biomass trajectory of a straight-forward data update of the 2011 reference case had a largely similar trend although absolute initial biomass was around 10% higher but latest biomass levels were very similar (Figure 10.3.3).

2014_oldCPUE

The substantial structural changes (regional and fisheries) in this stepwise development account for the large differences in absolute abundance and equilibrium quantities due to the higher recruitments estimated. These are likely to be implausible due the highly uncertain recruitments in the early periods of the model. Broad assumptions were needed to apply the CPUE indices from the 2011 assessment in this model, which is presented only as a step towards the next developmental stage.

2014_newCPUE

Applying CPUE indices consistent with the new fisheries structure had a noticeable effect on the trend in biomass over the period since the mid-1980's (Figure 10.3.3): the initial decline was less steep, and a steady but gradual decline is predicted since 2000. The extremely high and uncertain recruitment estimates preceding 1965 have reduced substantially, yet remain high relative to the period post-1965.

2014_rvsCPUE

Reducing conflict among the CPUE indices in the western equatorial region produced a moderate increase in absolute abundance for the period preceding 2000, but predicted similar current biomass to the previous model run and similar stock status (Table 10.3.2).

Ref.Case

Refining the CPUE indices included in the model fit (excluding HL-PH-7) has very little effect on absolute abundance or the biomass trajectory. However, excluding the terminal recruitment deviates "flattens" the total biomass trajectory in the final model year (2012, Figure 10.3.1).

Overall the effects of the stepwise developments were a moderate increase in historical absolute abundance, but with only a 6% difference in estimates of current total biomass (Table 10.3.2). Although absolute abundance was reasonably similar, equilibrium quantities are somewhat higher and consequently estimates of stock size relative to reference points are lower. This can be attributed to the new assumptions made among all tuna assessments for log-normal bias correction in the predictions of the BH-SRR, low relative weight being assigned to fitting this relationship, and constraints on the regional recruitment deviates, that have been demonstrated to increase equilibrium biomass and yield estimates (Davies et al. 2014).

6.5.2 One-off changes to the reference case

The comparison of annual recruitments and absolute biomass trends for the reference case model and the sensitivity runs is shown in Figure 41. The trends in biomass are similar for all seven model options with the difference relating to the biomass magnitude. Recruitments, and therefore biomass, for the alternative steepness options (h_0.65 and h_0.95) were nearly identical to the reference case, and the lines are therefore obscured on the plot (Figure 41). This result is to be expected because of the low relative weight assigned in fitting the BH-SRR such that the effect on model dynamic quantities is negligible. The differences for these model options relate to the equilibrium yield quantities, with *MSY* for the models h_0.65 and h_0.95 being lower and higher, respectively, compared to the reference case (Table 7), as can be expected given the effect on the BH-SRR predictions of average recruitment. Consequently, the estimates of stock status relative to the $SB_{F=0}$ and SB_{MSY} reference points for the models h_0.65 and h_0.95 were lower and higher, respectively, compared to the reference case.

The reference case model was insensitive to including the HL-PH-7 CPUE indices in the model fit with only minor differences evident in the early recruitments and biomass estimates for this model option (CP_all, Figure 41). Current biomass and equilibrium estimates were almost identical to the reference case model (Table 7). Apparently these data, of a very short time series, have very low relative weight in the overall model objective function.

For the model options with a shorter mixing period for tagged fish (Mix_1) and reduced relative weight of the size data in the model fit, (SZ_dw), recruitment estimates were on average lower and with a different trend since 2000 (Figure 41), resulting in lower absolute biomass throughout the model calculation period and slight differences in the recent biomass trend. Equilibrium yield quantities were lower, with *MSY* reduced by about 10% in the case of Mix_1, and estimates of stock status relative to the $SB_{F=0}$ and SB_{MSY} reference points being lower compared to the reference case (Table 7).

The reference case model was highly sensitive to the age-specific natural mortality schedule. For the model option M_est, the mortality estimates were lower for the first five age classes, higher for age classes 7 to 15, and lower for age classes 16 and older (Figure 10). The effect of the lower estimated mortality on younger fish is evident in lower average recruitments but with higher absolute biomass overall (Figure 41). In combination, the lower average recruitment and different mortality schedule resulted in higher SB_{MSY} but similar $SB_{F=0}$, and consequently the estimates of stock status relative to these reference points being higher compared to the reference case (Table 7).

The Kobe plots for the one-off sensitivity runs are compared in Figure 42. These computations incorporated the overall annual fishery selectivity and enables trends in the status of the stock relative to these two reference points to be followed over the model period. The general temporal patterns of the two reference points are similar among the runs with differences in the estimates of current status. Prior to 1980, exploitation rates and total and adult biomass remained at high levels relative to SB_{MSY}. Over the next 25 years, fishing mortality rates steadily increased and the biomass level declined relative to SB_{MSY}. Nonetheless, throughout the model period, including the most recent years, the biomass level is estimated to have remained above the SB_{MSY} levels, while fishing mortality rates have remained below F/F_{MSY}. Only the model sensitivity with the low value of steepness (0.65) has resulted in a recent stock status approaching the *MSY* based thresholds. In summary, the reference point estimates of current status for the key runs subsequently included in the structural uncertainty analysis (grid), indicate $F_{current}$ to be below F_{MSY} and spawning biomass above, or coincident with, SB_{MSY} (Figure 42). Those model runs for which a shorter tag mixing period (Mix_1) and lower steepness (h_0.65) were assumed, predicted $SB_{current}$ to be close to the SB_{MSY} level and higher values for $F_{current}$ (Figure 43).

6.5.3 Structural uncertainty analysis

In considering the results from the structural uncertainty analysis (grid, Figure 44), besides steepness, those options for the factors examined that produced a proportion of runs with spawning biomass below SB_{MSY} and fishing mortality above F_{MSY} included h_0.65, Mix_1, SZ_dw and CP_all. The range of the grid estimates was reasonably broad, e.g. with a median value for SB_{latest}/SB_{MSY} = 1.29, with the 5%ile of 1.00). This indicates that the probability that $SB_{current}$ and SB_{latest} exceed the *SB*-related reference points is relatively low.

Grid estimates for SB_{latest}/SB_{MSY} and $F_{current}/F_{MSY}$ are presented as boxplots for each option of the factors examined in Figure 45 and Figure 46. Relative to the reference case option (shown by the blue boxplot), those options that produced lower values for SB_{latest}/SB_{MSY} and higher values for $F_{current}/F_{MSY}$ were h_0.65, Mix_1 and SZ_dw. Those options that produced higher values for SB_{latest}/SB_{MSY} and lower values for $F_{current}/F_{MSY}$ were h_0.95 and M_est. The option CP_all (including the HL-PH-7 CPUE indices) had negligible effect.

6.5.4 Other model runs

The exploratory model runs examined the reference case model sensitivity to assumptions that were not plausible but may provide insight into aspects of the model that would benefit from closer examination. As such, the results were not reported together with the reference case and sensitivity runs, but the results of the exploration are mentioned.

Estimating steepness with a diffuse (uninformative) prior setting (run h_est) produced a value close to 1 with almost no change to the absolute biomass or other model dynamic quantities, but with lower equilibrium biomass estimates. Given that the estimate was at the upper bound of the plausible range, it is most likely a parameter for which little information was available. The distribution of the estimated recruitments for the years included (1965-2011) is visibly uniform (Figure 36, top panel) which supports this view. This result confirms the approach applied in the current (and previous) assessments to examine a plausible range of steepness values in the set of key model runs.

Including the uncertain early recruitments (pre-1965) in the years for estimating the BH-SRR resulted in an 8% increase in SB_{MSY} and a 9.5% increase in *MSY*. These recruitment estimates are substantially higher (Figure 36, top panel) and therefore, the BH-SRR predictions were higher as a result. As expected, dynamic model quantities, such as current spawning biomass, remained unaffected, and estimates of $SB_{current}$ and SB_{latest} relative to the *SB*-related reference points decreased. The assumption made in this exploratory model (SRR_full) is not recommended (see Section 7.2).

Estimating the terminal temporal recruitment deviates (2012) had very little effect on spawning biomass (see Annex 10.2.1 – run34) but produced slightly higher total biomass in 2012. This result confirmed the reference case assumption that excludes estimating these deviates (due to their higher uncertainty) and this has negligible effect on the *SB*-related reference points.

The exploratory model run that excluded the CPUE in the past 5 years (excl.CP_curr) obtained a slightly better fit to the tagging data (4.2 points) and, as might be expected, consistent trends were obtained for the effort deviates in the last 5 years for the longline fisheries affected (L-All-3, -7, and -8). There was almost negligible difference in the current biomass estimates (3%) and only a slight decrease in the $SB_{current}$ and SB_{latest} relative to the *SB*-related reference points (4%) relative to the reference case. This result indicates that assigning higher relative weight to the tagging data has little effect on the model estimates of current stock status.

For the exploratory model run (Tag_var_est), the tagging negative binomial variance estimates were at the lower bound for the fisheries S-ASS-All-8, S-UNS-All-8, S-ASS-All-3, S-UNS-All-3, all Misc fisheries in region 7, and PL-All-7. These fisheries account for 88% of the total number of recaptures, and therefore the tagging data was effectively down-weighted substantially. All the reporting rate estimates increased and several more were at the upper bound, with a somewhat worse fit to the PTTP data. Current biomass was unaffected and the status relative to the *SB*-related reference points was essentially quite similar to the reference case. This result suggests that while some data conflict exists, a model fit with lower relative weight to 88% of the tagging data does not substantially alter the general model quantities or the estimates of stock status. This exploratory model, besides providing insight to the degree of conflict among the tagging data and the other data input to the model, demonstrated the difficulties with estimating the negative-binomial variance parameters. This supports the approach taken in the reference case to use fixed values for these parameters.

6.6 Overall stock status conclusions

Based on the results from the reference case model provided in Sections 6.4.1, **Error! Reference source not found.**, and **Error! Reference source not found.** and the consideration of results from other model runs in Section **Error! Reference source not found.**, we make the following conclusions regarding stock status:

- Latest catches marginally exceed *MSY*;
- Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the level which will support the maximum sustainable yield;
- Recent levels of fishing mortality are most likely below the level that will support the maximum sustainable yield;
- Recent levels of spawning potential are most likely above (based on 2008-11 average and based on 2012) the limit reference point of 20%SBF=0 agreed by WCPFC; and
- Recent levels of spawning potential are most likely higher (by 1%, based on 2008-11 average) and lower than (by 2% based on 2012) the candidate biomass-related target reference points currently under consideration for skipjack tuna, i.e., 40-60%$SB_{F=0}$.

7 DISCUSSION AND CONCLUSIONS

7.1 Changes from the 2011 assessment

This assessment of yellowfin tuna for the WCPO applied a similar general modelling approach to that used in the 2011 assessment, however, the model's structure and key data sets were substantially revised; most importantly an expansion to 9 regions with 33 fisheries defined, and incorporating CPUE indices derived from operational catch and effort data from all fleets in the longline fishery in regions 3-9, with two other CPUE indices included. By comparison, the 2011 assessment entailed 6 regions, 25 fisheries, and CPUE indices were derived from Japanese data only. These changes have improved the assessment overall through reducing data conflicts and the incongruities in recruitment estimates. Also, the additional diagnostic analyses undertaken have confirmed the availability of information for estimating absolute abundance and supported the various assumptions made regarding the recruitment estimates used in deriving equilibrium reference points examined to infer stock status.

Although early recruitments remain relatively high, causing the discrepancy between unexploited dynamic biomass and unexploited equilibrium biomass, the high initial biomass relative to SB_0 is lower (128 %), compared to the 2011 reference case (156%). Also, the consistent decline in recruitment estimated in 2011 is reduced, such that for the period assumed for the long-term average recruitment there is almost no trend, especially for equatorial regions (3, 4, 7, and 8, Figure 26). Uncertainty in recruitment is substantially reduced since the late 1980s, which coincides with the period for which tag-recapture data and CPUE indices are available. With the lack of a consistent recruitment trend since 1965, the reference case model predicts that the substantial biomass decline in these regions over this period has been driven primarily by fishing impacts.

As mentioned, the assumed period for long-term average recruitment was 1965 – 2011, whereas for the 2011 assessment the full model period was used. Excluding the uncertain high initial recruitments reduced the BH-SRR predictions and therefore the equilibrium biomass and yield quantities. However, this was offset to some extent by the change (since 2011) to include log-normal bias correction of the BH-SRR predictions.

Cumulatively, these changes in the current assessment caused no substantial change in the key results from the 2011 assessment, with a similar overall level of spawning biomass (999,000 mt and 845,000 mt, respectively), and moderately lower spawning biomass, SB_{latest} relative to SB_{MSY}, (1.24 and 1.30, respectively), with similar estimates of $F_{current}/F_{MSY}$ (around 0.7).

For the first time in WCPO yellowfin assessments, standardised CPUE indices from purse seine were included in the reference case model fit, viz. for the associated fishery in region 8 (S-ASS-All-8) and the Philippines-Indonesia fishery in region 7 (S-PHID-7). No clear indications of conflict with these and other data were apparent and the indices for region 8 appeared to be consistent with tagging data, unlike those for the longline fishery. Despite the brevity of these time series, the indices have added to the assessment and further consideration of purse seine CPUE for the yellowfin assessment is warranted.

7.2 Sources of uncertainty

Clear contrast was evident in the likelihood profile in respect of the total population scaling parameter values associated with a plausible range in absolute abundance (Annex 10.1). The maximum likelihood estimate for this parameter occurred at the nadir of the profile as could be expected, with a clear increase in the negative log-likelihood (i.e. a reduction in model fit) when larger or smaller fixed values were assumed. This result indicates there to be sufficient and coherent information in the observations from which absolute abundance can be inferred. This result might be expected given the large amount of tag-recapture observations offered to the model that provide a strong signal for total abundance.

Estimated recruitments appear to be uncertain for the terminal time period (2012) as was indicated by the retrospective analyses (Annex 10.2.1), with the final recruitment estimate in each retrospective model altering as more data is added (Figure 10.2.1). This most likely reflects the lack of observations for these recent cohorts and the temporal recruitment deviates are therefore uncertain. The effect of the terminal recruitment estimates on spawning biomass in the final year was negligible when comparing the run34 with run33 (fixed at the mean value), (Figure 10.2.2). On the basis of this result, the terminal (2012) temporal recruitment deviates were not estimated in the reference case model and were assumed at the mean value.

Despite some differences in the estimated historical variability in recruitments, the retrospective comparison of the reference case models from the 2009, 2011 and the current (2014) assessments, are consistent in respect of the overall declining trend in relative abundance of WCPO yellowfin tuna (Annex 10.2, Figure 10.2.2). The values of absolute abundance differ among the among the assessments due to a number of factors including changes in model structure, assumptions, input data and the MULTIFAN-CL software. However, the general result of relative decline in the population appears consistent among these three assessments.

Two main sources of uncertainty were identified in the reference case model: data conflict in region 8 between the PTTP data and the L-All-8 CPUE indices, and the distribution of regional recruitments that are confounded with movement coefficients.

The conflict between the tagging and CPUE data in region 8 was addressed to some extent by replacing the CPUE indices with the nominal catch rates for the L-All-8 fisheries with a lower penalty assumed for the effort deviations. However, a conflict was still indicated by the tag reporting rates for the S-ASS-All-8 fishery group in region 8 being estimated at the upper bounds and consistent patterns in the effort deviates for the L-All-8 fishery over the period since 2003. It appears the model fit was improved by high biomass in region 8 achieved by predicting low recaptures for recapture group 23 via high reporting rate estimates for the PS ASS 8 and PS UNS 8 fisheries. These fisheries were responsible for the bulk of PTTP tag returns (76%). This resulted in some lack of fit for the years 2009-10 by under-estimating the observed tags. Concurrently, the consistent pattern in the effort deviates for the L-All-8 fishery indicated a lack of fit to the nominal catch rates. The conflict seems to involve the increasing trend in the LL ALL 8 catch rates and the time series of PTTP data suggesting a lower recent biomass or a sudden decline in 2009-10. However, the overall impact of this conflict appears minimal as was demonstrated in the rather extreme exploratory model runs (excl.CP_curr, Tag_var_est) which demonstrated minimal effect on the current biomass estimates because biomass in region 8 comprised <9% of the WCPO total.

Estimates of the regional recruitment distribution and the quarterly movement coefficients appear to be confounded, resulting in the counter-intuitive distribution of recruitments among regions 3, 4, 7, and 8. Pre-recruit processes are described in the model using a combination of recruitment distribution among regions, movement and growth. In yellowfin, these processes determine the distribution of fish in the first age-class ('1 quarter') among the regions and in the 2014 reference case, the spatial disaggregation of the western equatorial region has increased the complexity of this process. For the 2011 reference case model, the western equatorial region was aggregated and the proportion of age class 1 quarter in the population was necessarily high, and despite very low estimated selectivity-at-age for this age class, a relatively poor fit to the purse seine size data was obtained. For the 2014 reference case, dis-aggregating the western equatorial region facilitated heterogeneity in the age composition among regions. The proportions of age class 1 quarter in regions 3 and 4 were estimated to be low, and with low estimated selectivity-at-age for this age class, a relatively good fit to the purse seine size data was obtained. High recruitment was estimated to region 7 where the miscellaneous small fish fisheries occur, and relatively good fits to these size data were also obtained. By means of the high estimated movement coefficients, the age class 1 quarter fish are distributed from region 7 to regions 3 and 4 which facilitates reasonable predictions in these recipient regions for age classes 2 quarters and older. It is worth noting here that the good overall fit to observed recaptures of tagged fish by time period at liberty (quarter) from the region of release to the region of recapture would suggest the movement estimates in the model were strongly determined by the tagging data. In conclusion, the spatial disaggregation assumed for the 2014 reference case has facilitated, by means of the regional recruitment distribution and movement processes, a complex pre-recruit process that achieves a better fit to the size data for the equatorial purse seine fisheries compared to the 2011 reference case, albeit being with an apparently counter-intuitive distribution of recruitment among regions.

Recruitments estimates for the first 14 years of the model period are highly uncertain, and this uncertainty has been removed from the estimates of stock status relative to the SB_{MSY}–related reference points (by excluding them from the BH-SRR fit). This is considered to be a reasonable approach as the observations from that period are scant and unreliable, and the high recruitments create discrepancy between the estimates of dynamic and equilibrium unfished biomass.

Also in relation to the recruitment estimates, the other major source of uncertainty in this assessment is steepness. As mentioned in previous yellowfin assessments there is little information available with which to estimate this biological parameter as was confirmed in the exploratory model run that attempted this. Nothing further of substance has been added to the current assessment that changes this situation. Consequently, the parsimonious approach has again been taken to explore model sensitivity to this parameter over a plausible range (in the structural uncertainty analysis) and from which to summarise the management quantities.

While estimates of the natural mortality-at-age schedule were obtained with a substantial improvement in the fit to the size data component (Table 8), the level of uncertainty is most likely very high and has not been fully explored; such a study is beyond the scope of this assessment and entails detailed examination of the relative influence of data types upon the estimates. Therefore, the M_est model run estimates must be taken with caution and a detailed consideration of this parameter is recommended in future assessments. While the large amount of tagging data offers promise for estimating natural mortality, a suggested approach is to derive estimates from a model fit to tagging data primarily by down-weighting other data types (pers. comm. John Hampton, SPC).

7.3 Recommendations for further work

In order to further improve the yellowfin tuna stock assessment recommendations are provided below under the categories of General, MULTIFAN-CL/Modelling, Data analysis, and Research.

<u>General Recommendations</u>

- The SC considers the frequency of assessments for the key tuna species, and the relative priority of other investigations of inputs to the models and examination of model assumptions, as are required to address key areas of uncertainty in the assessments.

<u>MULTIFAN-CL/Modelling</u>

- Reducing the confounding between regional recruitment distribution and movement parameters, possibly by assuming an orthogonal recruitment structure.
- Examine the implications of regional growth variation for stock assessment results, via simulation and region-scale models.
- MULTIFAN-CL be modified to allow the incorporation of tag-based length increment observations to improve the estimation of growth.
- Alternative functional forms, including length-based selectivity, be considered for the small-fish domestic fisheries.
- Estimate natural mortality from dedicated model fits to tagging data.

- Develop sex-structured models with length-based maturity ogives to express the "proportion mature" by representing the proportion of biomass in each age class that is mature and female, and possibly including fecundity-at-age. Consider the possible difference obtained via this approach in terms of depletion-based reference points.
- An examination of the effects of model complexity on the uncertainty of output quantities. Applying the diagnostic of likelihood profiling is an effective approach and could be applied to other parameters beside the total population scaling parameter, e.g. length at maximum age, and profiling the likelihood for individual data components.
- Estimate separate selectivities for the S-JP-1 fishery over two time periods: pre-mid80s and post-mid-80s; which may considerably improve the fit to the length frequency data.

Data analysis

- Work to improve approaches to the modelling of longline CPUE data should continue, integrating the distant water fishing nation's logsheet data across flags to maximise its value in terms of coverage and sample size. Also to continue the development of indices from the purse seine fisheries. This is the highest priority activity to support the yellowfin assessment.
- Undertake a detailed examination of the conflicting trends in longline CPUE indices among regions 3,7, and 8.
- The importance of tagging data in the yellowfin assessment is clearly recognised. Further analysis of PTTP data in region 8 and the adjacent western equatorial regions to examine the relative trends in biomass and mixing processes is required, particularly for juvenile yellowfin.
- Analysis of available tagging data to examine the potential for estimating natural mortality rates of yellowfin.
- Detailed investigations be undertaken of the Japanese longline length data throughout the WCPO and other length and weight frequency data from longline fisheries in regions 3 and 4. Such investigations will require details of sampling protocols and operational level CPUE data. Collaborations with national scientists will be important if these data continue to not be provided to the WCPFC due to domestic legal constraints.

Data improvement

- Direct ageing of yellowfin tuna, in particular throughout the WCPO so as to characterise any regional differences in growth.
- Continuation of the work to refine both the species composition and total catches from the domestic fisheries that occur in Indonesia, Vietnam and the Philippines.
- Continuation of tag seeding work, to provide better estimates of tag reporting rates.

7.4 Main conclusions

The main conclusions of the current assessment (based upon the median of the uncertainty grid estimates, and the sensitivity model runs) are as follows.

1. The new regional structure appears to work well for yellowfin, and in combination with other modelling and data improvements, provides a more informative assessment than in the past.
2. Spatially-aggregated recruitment is estimated to decline in the early part of the assessment, but there is no persistent trend post-1965. The analysis suggests that the substantial declines in spawning potential are being driven primarily by the fishing impacts rather than long-term declines in recruitment. However, recent recruitment is estimated to be slightly lower than the long-term average (by approximately 6%).
3. Biomass is estimated to have declined throughout the model period. The biomass trends in the model are principally driven by the time-series of catch and GLM standardised effort from the principal longline fisheries, and more recently by tagging data. Over recent years, there has been considerable refinement of the longline CPUE indices, largely as a result of the utilisation of the operational level data from the longline fishery. This data enables a number of factors to be incorporated within the analysis to account for temporal trends in the catchability of the fleet.

4. Further refinements have been made to process the longline size frequency data (length and weight data) and improvements have been made in the fit to both the size frequency data and the CPUE indices.

5. The spatial dis-aggregation of the western equatorial region has facilitated heterogeneity in the age-compositions among the new regions that have considerably improved the fit to size data from the purse seine fisheries, and hence better describes the removal of fish-at-age from the population compared to previous assessments.

6. There is conflict between the tagging data (principally from the PTTP) and the other key sources of data included in the model, primarily the CPUE indices, especially in region 8. However, this does not add considerable uncertainty to the assessment, but further auxiliary analysis of the PTTP tagging data and longline CPUE in region 8 are required to resolve the conflict between these key sources of data.

7. Fishing mortality for adult and juvenile yellowfin tuna is estimated to have increased continuously since the beginning of industrial tuna fishing; being on average higher for juveniles. A significant component of the increase in juvenile fishing mortality is attributable to the Philippines, Indonesian and Vietnamese surface fisheries, which have the most uncertain catch, effort and size data. Recently good progress has been made in acquiring a large amount of historical length frequency data from the Philippines. However, there is an ongoing need to improve estimates of recent and historical catch from these three fisheries and to maintain and enhance the current fishery monitoring programme within the WPEA region. Fishing impact analyses from this assessment have shown the importance of these fisheries on the levels of depletion in all the western equatorial regions. Therefore, improved estimates of historical and current catch from these fisheries are important for determining the fishing impacts upon the stock.

8. The ratio $SB_t/SB_{F=0}$ provides a time-series index of population depletion due to fishing. Depletion has increased steadily over time, reaching a level of 60% of unexploited biomass in 2012, (i.e. $SB_{latest}/SB_{F=0}$=40%). This represents a moderate level of stock-wide depletion although the stock remains higher than the equivalent equilibrium-based reference point (SB_{latest}/SB_0 of approximately 30%). However, depletion is higher in the equatorial region 4 where recent depletion levels are approximately 0.31 for spawning biomass (a 69% reduction from the unexploited level) and 0.24 in region 8. If stock-wide over-fishing criteria were applied at the level of our model regions, we would conclude that regions 4 and 8 are fully exploited and the remaining regions are under-exploited.

9. The attribution of depletion to various fisheries or groups of fisheries indicates that the associated-set purse-seine fishery and Philippines/Indonesian/Vietnamese domestic fisheries have the highest impact, particularly in region 7. While the unassociated-set purse seine fishery has a moderate impact, it is increasing in region 8. These fisheries are also contributing to the fishery impacts in all other regions. In all regions, the longline fishery has a relatively small impact, less than 5%.

10. For the most plausible range of models, the fishing mortality based reference point $F_{current}/F_{MSY}$ is estimated to be below 1.0 (0.51–0.90). The corresponding biomass based reference point SB_{latest}/SB_{MSY} is estimated to be above 1.0 (1.05–1.51). The stock status indicators are sensitive to the assumed value of steepness for the stock-recruitment relationship. A value of steepness greater than the default value (0.95) yields a more optimistic stock status and estimates considerably higher potential yields from the stock. Conversely, for a lower (0.65) value of steepness, the stock is estimated to be very close to the *MSY* based fishing mortality and biomass thresholds (0.9 and 1.05, respectively).

11. The estimates of *MSY* for the principal model options (526,400–744,800 mt) are comparable to the recent level of (estimated) catch from the fishery (597,000 mt), and for most of the plausible model runs the recent catch exceeds *MSY* (0.8–1.13). Further, while estimates of current fishing mortality are generally below F_{MSY} , any increase in fishing mortality would most likely increase the depletion levels within regions 4 and 8.

12. The current assessment investigated the impact of a range of sources of uncertainty in the current model and the interaction between these assumptions. Nonetheless, particular issues were

highlighted in the reference case and there remains a range of other assumptions in the model that should be investigated either internally or through directed research. The confounding of movement coefficients and recruitment distribution among regions requires investigation, as does the conflict between CPUE and tagging data in region 8. Further studies are required to refine our estimates of growth, natural mortality and reproductive potential, incorporating consideration of spatio-temporal variation and sexual dimorphism; to consider size-based selectivity processes in the assessment model; to collect age frequency data from the commercial catch in order to improve current estimates of the population age structure; to continue to improve the accuracy of the catch estimates from a number of key fisheries, particularly those catching large quantities of small yellowfin; to refine the methodology and data sets used to derive CPUE abundance indices from the longline fishery; and to refine approaches to integrate the recent tag release/recapture data into the assessment model.

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Table 1. Definition of fisheries for the nine-region MULTIFAN-CL analysis of yellowfin tuna.

Fishery	Nationality	Gear	Region
1. L ALL 1	All	Longline	1
2. L ALL 2	All, except US	Longline	2
3. L US 2	United States	Longline	2
4. L All 3	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	3
5. L OS-E 3	Eastern LL region 3: CT-Offshore, CN, FSM, MH, PH, PW, and ID	Longline	3
6. L OS-W 7	Western LL region 7: CT-Offshore, CN, FSM, MH, PH, PW, VN, and ID	Longline	7
7. L All 7	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PW	Longline	7
8. L All 8	All	Longline	8
9. L All 4	All, except US	Longline	4
10. L US 4	United States	Longline	4
11. L AU 5	Australia	Longline	5
12. L All 5	All excl. Australia	Longline	5
13. L All 6	All	Longline	6
14. S-ASS All 3	All, except ID and PH dom	Purse seine, log/FAD sets	3
15. S-UNS All 3	All, except ID and PH dom	Purse seine, school sets	3
16. S-ASS All 4	All	Purse seine, log/FAD sets	4
17. S-UNS All 4	All	Purse seine, school sets	4
18. Misc PH 7	Philippines	Miscellaneous (small fish), including purse seine within PH archipelagic waters.	7
19. HL ID-PH 7	Philippines, Indonesia	Handline (large fish)	7
20. S JP 1	Japan	Purse seine, all sets	1
21. P JP 1	Japan	Pole-and-line	1
22. P All 3	All, except Indonesia	Pole-and-line	3
23. P All 8	All	Pole-and-line	8
24. Misc ID 7	Indonesia	Miscellaneous (small fish), including purse seine within ID archipelagic waters.	7
25. S PHID 7	Philippines and Indonesia	Offshore purse seine in waters east of about 125°E (and outside of PH and ID archipelagic waters).	7
26. S-ASS All 8	All	Purse seine, log/FAD sets	8
27. S-UNS All 8	All	Purse seine, school sets	8
28. L AU 9	Australia	Longline	9
29. P All 7	All	Pole-and-line	7
30. L All 9	All	Longline	9
31. S-ASS All 7	All, except ID and PH dom	Purse seine, log/FAD sets	7
32. S-UNS All 7	All, except ID and PH dom	Purse seine, school sets	7
33. Misc VN 7	VN	Miscellaneous including purse seine and gillnet within VN waters	7

Table 2. Number of release groups (n.groups), tagged fish released (n.release) and recaptured (n.recaps) by program and release region input to the reference case.

Programme		**Region**							**Total**
		3	**4**	**5**	**6**	**7**	**8**	**9**	
Coral Sea	n. groups	-	-	2	1	1	1	3	8
1991-1995	n. release	-	-	578.1	30.8	3086.1	173.1	2567.4	6435.6
	n. recaps	-	-	4	-	952	22	66	1044
PTTP	n. groups	11	6	5	-	3	15	-	40
2005-2012	n. release	5202.7	1649.0	3143.8	-	6184.7	36274.8	-	52455.0
	n. recaps	1023	335	460	-	1396	10293	-	13507
RTTP	n. groups	7	5	2	2	6	8	-	30
1989-1992	n. release	2259.1	1840.6	869.7	656.7	7687.1	10377.6	-	23690.8
	n. recaps	232	177	19	7	1414	721	-	2570

Table 3. Comparison of the main assumptions of the reference case model from the 2011 assessment (run LLcpueOP_TWcpueR6_PTTP), with the Ref.Case model for the current (2014) assessment and details of the major changes to the assessment.

Component	**2011 assessment** (LLcpueOP_TWcpueR6_PTTP)	**2014 assessment** (Ref.Case)
Regional structure	Six regions	Nine regions with two new regions added to the western equatorial region and one to the south western region.
Fishery structure	26 fisheries	33 fisheries and the first inclusion of some Japanese and Vietnamese coastal fishery catches
Longline CPUE	Operational indices based on Japanese logsheet data.	Operational CPUE indices based on either Japanese logsheet data, or all operational data (combined flags) available to SPC.
Longline size data	All available data. Japanese data spatially weighted by CPUE	Either weight or length used for fisheries depending on quality and coverage. Japan data weighted spatially by catch and all fleets data for some fisheries.
Purse seine size data	Selectivity bias corrected observer samples	Selectivity bias corrected observer samples plus Pago Pago port sampling data. All weighted by set catch.
Recruitment and spawner recruitment relationship	All deviates estimated and moderate constraint on fitting the SRR curve	Terminal four recruitment deviates not estimated and these and the first 56 recruitment deviates (first 14 years) not included in the estimation of the SRR. Lognormal bias correction applied to the SRR and low penalty on fitting the SRR.

Table 4. Summary of the groupings of fisheries within the assessment for selectivity curve, catchability (used for the implementation of regional weights), tag recaptures (typically for purse seine fisheries within a region), and tag reporting rates. Note for the latter, for some fishery groups different reporting rates were estimated for different tag release programmes. See Table 1 for further details on each fishery.

Fishery	Region	Selectivity	Catchability	Tag recaptures	Tag reporting
1. L ALL 1	1	1	1	1	1
2. L ALL 2	2	1	1	2	1
3. L US 2	2	2	2	3	2
4. L All 3	3	3	1	4	1
5. L OS-E 3	3	4	3	5	1
6. L OS-W 7	7	5	4	6	1
7. L All 7	7	6	1	7	1
8. L All 8	8	7	1	8	1
9. L All 4	4	3	1	9	1
10. L US 4	4	8	5	10	2
11. L AU 5	5	9	6	11	3
12. L All 5	5	3	1	12	4
13. L All 6	6	3	1	13	1
14. S-ASS All 3	3	10	7	14	5
15. S-UNS All 3	3	11	8	14	5
16. S-ASS All 4	4	10	9	15	6
17. S-UNS All 4	4	11	10	15	6
18. Misc PH 7	7	12	11	16	7
19. HL ID-PH 7	7	13	12	17	8
20. S JP 1	1	14	13	18	9
21. P JP 1	1	15	14	19	10
22. P All 3	3	16	15	20	11
23. P All 8	8	17	16	20	12
24. Misc ID 7	7	12	17	21	13
25. S PHID 7	7	10	18	22	14
26. S-ASS All 8	8	10	19	23	15
27. S-UNS All 8	8	18	20	23	15
28. L AU 9	9	19	21	24	16
29. P All 7	7	20	22	25	17
30. L All 9	9	3	1	26	18
31. S-ASS All 7	7	10	23	27	5
32. S-UNS All 7	7	11	24	27	5
33. Misc VN 7	7	12	25	28	19

Table 5. Summary of the reference case model and one-off sensitivities to the reference case, with those in **bold** being key model runs for the assessment and factors applied in the uncertainty grid analysis.

Run	Name	Description
run37	**Ref.Case**	Exclude CPUE indices from the fit for fisheries L-All-8 and HL- PH-7, BH-SRR fit to a subset of the model period (1965-2011), steepness=0.8, size data weighting nsample/20, tag mixing period=2 quarters, natural mortality assumed at fixed values.
tagmix_1qtr	**Mix_1**	Tag mixing period=1 quarter
steep_0.65	**h_0.65**	Steepness=0.65.
steep_0.95	**h_0.95**	Steepness=0.95.
CPUE_ALL	**CP_all**	Include HL- PH-7 standardised CPUE indices.
sz_wt_40	**SZ_dw**	Down weight the relative influence of the size data by 100%, nsample/40.
M_est	**M_est**	Estimate age-specific natural mortality schedule.
run39	Rterm_est	Estimate terminal recruitment deviates in 2012.
run40	h_est	Estimate steepness.
run41	SRR_full	Estimate the BH-SRR to estimated recruitments over the full model calculation period.
run42	excl.CP_curr	Exclude CPUE indices for L-All-3, L-All-7, and exclude nominal catch rates for L-All-8 for the most recent 5 years.
run43	Tag_var_est	Estimate the tagging likelihood negative binomial variance parameters.

Table 6. Description of symbols used in the yield analysis. For the purpose of this assessment, 'current' is the average over the period 2008-2011 and 'latest' is 2012.

Symbol	Description
$Y_{F_{MSY}}$ or MSY	Equilibrium yield at F_{MSY}. Better known as MSY
C_{latest}/MSY	Catch in the most recent year relative to MSY
$F_{current}/F_{MSY}$	Average fishing mortality-at-age for a recent period relative to F_{MSY}
B_0	Equilibrium unexploited total biomass
$B_{current}$	Average annual total biomass over a recent period
SB_0	Equilibrium unexploited spawning biomass
SB_{MSY}	Equilibrium spawning biomass that supports MSY
$SB_{F=0}$	Annual spawning biomass in the absence of fishing
$SB_{current}$	Average annual spawning biomass over a recent period
SB_{latest}	Spawning biomass in the most recent year
$SB_{current}/SB_{F=0}$	Average annual spawning biomass over a recent period relative to $SB_{F=0}$
$SB_{latest}/SB_{F=0}$	Spawning biomass in the most recent year relative to $SB_{F=0}$
$SB_{current}/SB_{MSY}$	Average annual spawning biomass over a recent period relative to SB_{MSY}
SB_{latest}/SB_{MSY}	Spawning biomass in the most recent year relative to SB_{MSY}

Table 7. Estimates of management quantities for the selected stock assessment models and the structural uncertainty analysis (grid). 'Current' is the average over the period 2008-2011 and 'latest' is 2012.

	Ref.Case	Mix_1	h_0.65	h_0.95	CP_all	SZ_dw	M_est
MSY (mt)	586400	526400	527200	642800	586800	574400	744800
C_{latest}/MSY	1.02	1.12	1.13	0.93	1.02	1.03	0.8
$F_{current}/F_{MSY}$	0.72	0.87	0.9	0.58	0.72	0.73	0.51
B_0	4319000	3862000	4475000	4221000	4324000	4151000	5694000
$B_{current}$	1994655	1597536	1996179	1995224	1996660	1871560	2841550
SB_0	2467000	2202000	2557000	2411000	2470000	2242000	2702000
SB_{MSY}	728300	648000	859600	594500	728800	631600	843100
$SB_{F=0}$	2368557	2206510	2556733	2255523	2369854	2170826	2359912
$SB_{current}$	998622	746743	999474	998914	1000101	849412	1308171
SB_{latest}	899496	770210	899362	898389	898378	769504	1224712
$SB_{current}/SB_{F=0}$	0.42	0.34	0.39	0.44	0.42	0.39	0.55
$SB_{latest}/SB_{F=0}$	0.38	0.35	0.35	0.4	0.38	0.35	0.52
$SB_{current}/SB_{MSY}$	1.37	1.15	1.16	1.68	1.37	1.34	1.55
SB_{latest}/SB_{MSY}	1.24	1.19	1.05	1.51	1.23	1.22	1.45

Table 7 cont.

	Grid median	5%ile	95%ile
MSY (mt)	583862	477140	745320
C_{latest}/MSY	1.04	0.8	1.24
$F_{current}/F_{MSY}$	0.76	0.51	1.09
B_0	4398948	3553000	5693300
$B_{current}$	1945664	1411004	2839906
SB_0	2087812	1192400	2709150
SB_{MSY}	607024	309150	859990
$SB_{F=0}$	1990529	1086460	2478299
$SB_{current}$	811014	454639	1307270
SB_{latest}	773429	385949	1223085
$SB_{current}/SB_{F=0}$	0.41	0.29	0.55
$SB_{latest}/SB_{F=0}$	0.38	0.29	0.52
$SB_{current}/SB_{MSY}$	1.37	0.97	1.82
SB_{latest}/SB_{MSY}	1.29	1.00	1.69

Table 8. Details of objective function components for the Ref.Case and sensitivity model options**.**

Run	npars	Total	Catch	Length freq.	Weight freq	Tag	Penalties
Ref.Case	8699	-1195769.31	25.68	-272144.95	-935896.10	8293.67	6959.60
Mix_1	8699	-1193797.22	50.72	-272082.73	-935899.31	9992.86	7260.51
h_65	8699	-1195763.94	25.71	-272151.26	-935899.25	8297.65	6971.58
h_95	8699	-1195763.79	25.68	-272150.52	-935899.59	8297.39	6972.16
CP_all	8678	-1195770.35	25.67	-272145.23	-935894.54	8293.55	6956.36
SZ_40	8699	-1056861.43	23.33	-237945.12	-830329.02	7839.36	6459.88
M_est	8728	-1196158.52	27.24	-272290.98	-936338.91	8294.01	7090.25

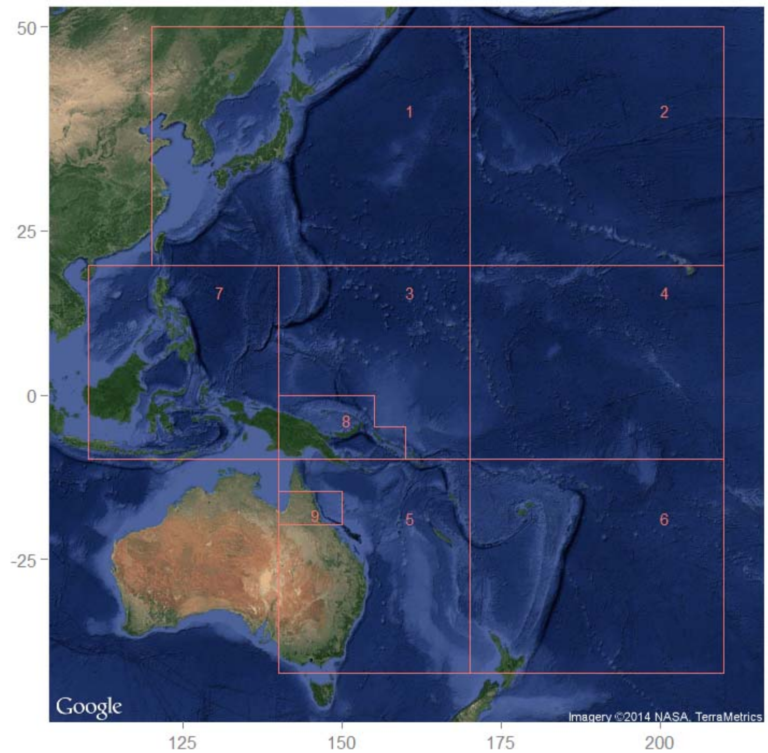


Figure 1. Regional structure of the reference case model.

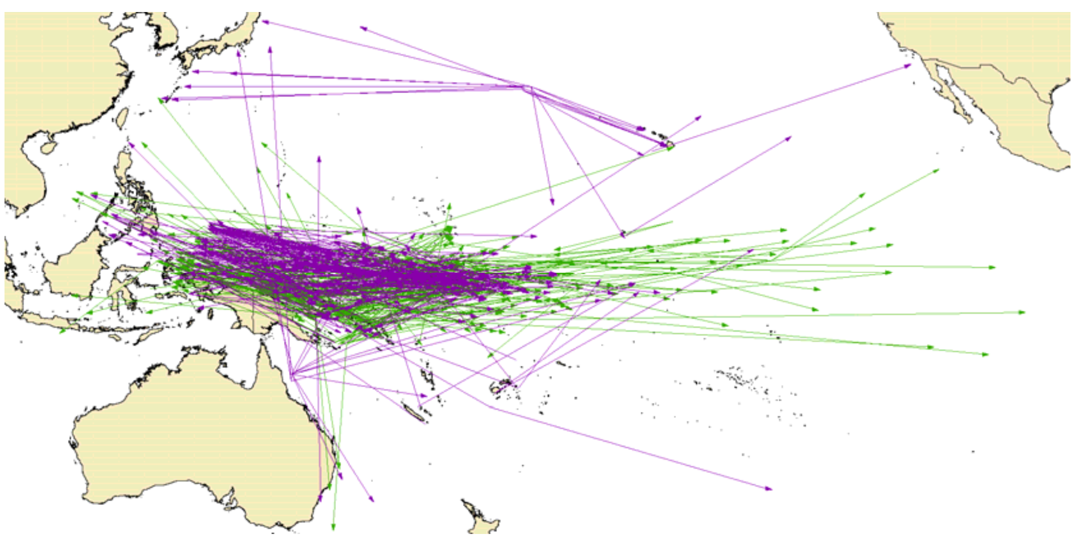


Figure 2. Long-distance (>1,000 nmi) displacements of tagged yellowfin in the Pacific Ocean from data available to SPC. The green arrows are data from the Pacific Tuna Tagging Programme (2008 – current). The purple arrows are from earlier SPC tagging in the western Pacific (Regional Tuna Tagging Project, 1989-1992), the IATTC in the eastern Pacific and the University of Hawaii in the North Pacific around Hawaii.

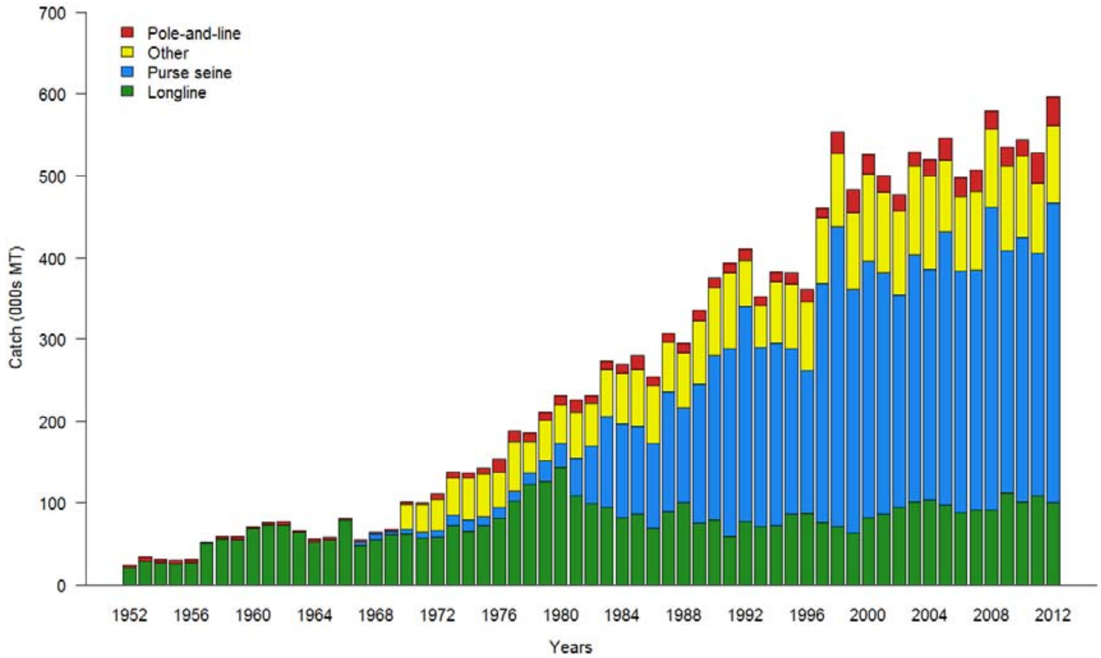


Figure 3. Total annual catch (1000s mt) by fishing gear from the reference case model.

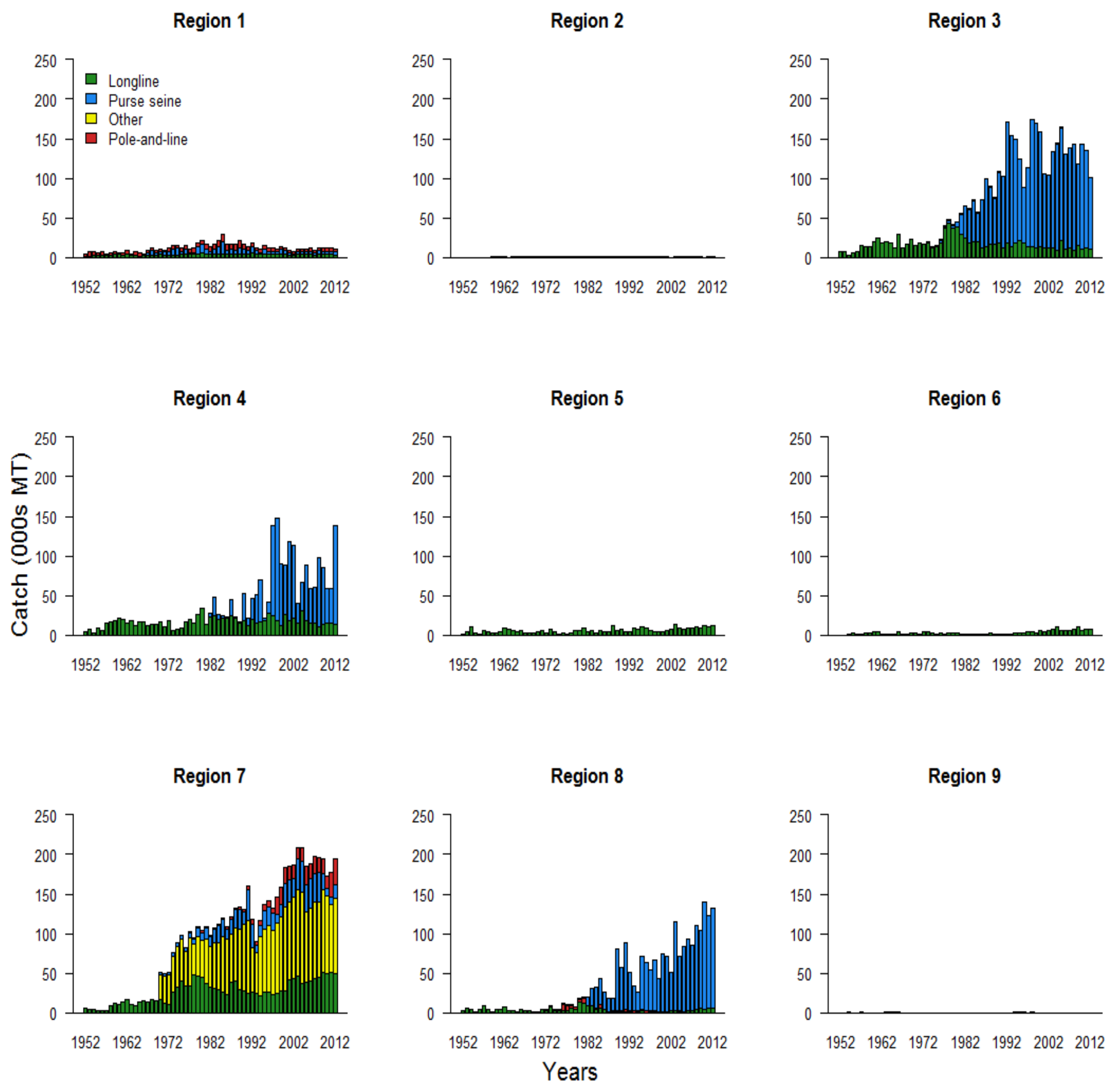


Figure 4. Total annual catch (1000s mt) by fishing method and assessment region from the reference case model.

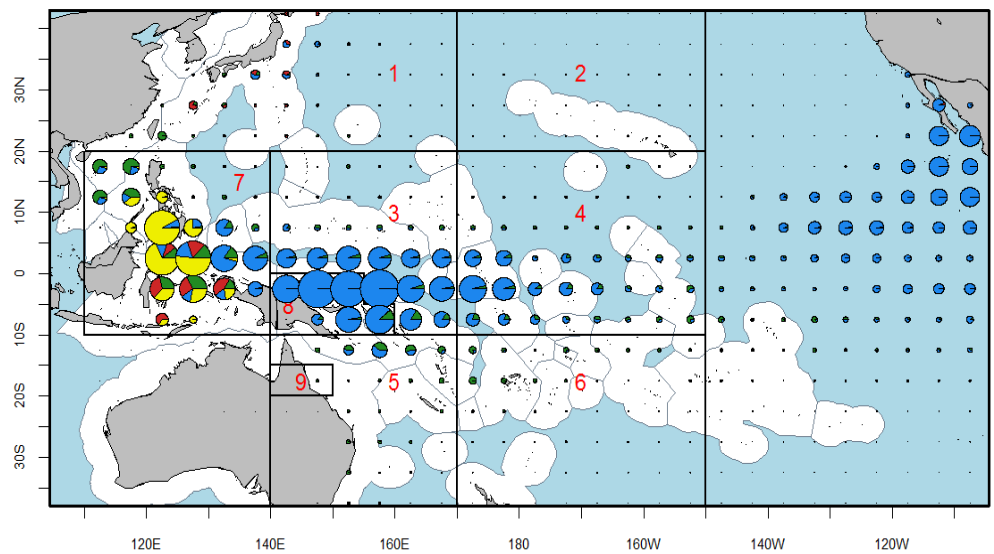


Figure 5. Catch distribution (1990-2010) by 5 degree squares of latitude and longitude and fishing method: longline (green), purse-seine (blue), pole-and-line (red), and other (yellow). Overlaid are the regions for the assessment model.

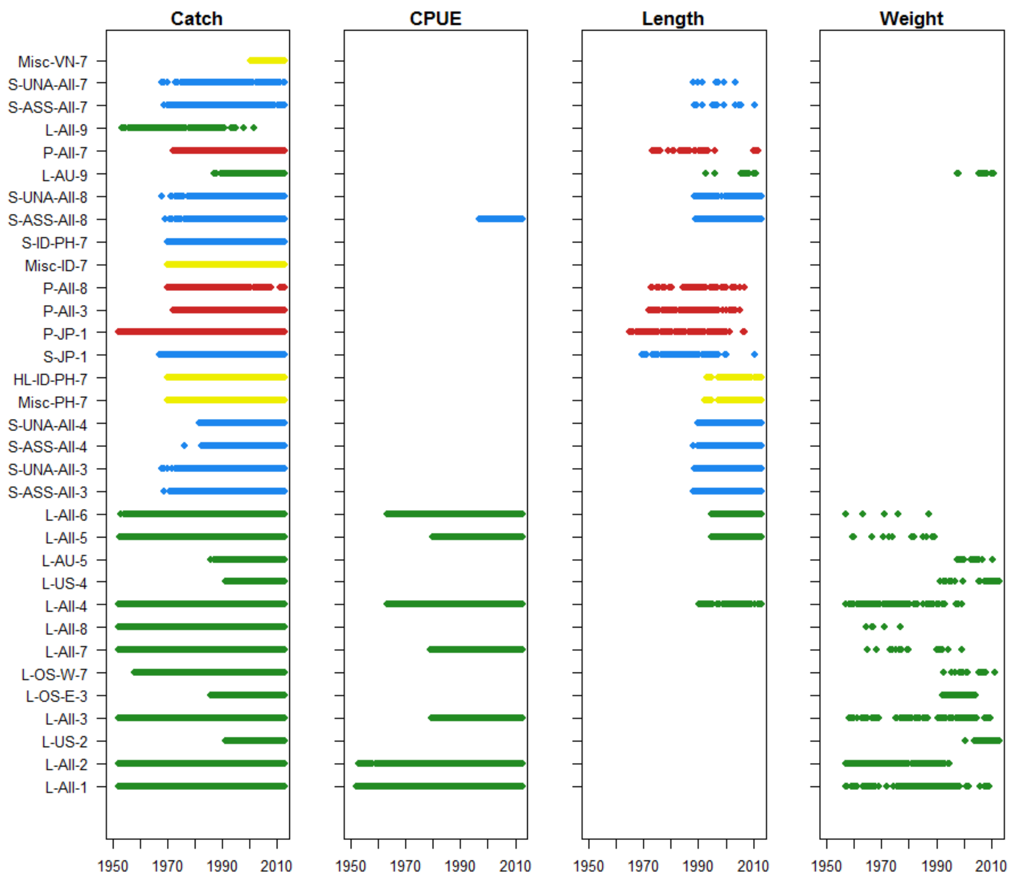


Figure 6. Presence of catch, standardised CPUE, and length and weight frequency data by year and fishery for the reference case model.

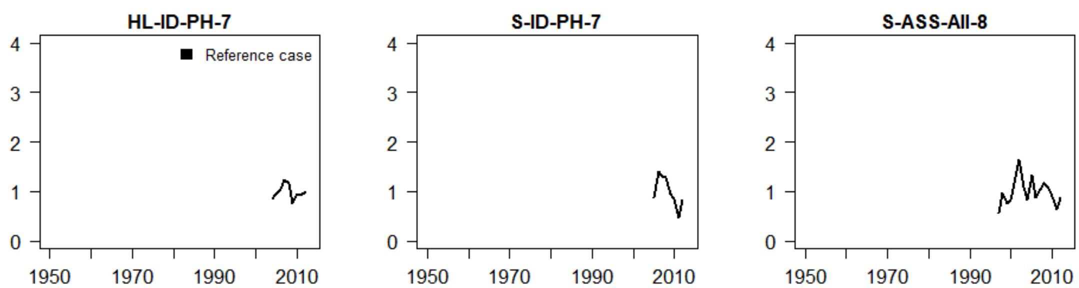


Figure 7. GLM standardised catch-per-unit-effort (CPUE) for the PH handline and domestic Purse seine fisheries and Purse seine All in region 8 from the reference case model. Indices are scaled by the respective region scalars. See Bigelow et al. (2014) and Pilling et al. (2014) for further details of the CPUE.

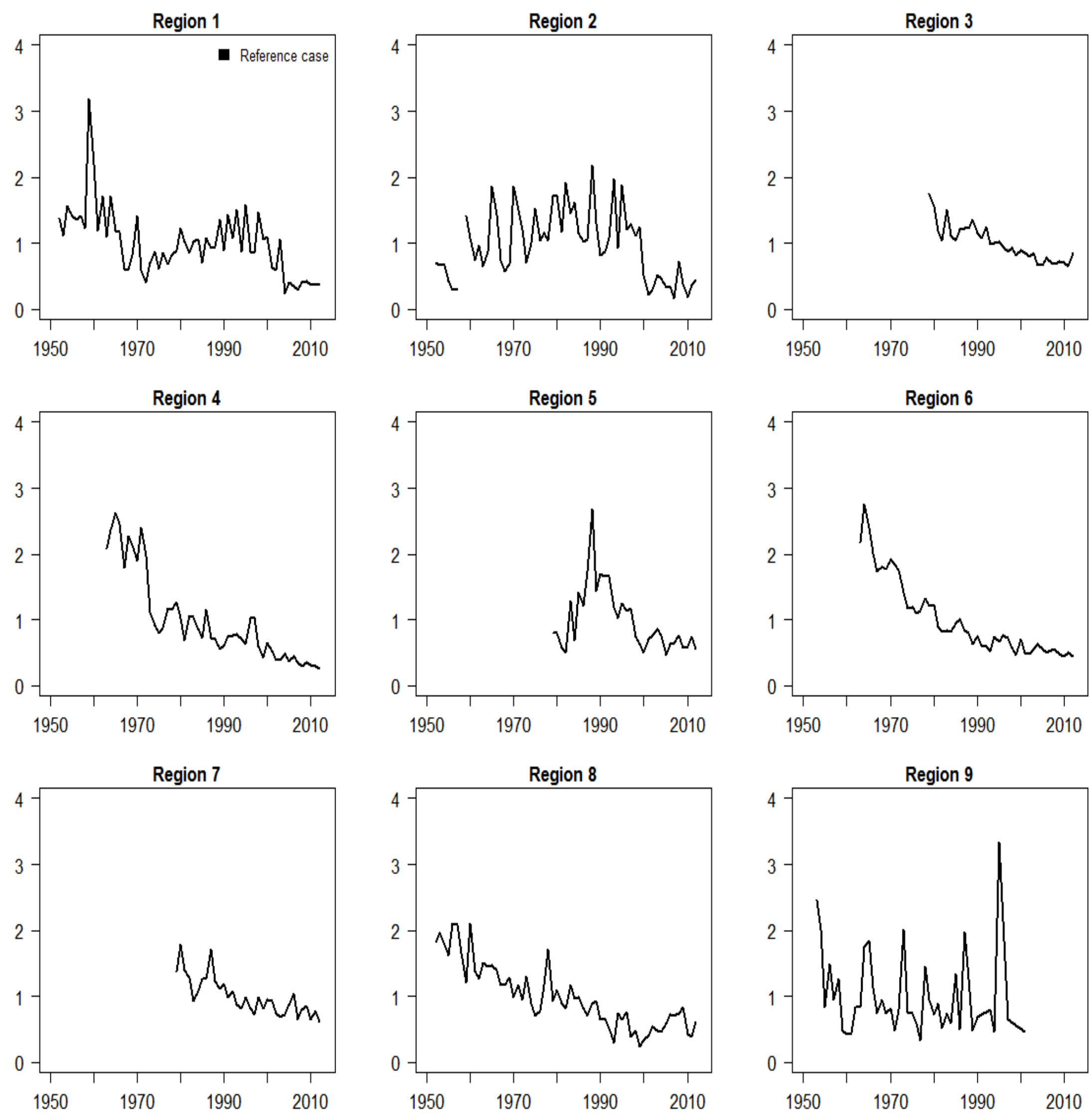


Figure 8. GLM standardised catch-per-unit-effort (CPUE) for the principal longline fisheries (LL ALL 1-9) from the reference case model. Indices are scaled by the respective region scalars. See McKechnie (2014) and McKechnie et al. (2014b) for further details of the CPUE and region scalars. Note: region 9 CPUE is based on nominal rather than standardised CPUE.

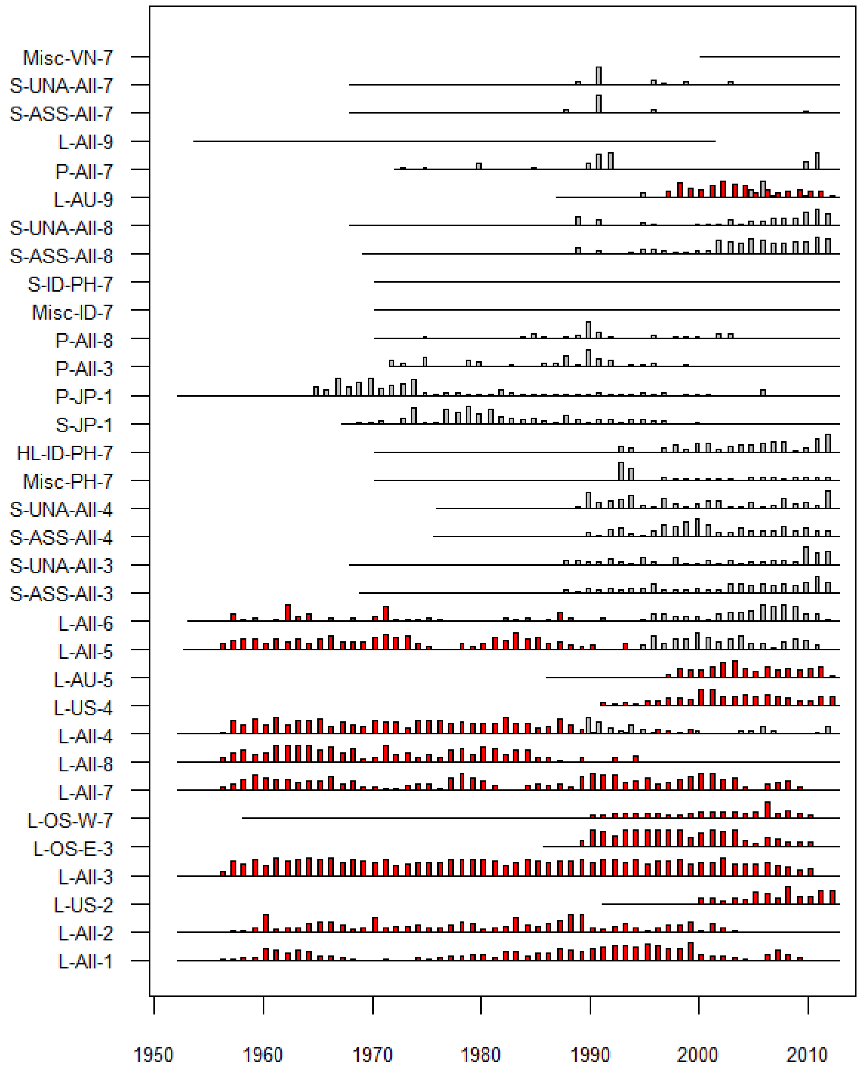
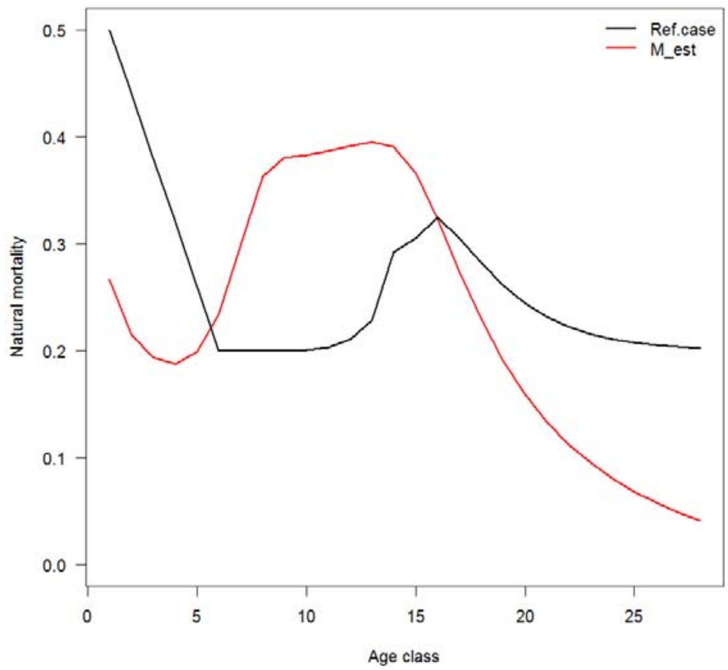


Figure 9. Number of weight (red) and length (grey) frequency samples from the reference case model. The maximum value is that for a given fishery over its time series, but note that in the reference case model a maximum sample size of 1000 is allowed.



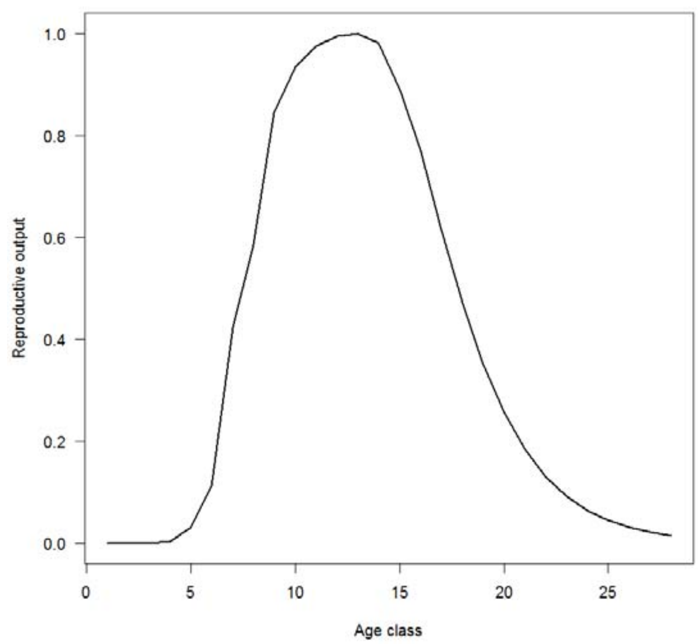


Figure 10. Natural mortality-at-age (top) and % mature (bottom) as assumed in the reference case. Note that estimate of maturity is actually used to define an index of spawning potential incorporating information on sex ratios, maturity at age, fecundity, and spawning fraction (see Hoyle and Nicol 2008 for further details).

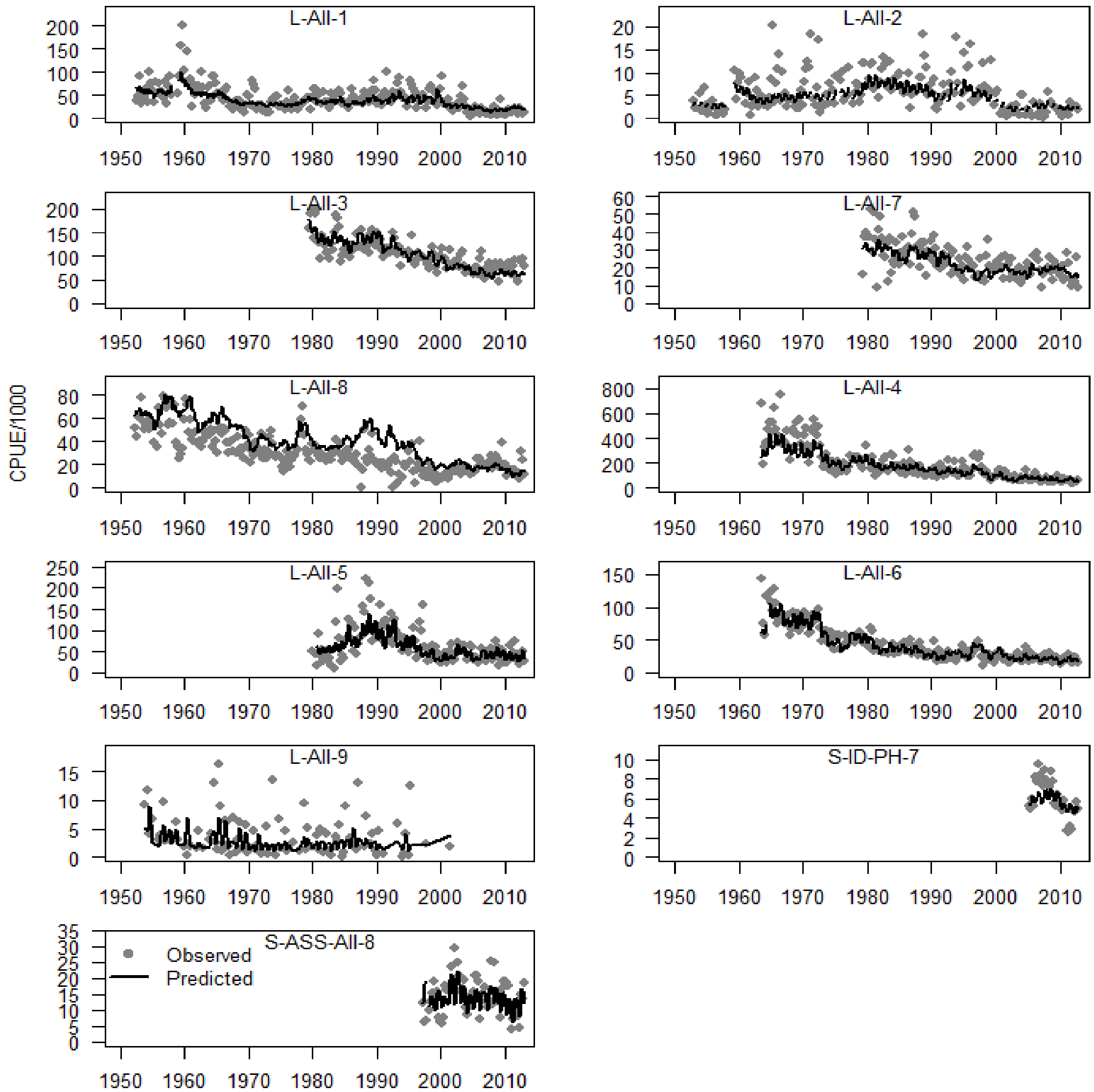


Figure 11. Observed and predicted CPUE for the major longline fisheries for the reference case.

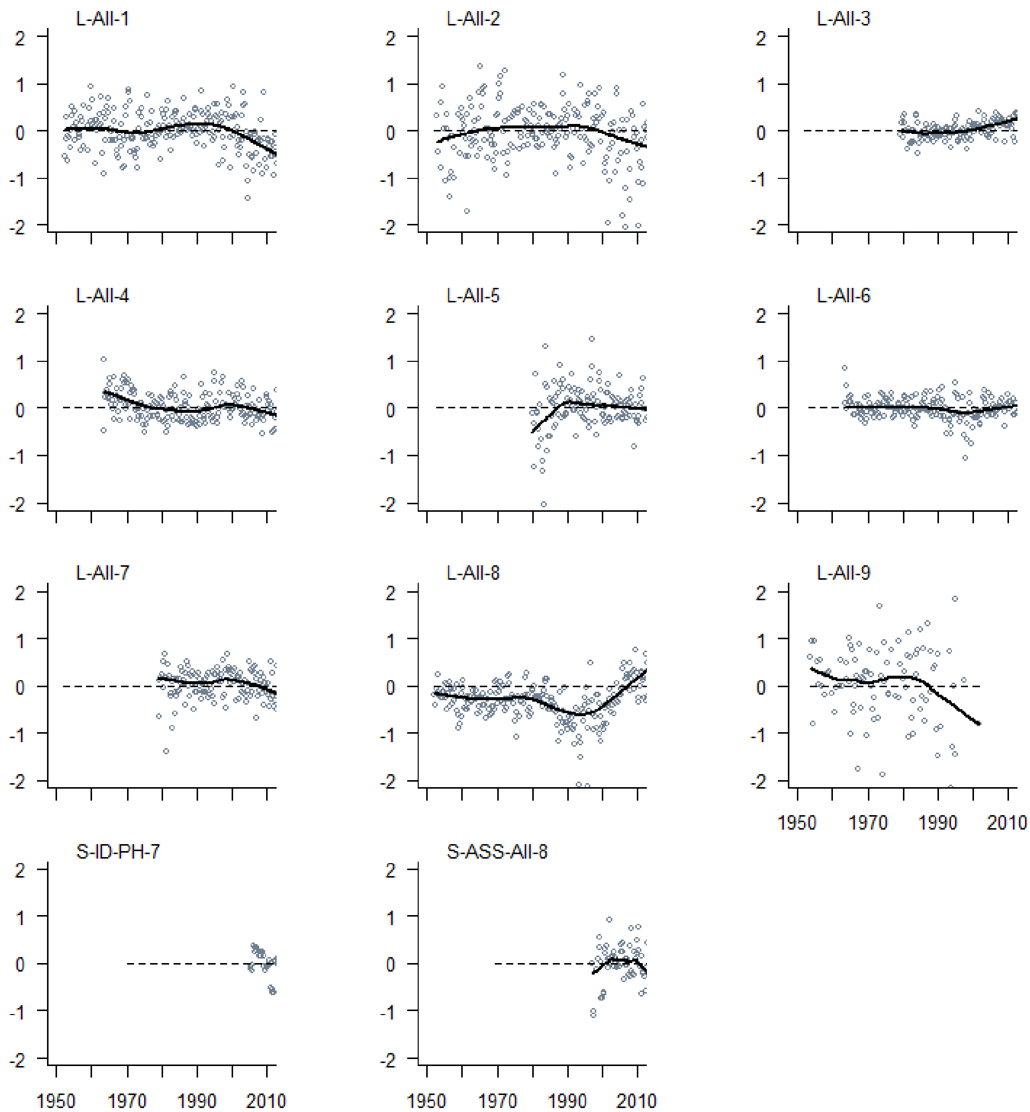


Figure 12. Effort deviations by time period for fisheries for which standardised effort indices were available (Ref.case). Note that for L-All-8 the model was fit to the nominal effort. For fisheries with longer time series, the dark line represents a lowess smoothed fit to the effort deviations.

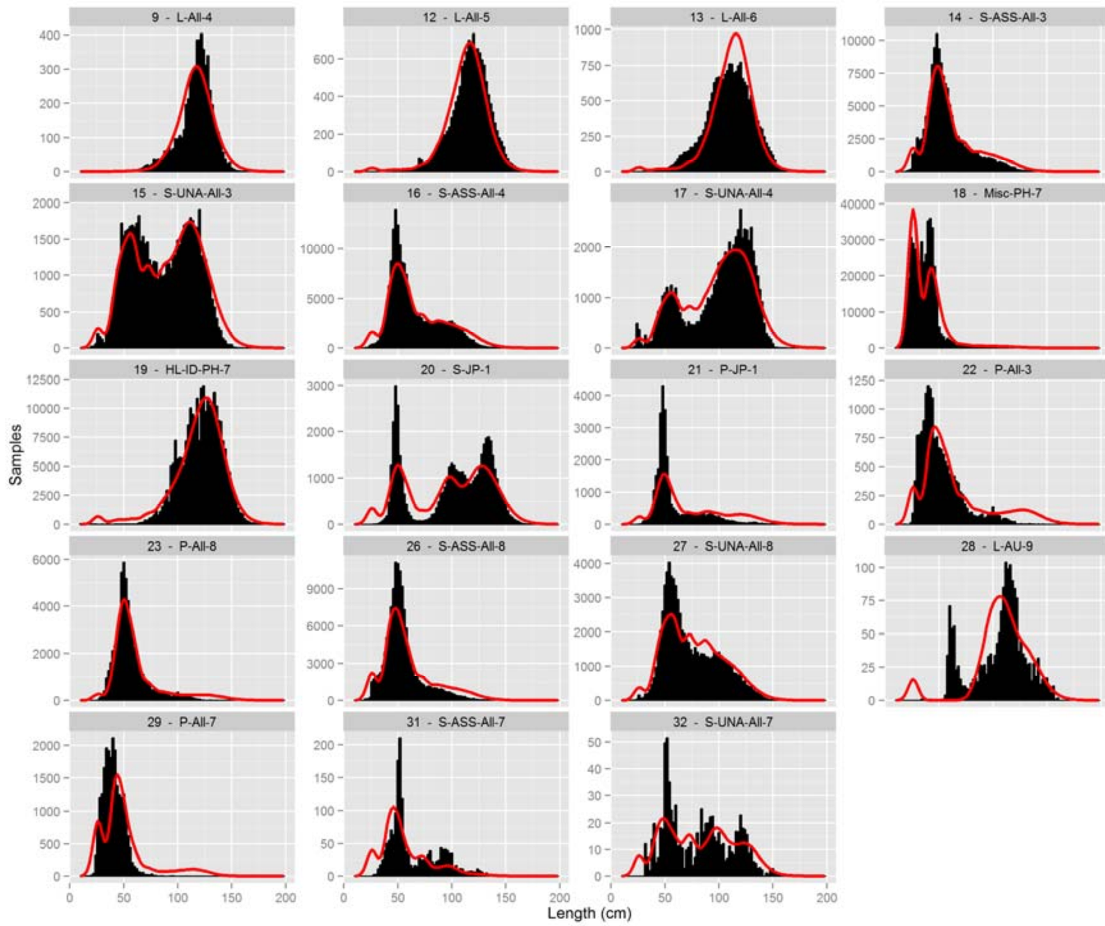


Figure 13. Composite (all time periods combined) observed (black histograms) and predicted (red line) catch at length for all fisheries with samples for the reference case.

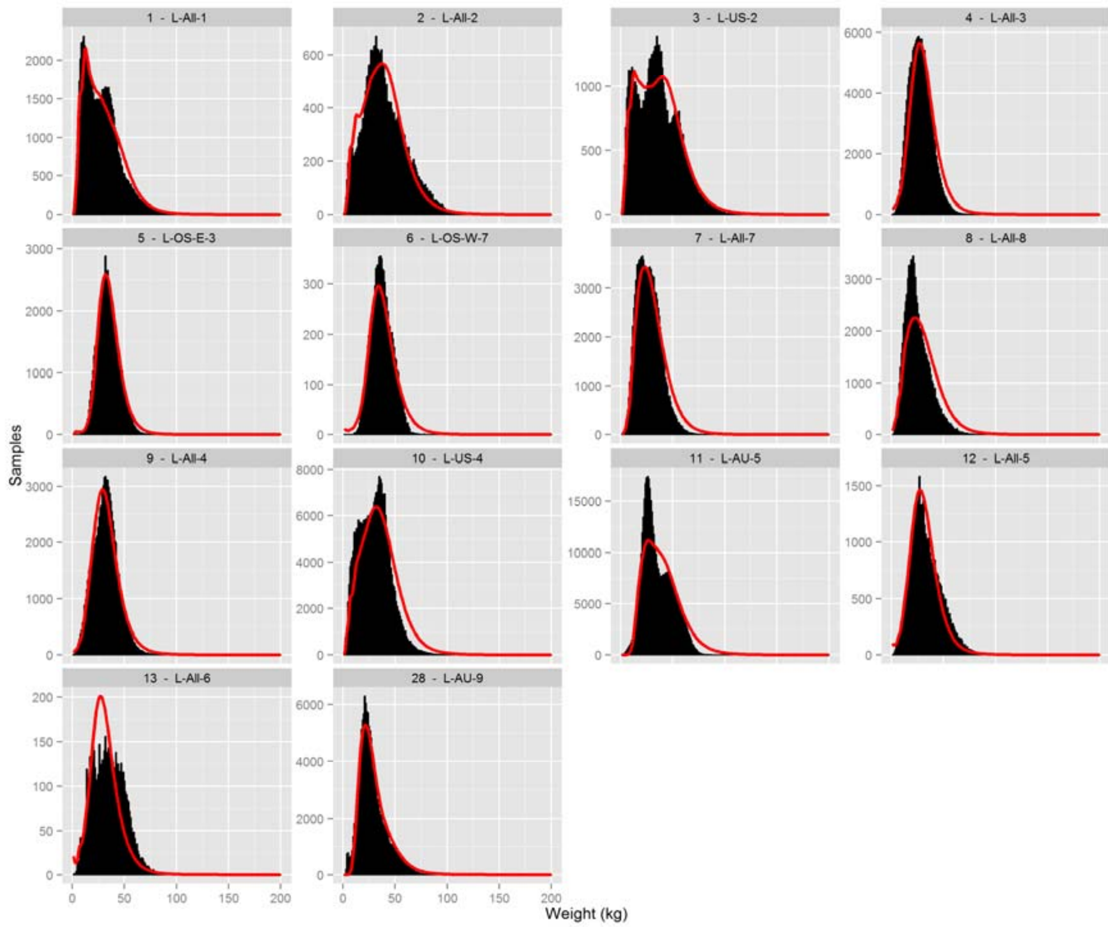


Figure 14. Composite (all time periods combined) observed (black histograms) and predicted (red line) catch at weight for all fisheries with samples for the reference case.

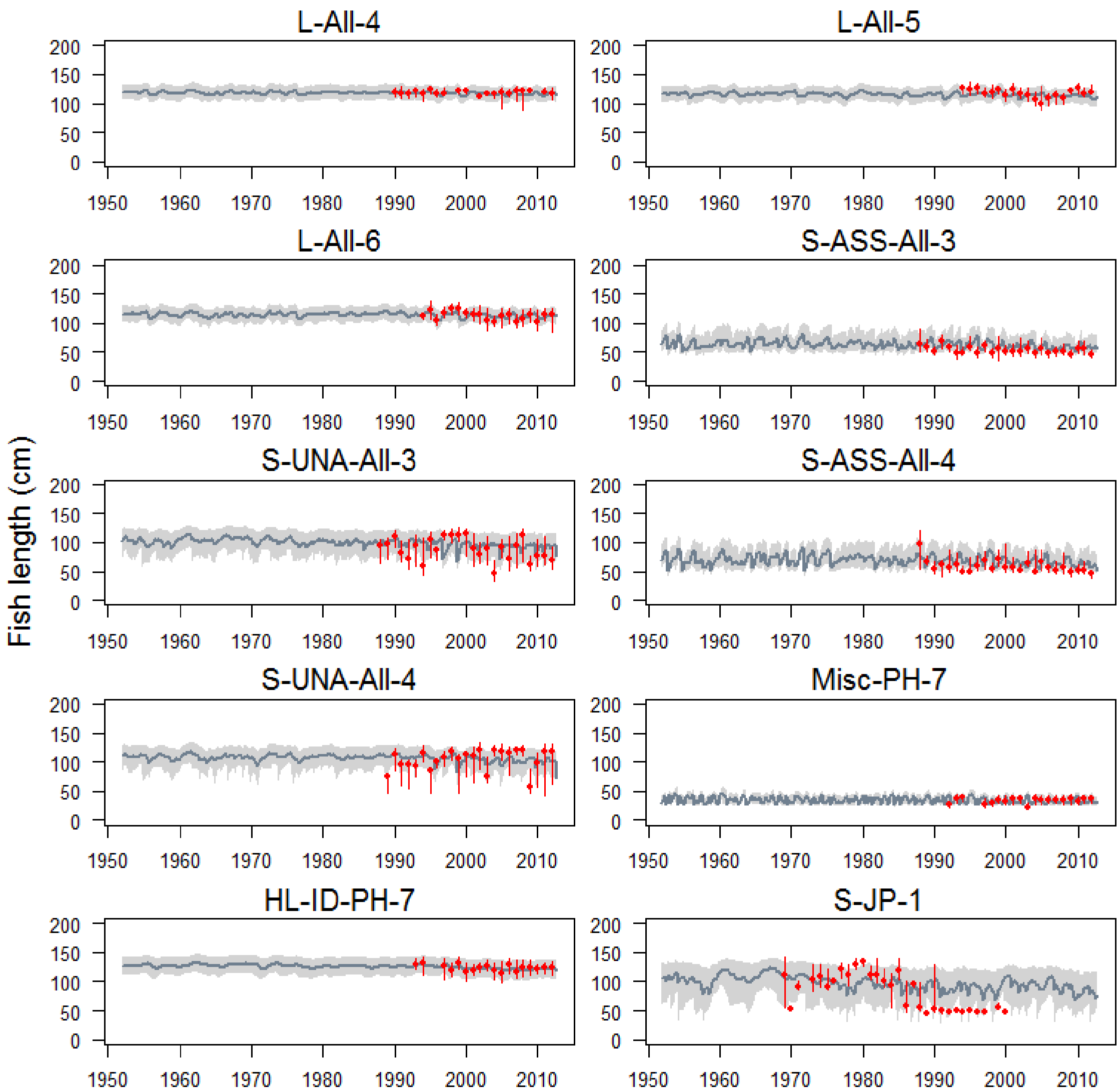


Figure 15. A comparison of the observed (red points) and predicted (grey line) median fish length (FL, cm) for all fisheries with samples for the reference case. The confidence intervals represent the values encompassed by the 25% and 75% quantiles. Sampling data are aggregated by year and only length samples with a minimum of 30 fish per year are plotted.

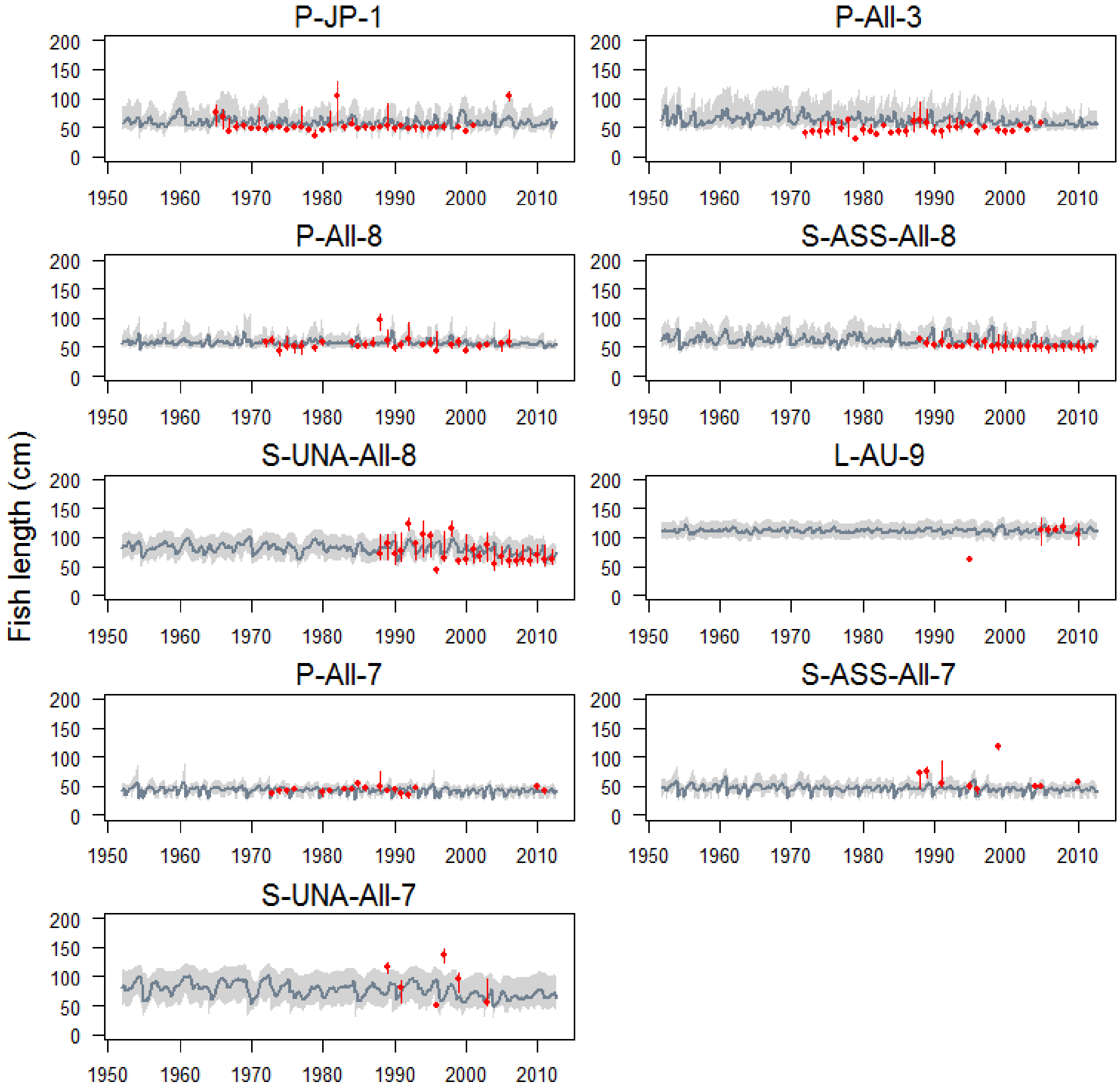


Figure 15 cont.

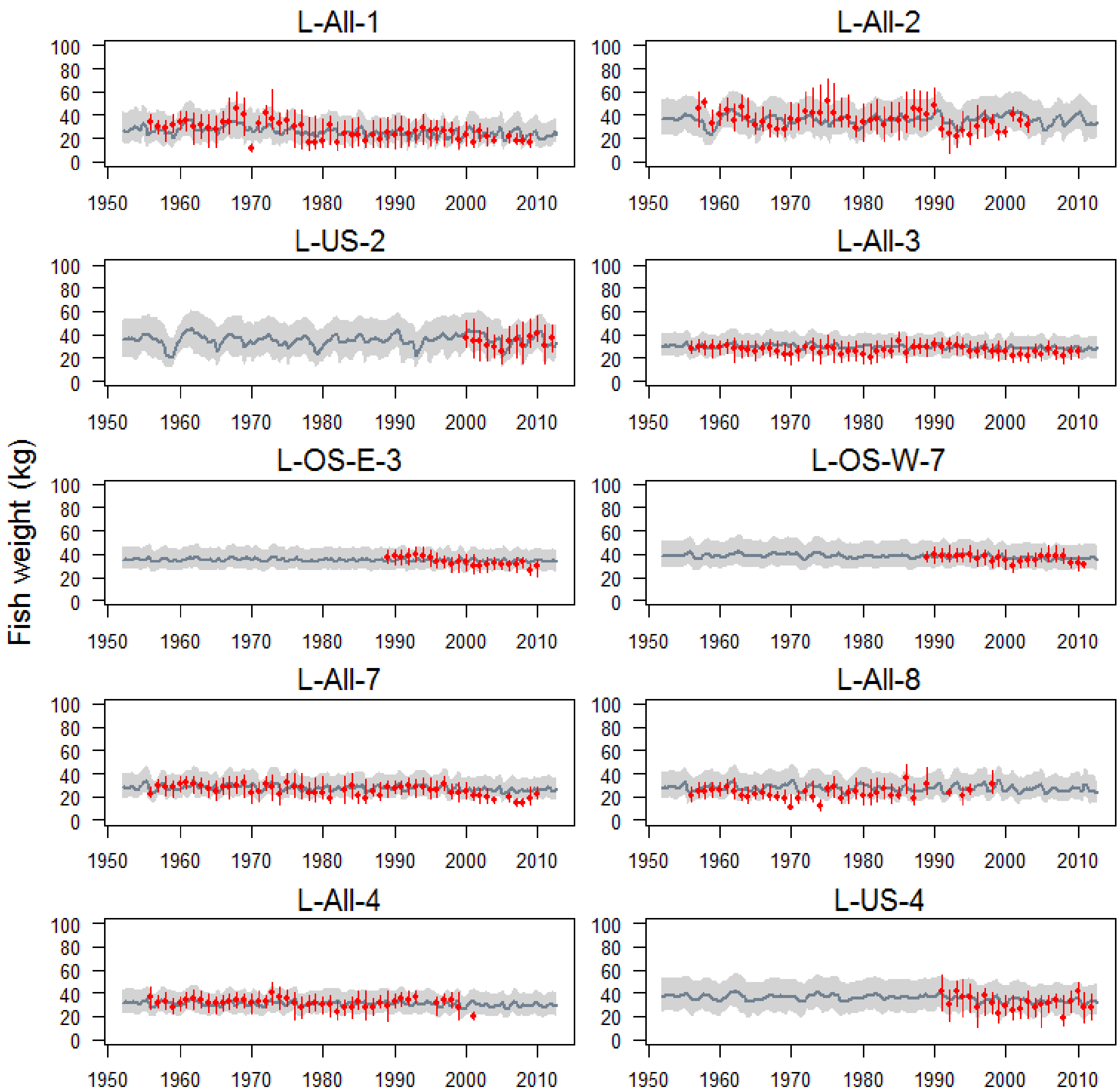


Figure 16. A comparison of the observed (red points) and predicted (grey line) median fish weight (kg) for all fisheries with samples for the reference case. The confidence intervals represent the values encompassed by the 25% and 75% quantiles. Sampling data are aggregated by year and only weight samples with a minimum of 30 fish per year are plotted.

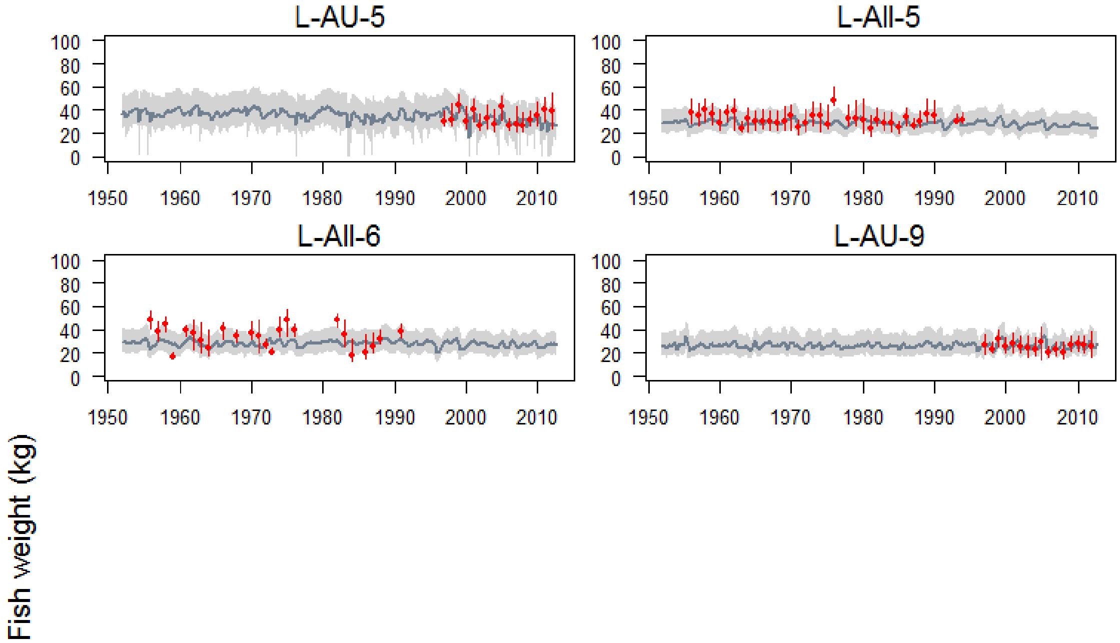


Figure 16 cont.

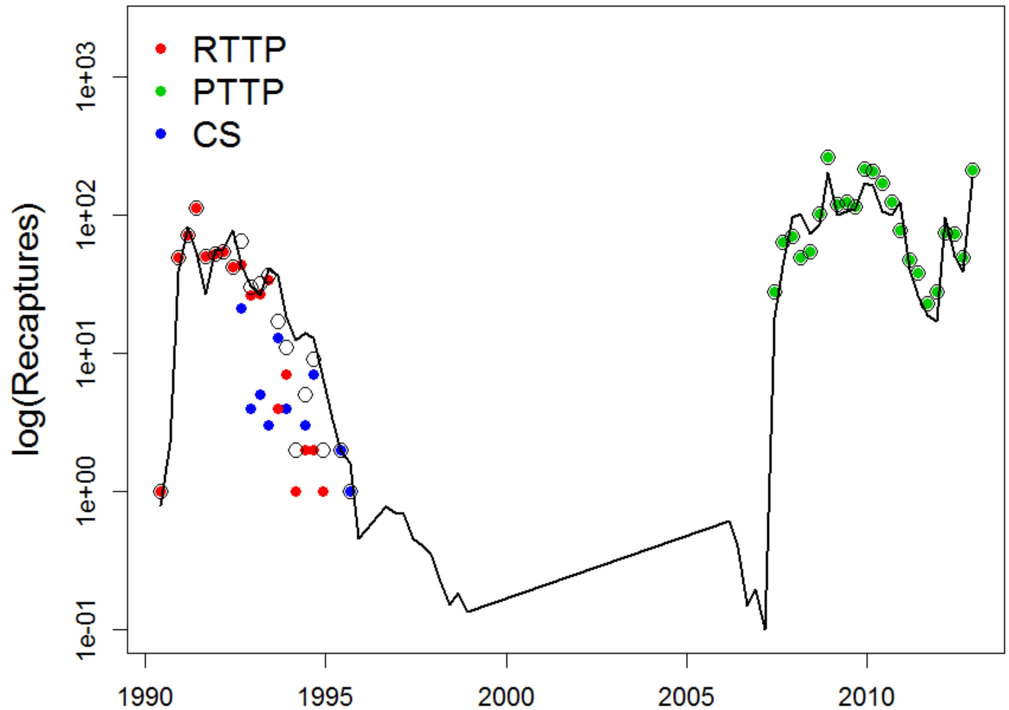


Figure 17. Observed recaptures for the reference case by time period specific to each release program shown by coloured dots: green = PTTP, blue = CS, red = RTTP. The model (black line) is fitted to the total observed recaptures in a time period (black circles), that are made up of the sum of the program-specific recaptures occurring in that time period, hence a dot and circle will coincide if recaptures are derived from only one program.

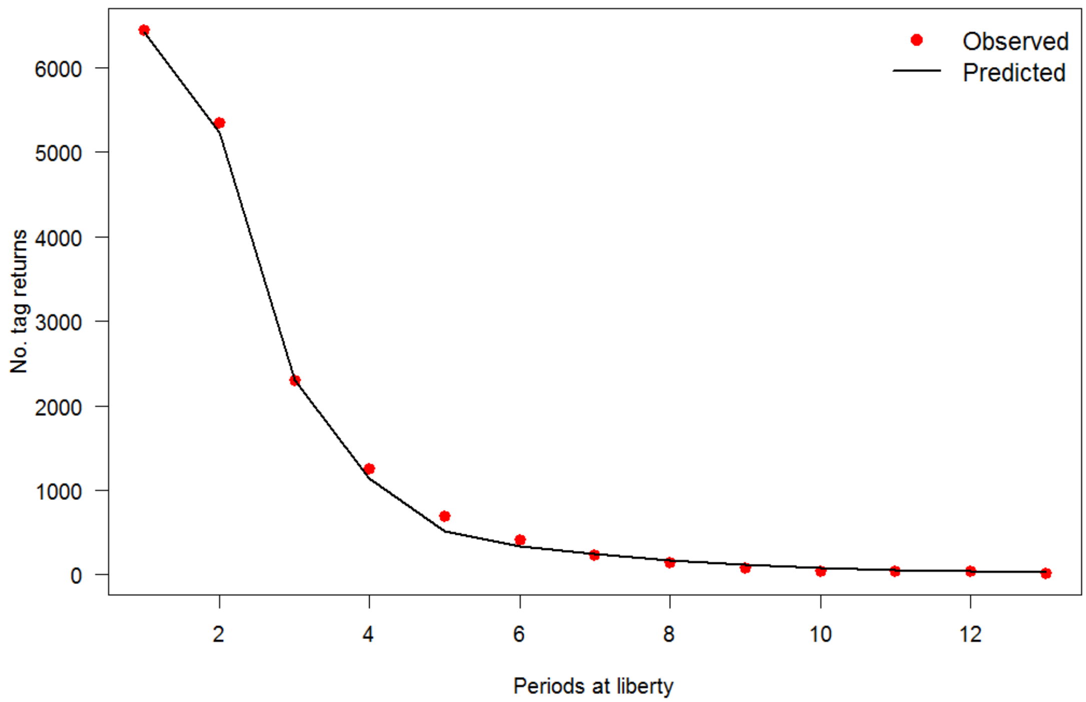


Figure 18. Observed and predicted tag attrition for the reference case across all tag release events.

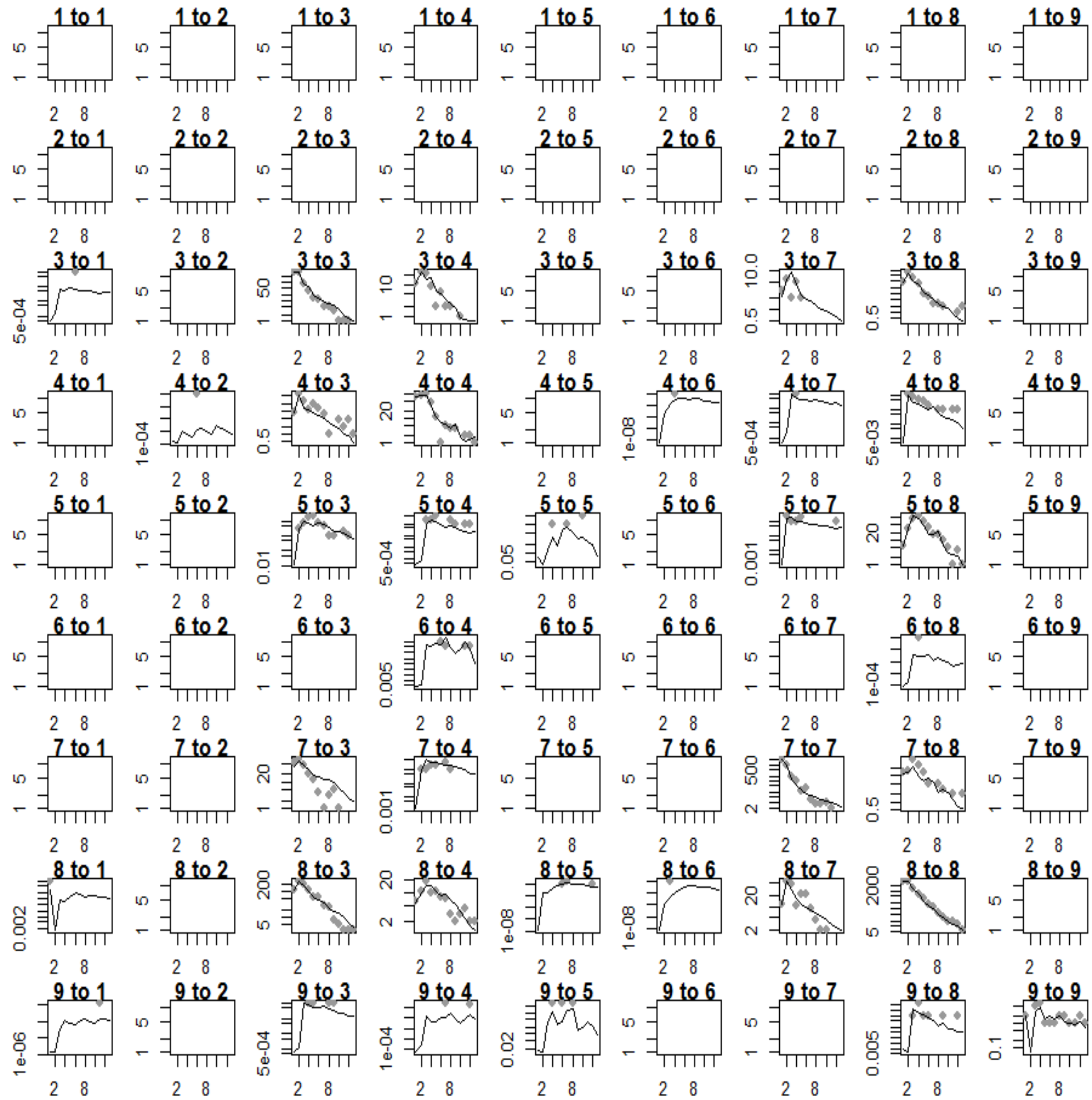


Figure 19. Predicted and observed recaptures of tagged fish by time period at liberty (quarter) from the region of release to the region of recapture.

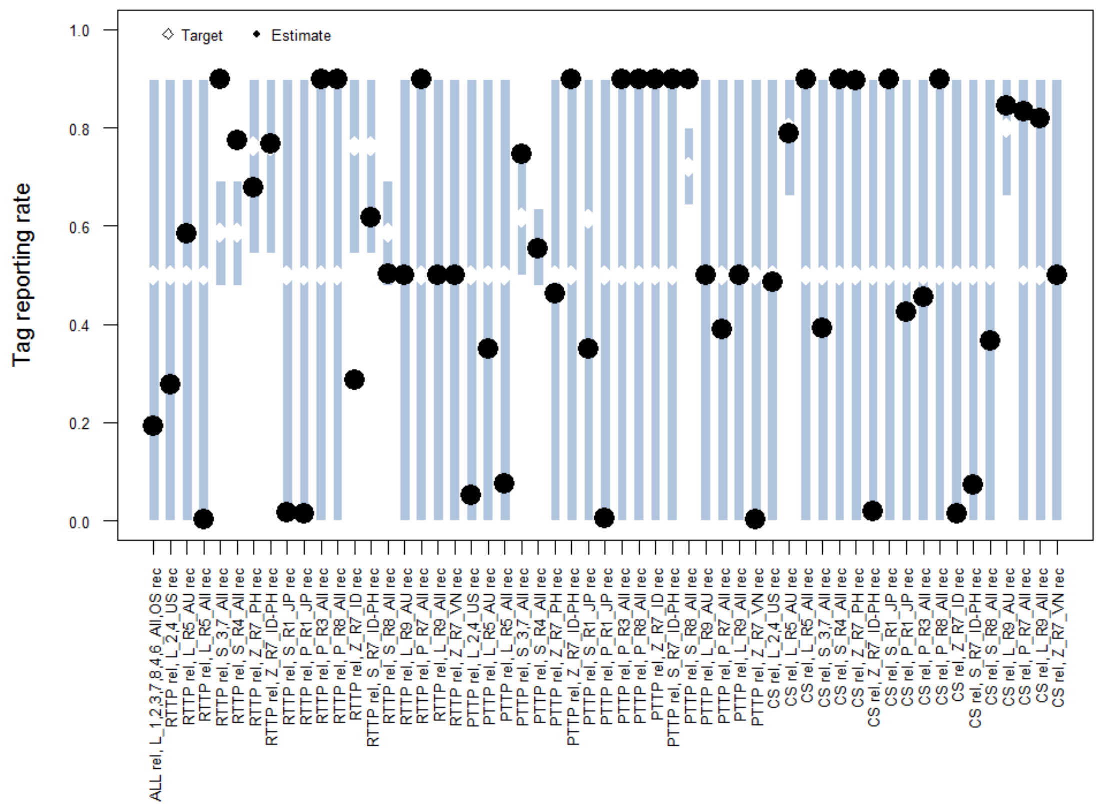


Figure 20. Estimated reporting rates for the reference case. Reporting rates can be estimated separately for each release program and recapture fishery group (histograms). See text for further details of tagging programmes. Certain estimates are grouped over release programs and over recapture fisheries, (e.g. L-All and HL fisheries). The prior mean ±1.96 SD is also shown for each reporting rate group.

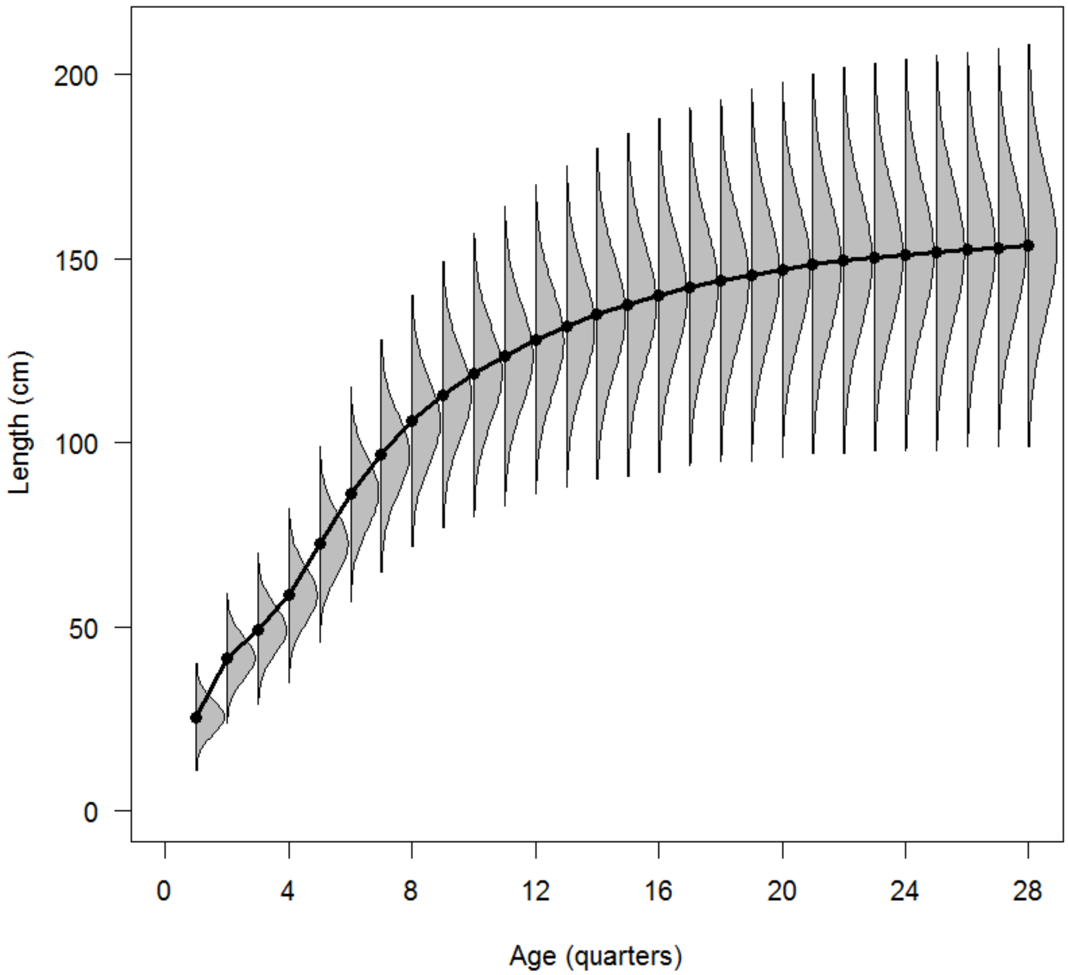


Figure 21. Estimated growth for the reference case. The black line represents the estimated mean length (FL, cm) at age and the grey area represents the estimated distribution of length at age.

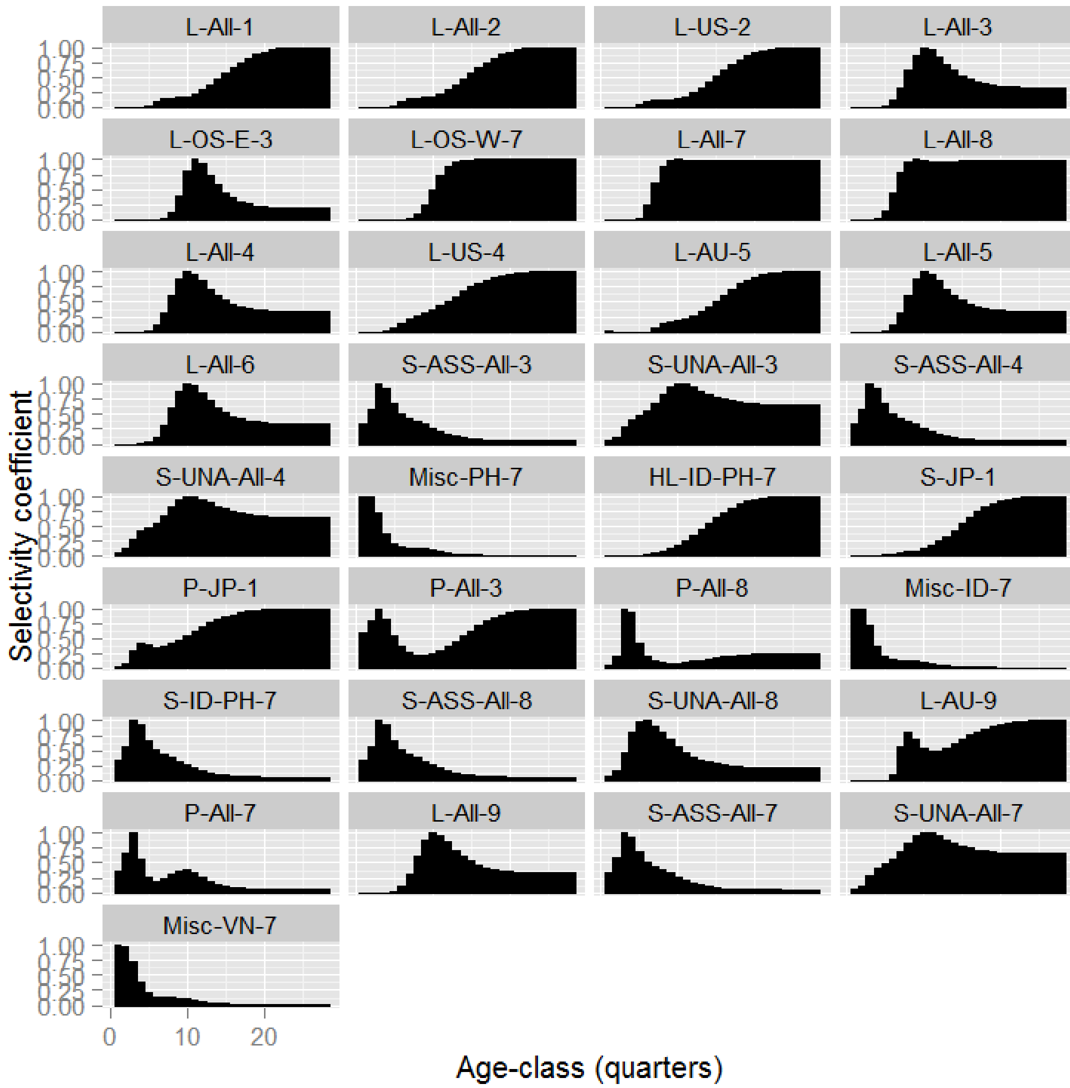


Figure 22. Selectivity coefficients by fishery.

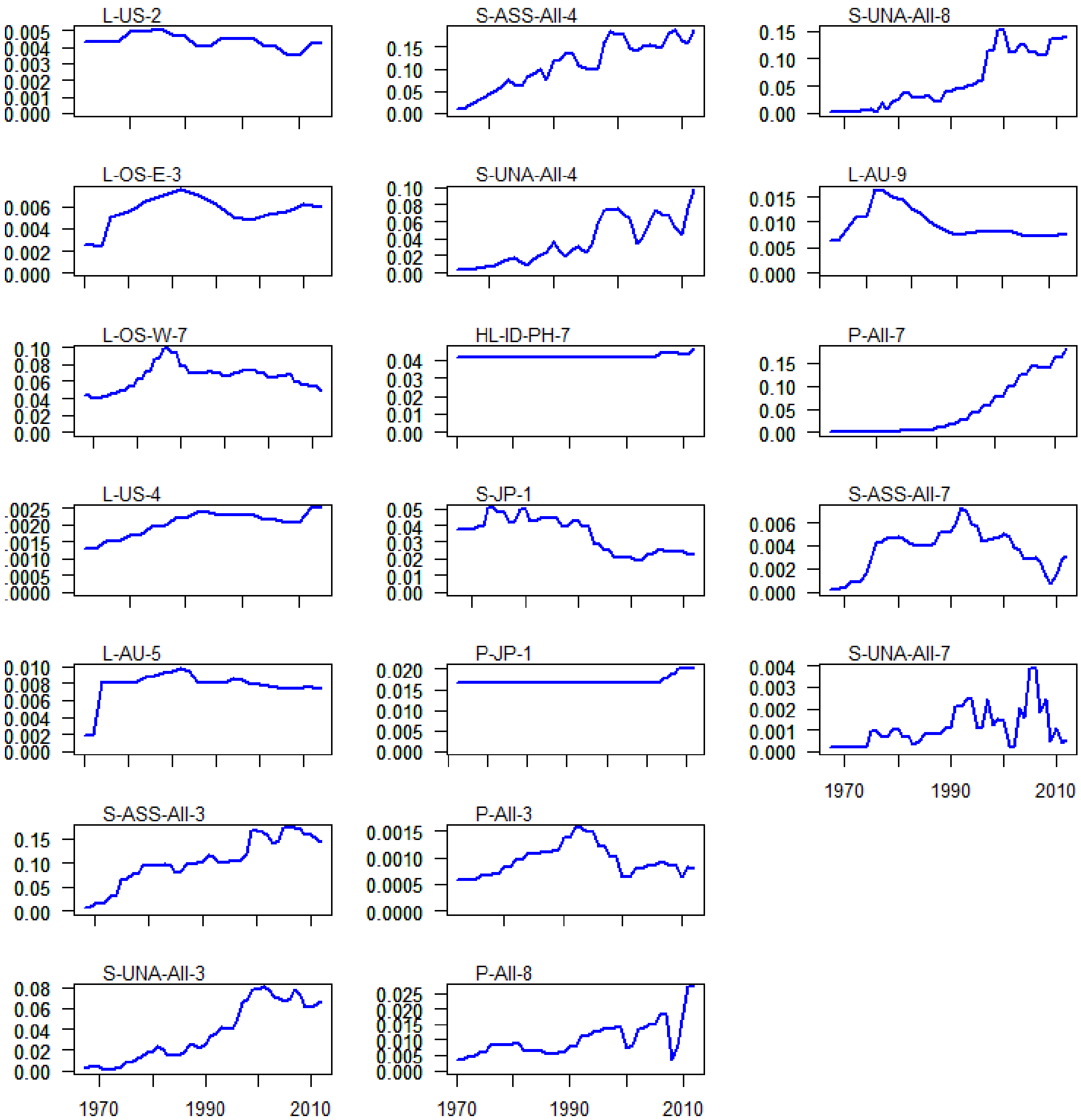


Figure 23. Catchability coefficients for fisheries having time-variant estimated catchability.

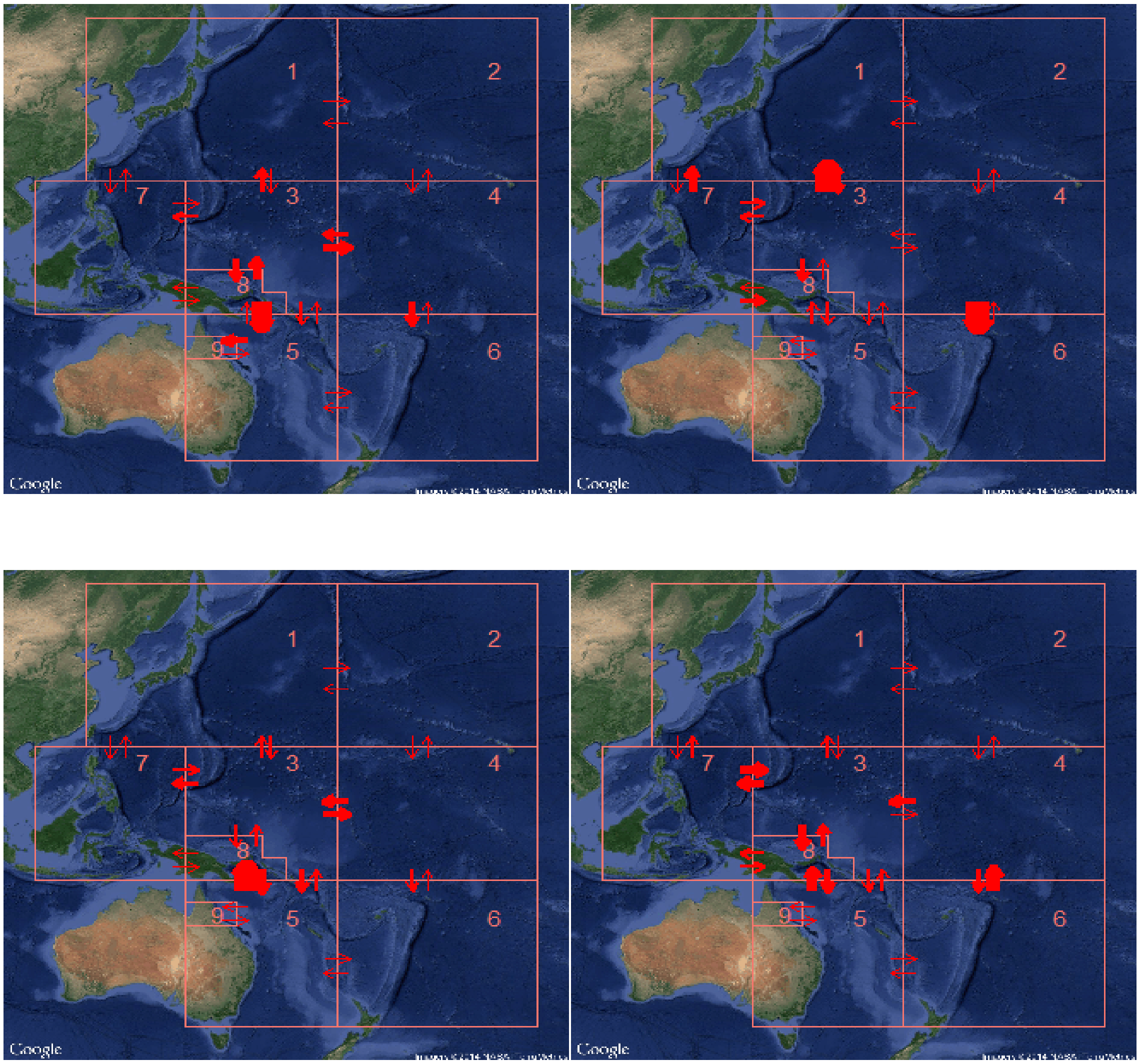


Figure 24. Estimated quarterly movement coefficients for the reference case. The movement coefficient is proportional to the width of the arrow.

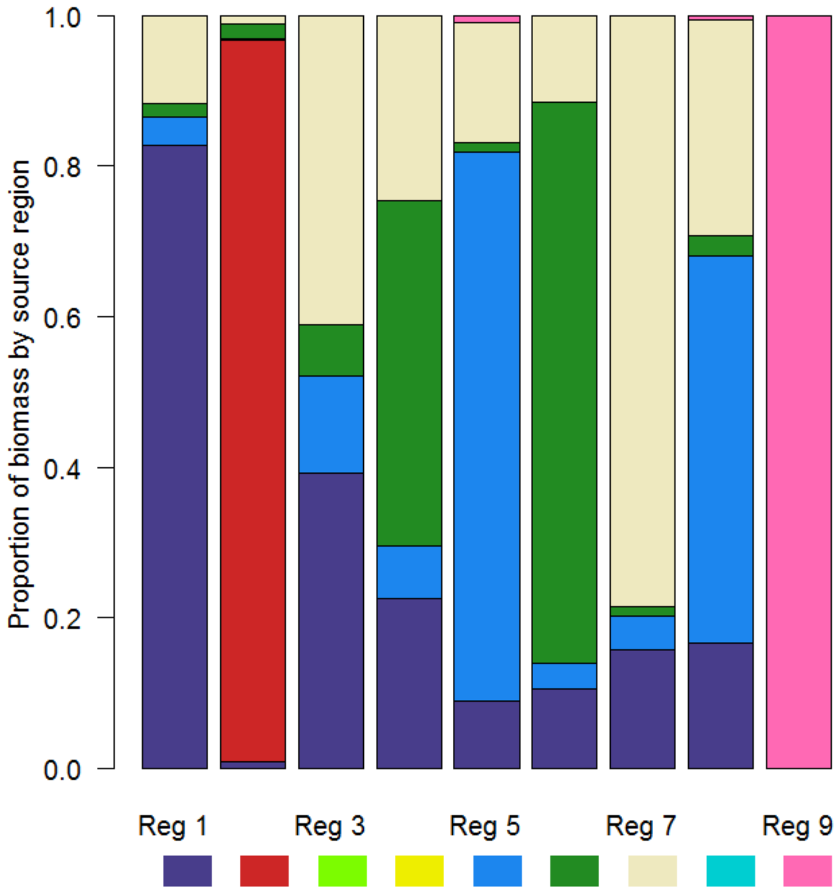


Figure 25. Proportional distribution of total biomass (by weight) in each region apportioned by the source region of the fish for the reference case. The colour of the home region is presented below the corresponding label on the x-axis. The biomass distributions are calculated based on the long-term average distribution of recruitment between regions, estimated movement parameters, and natural mortality. Fishing mortality is not taken into account.

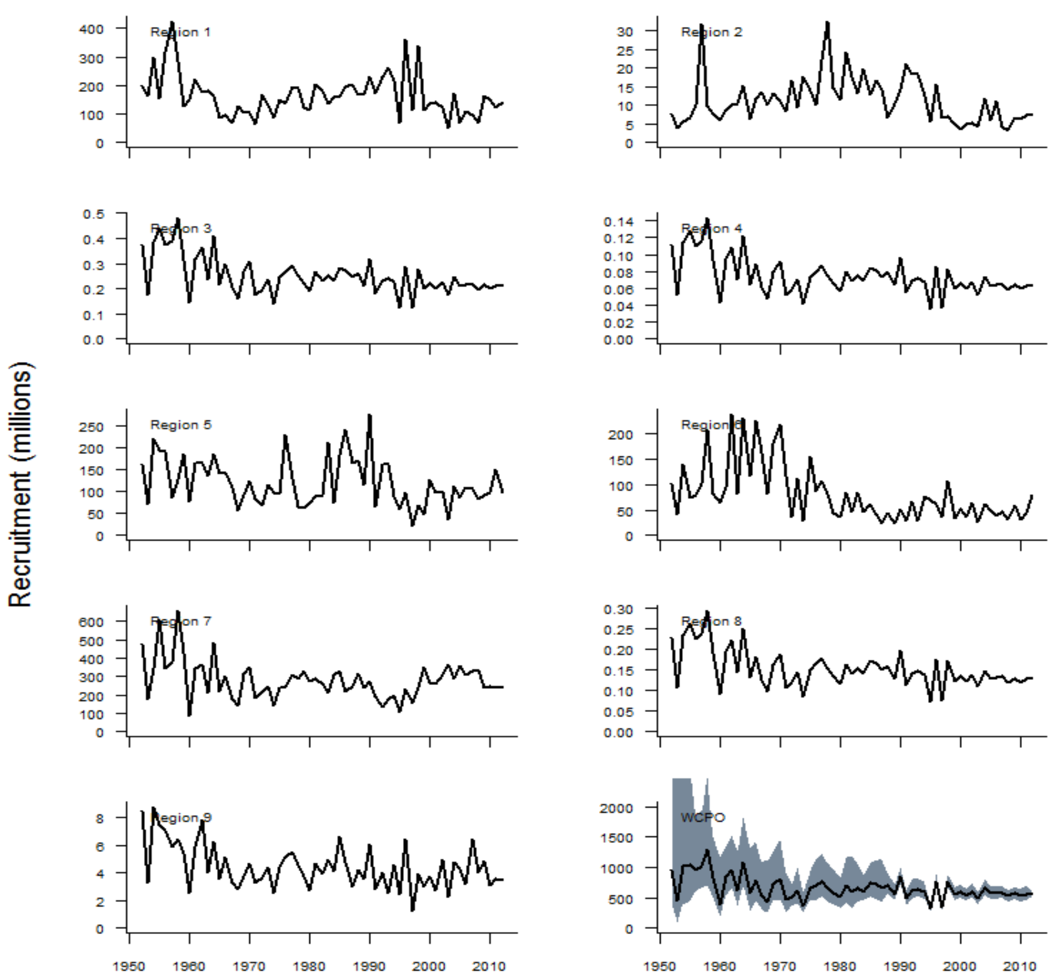


Figure 26. Estimated annual recruitment (millions) by region and for the WCPO for the reference case. The shaded areas indicate the approximate 95% confidence intervals.

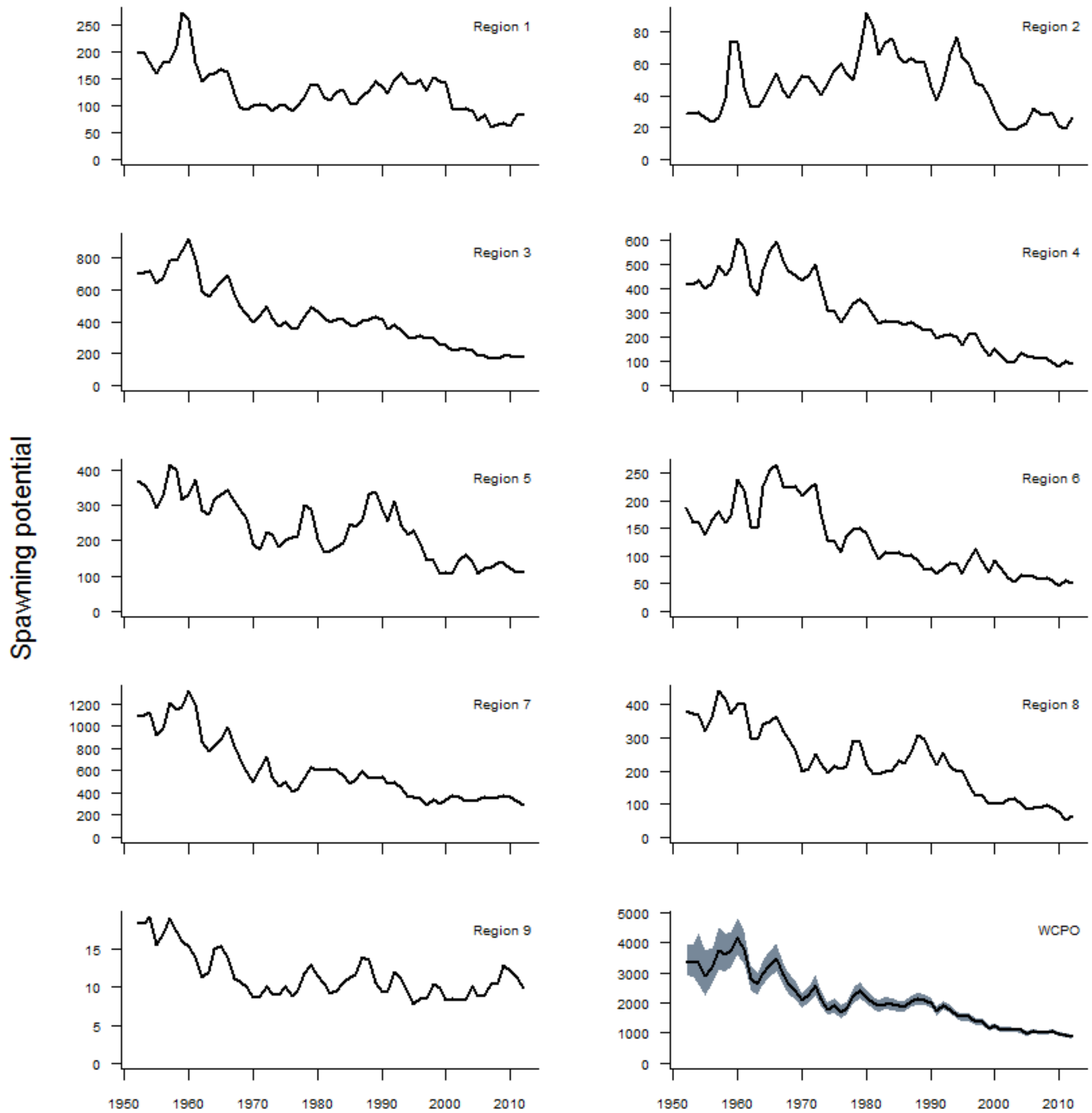


Figure 27. Estimated annual average spawning potential by region and for the WCPO for the reference case. The shaded areas indicate the approximate 95% confidence intervals.

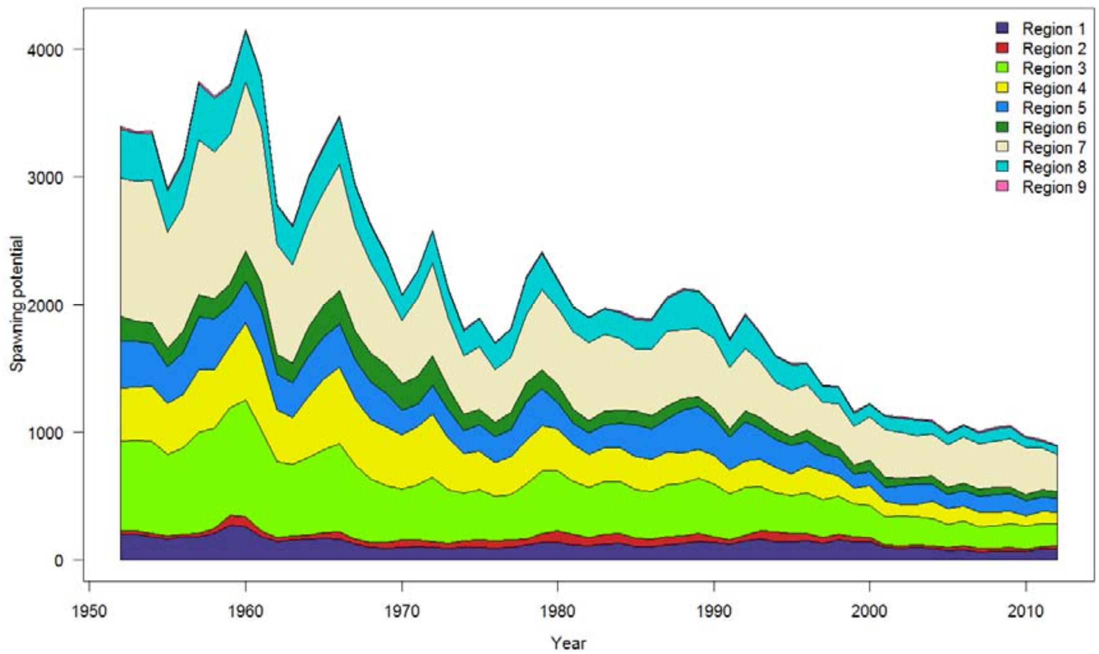


Figure 28. Estimated average annual spawning potential by model subregion for the reference case.

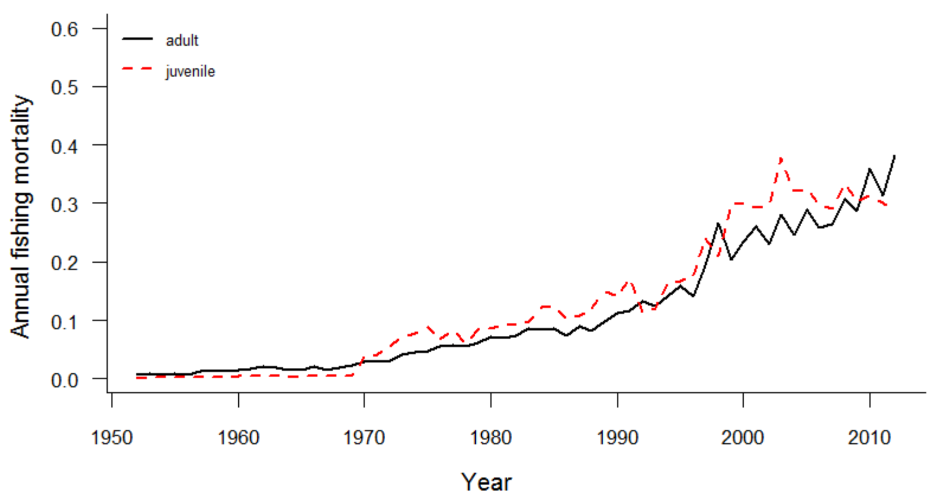


Figure 29. Estimated annual average juvenile and adult fishing mortality for the WCPO for the reference case.

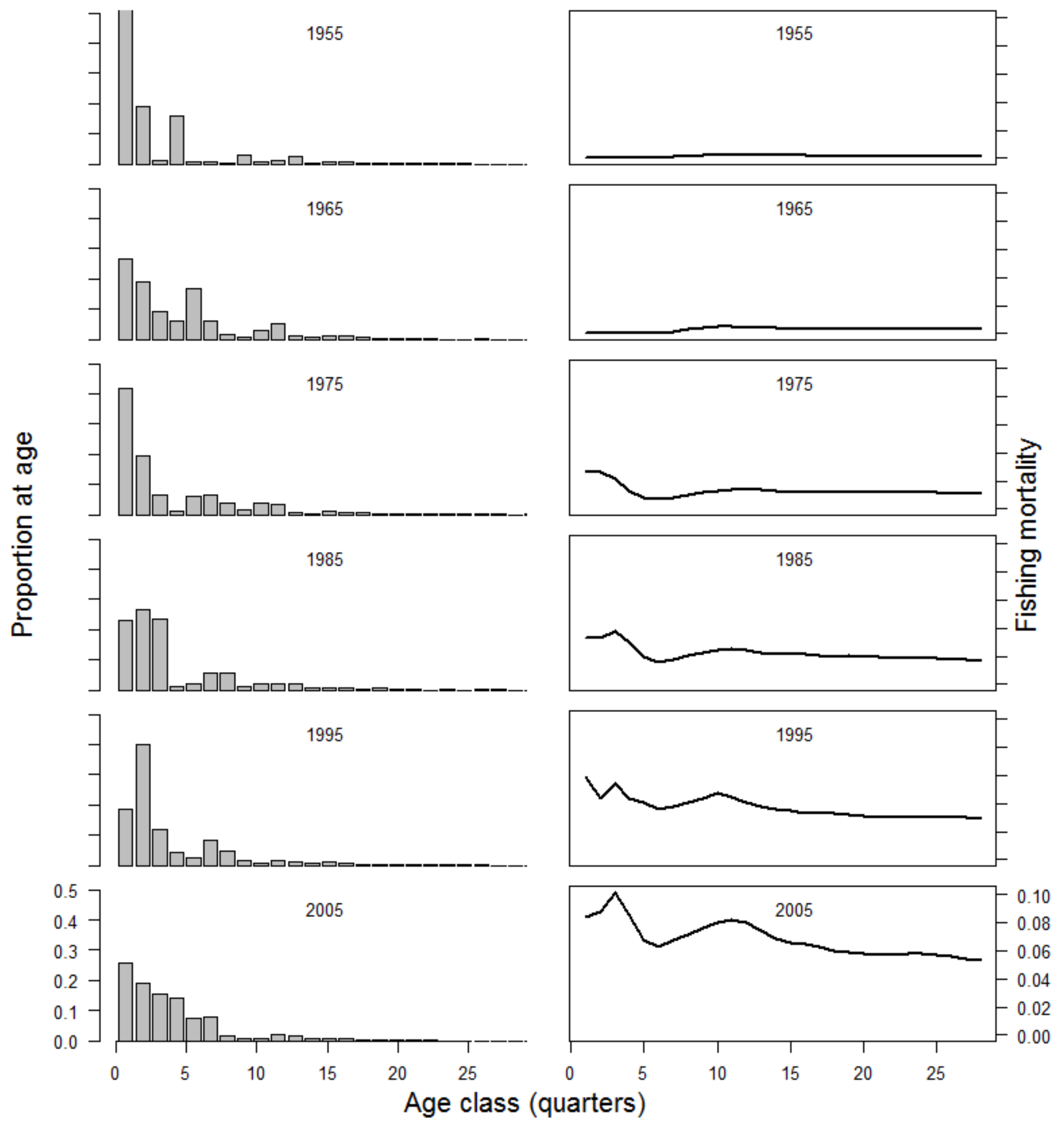


Figure 30. Estimated proportion at age (quarters) for the WCPO bigeye population (left) and fishing mortality at age (right) by year at decade intervals for the reference case.

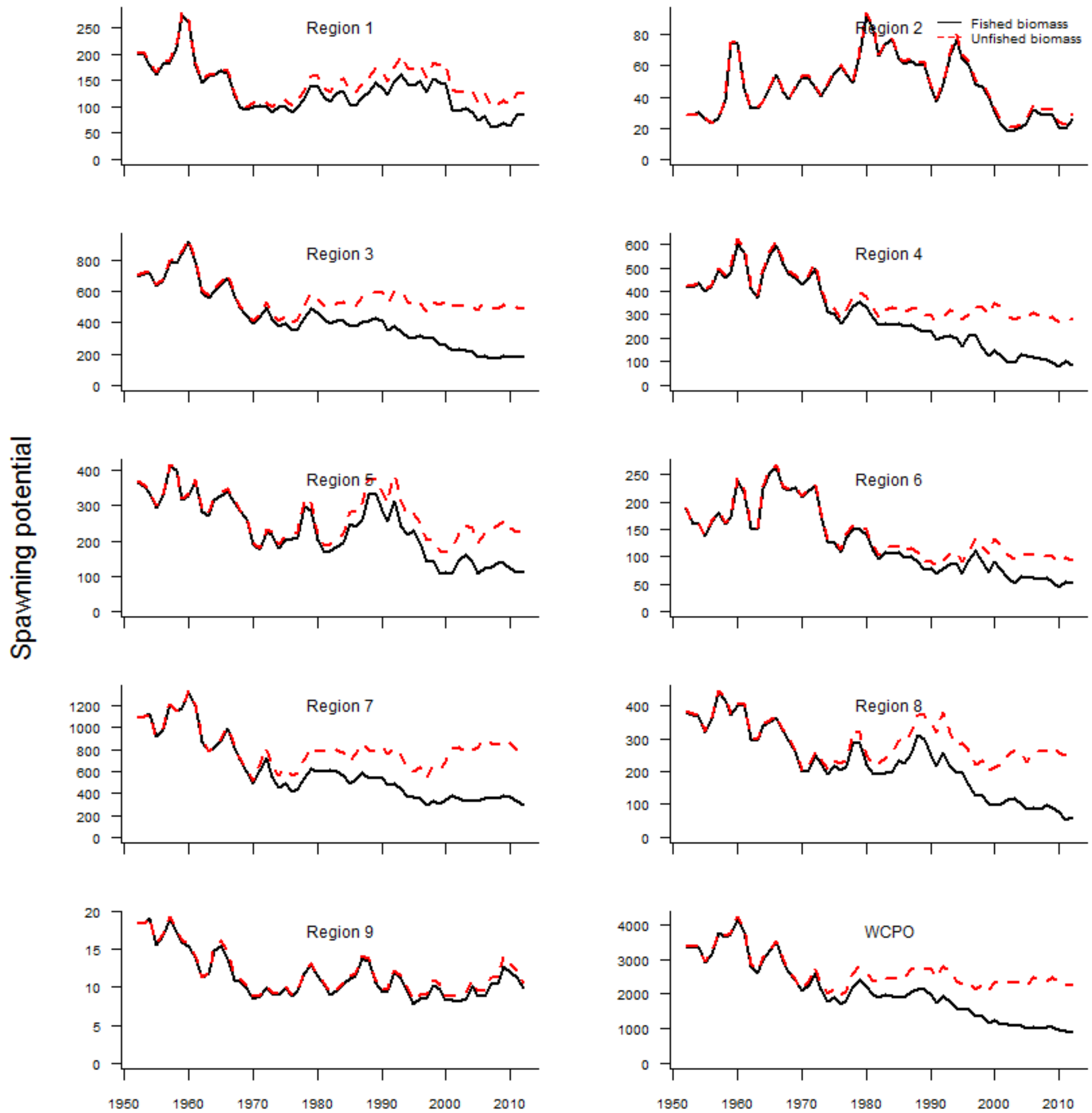


Figure 31. Comparison of the estimated spawning potential trajectories (lower solid black lines) with those trajectories that would have occurred in the absence of fishing (upper dashed red lines) for each region and for the WCPO for the reference case.

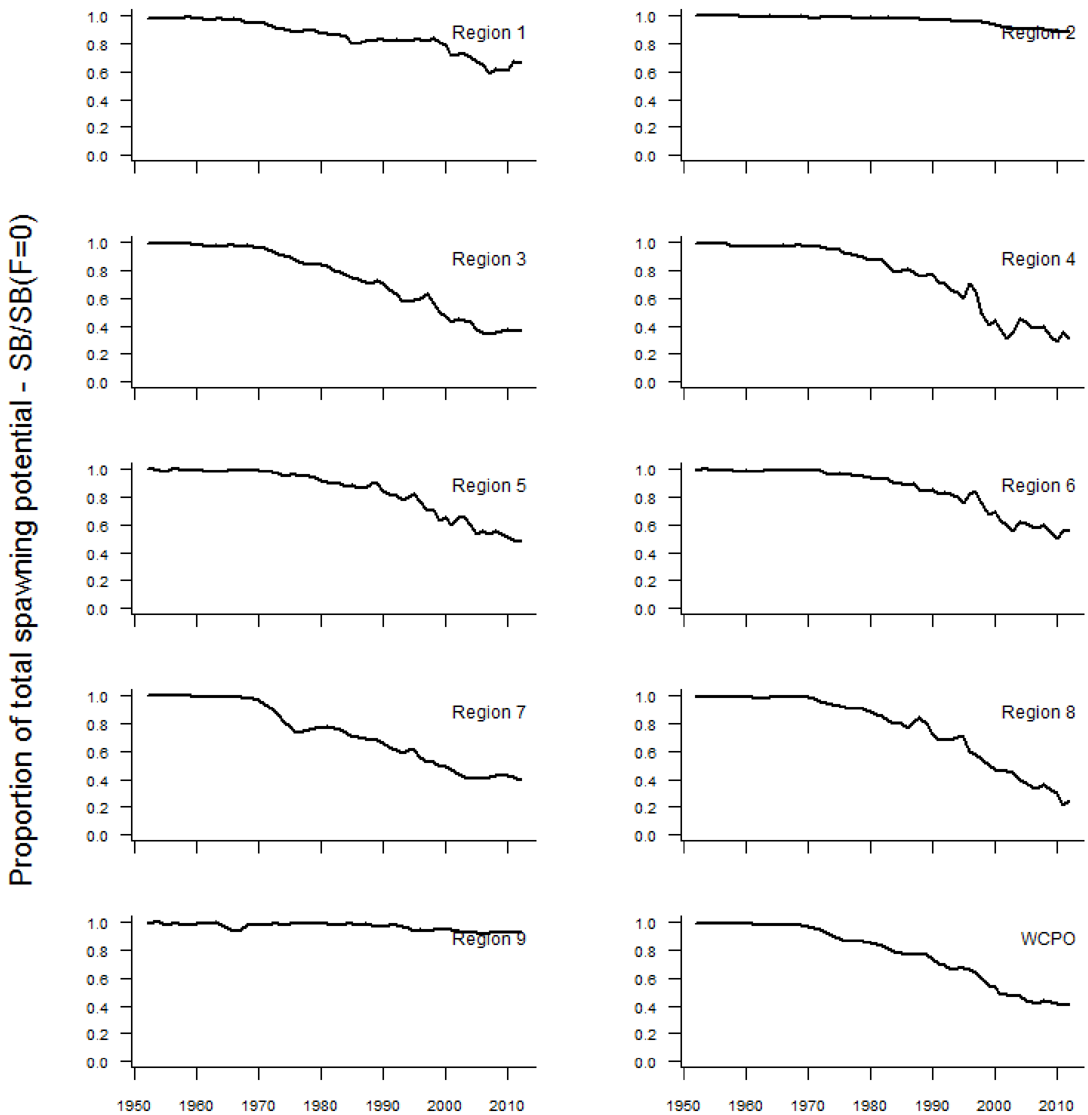


Figure 32. Ratios of exploited to unexploited spawning potential $SB/SB_{F=0}$ for each region and the WCPO for the reference case.

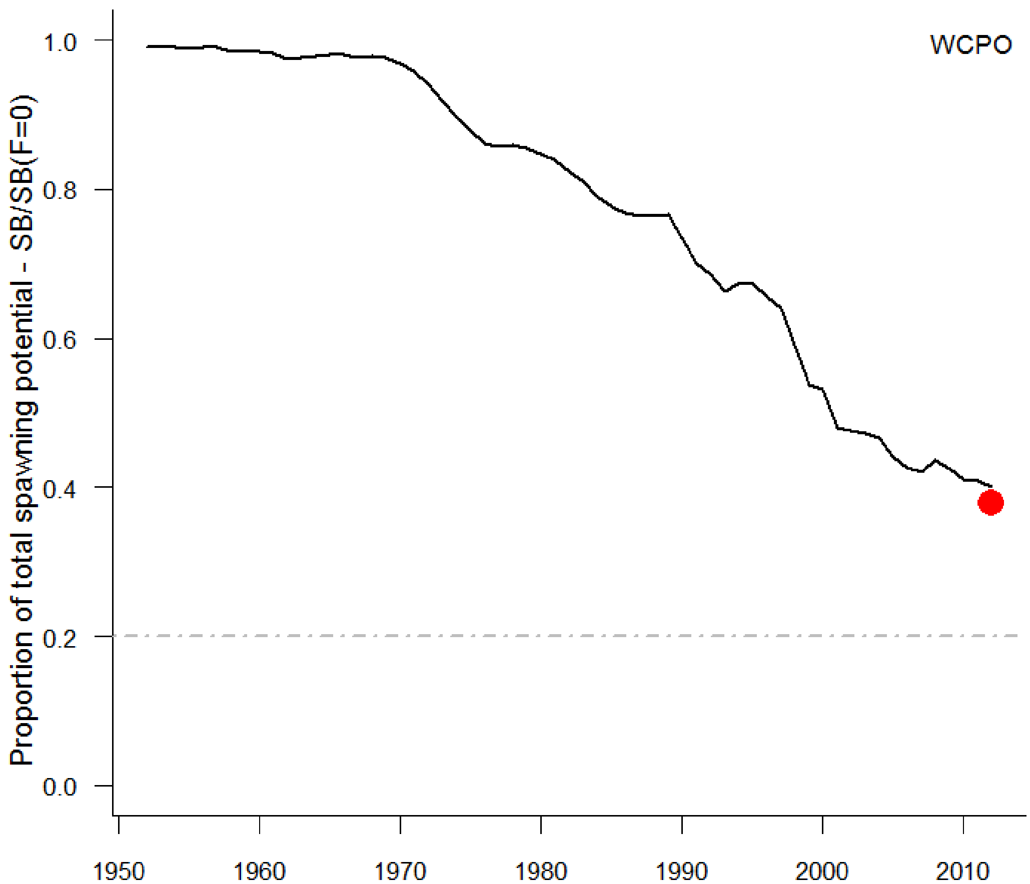


Figure 33. Ratio of exploited to unexploited spawning potential, $SB/SB_{F=0}$, for the WCPO for the reference case. The current WCPFC limit reference point of 20%$SB_{F=0}$ is provided for reference as the grey dashed line and the red circle represents the level of spawning potential depletion based on the agreed method of calculating $SB_{F=0}$ over the last ten years of the model (excluding the last year).

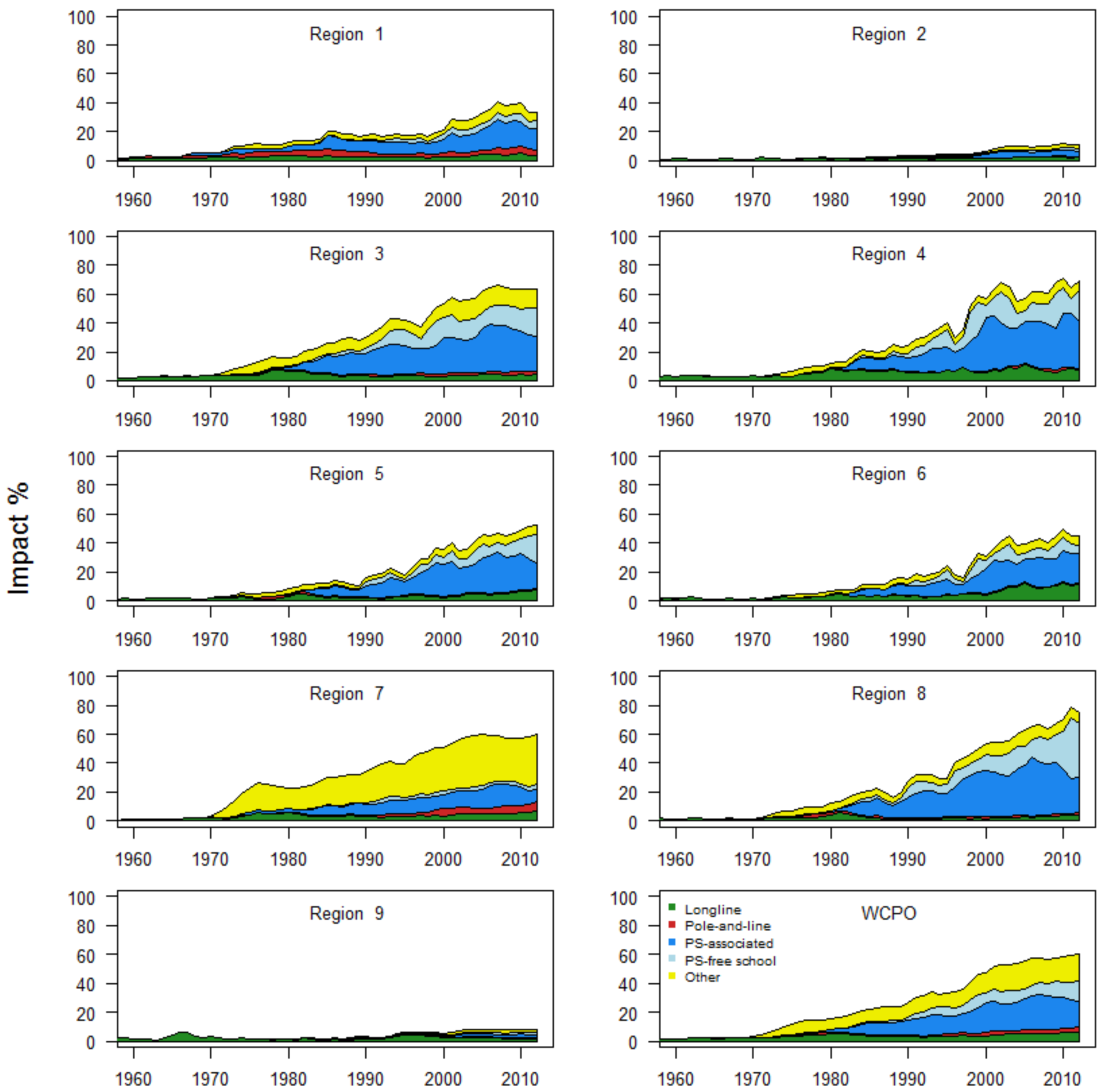


Figure 34. Estimates of reduction in spawning potential due to fishing (fishery impact = $\mathbf{1} - \boldsymbol{SB_t}/\boldsymbol{SB_{t_{F=0}}}$) by subregion and for the WCPO attributed to various fishery groups for the reference case.

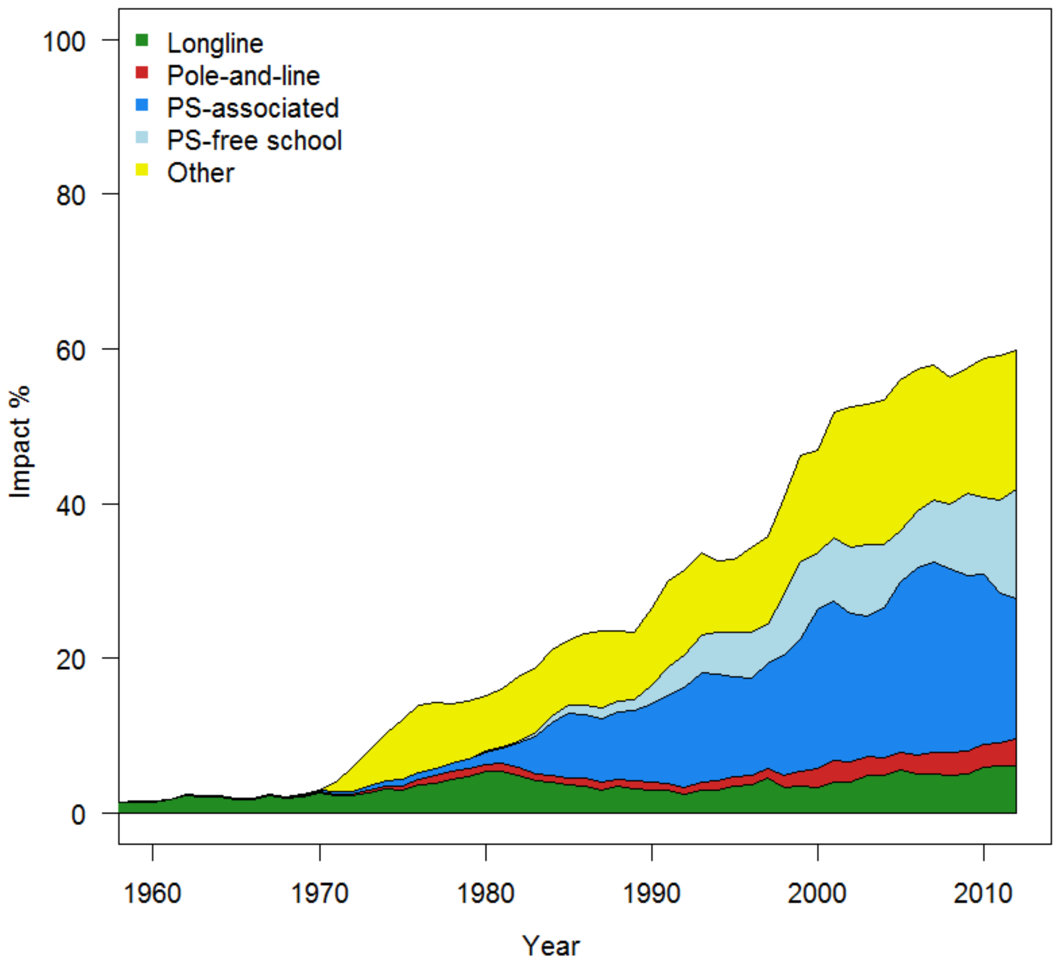
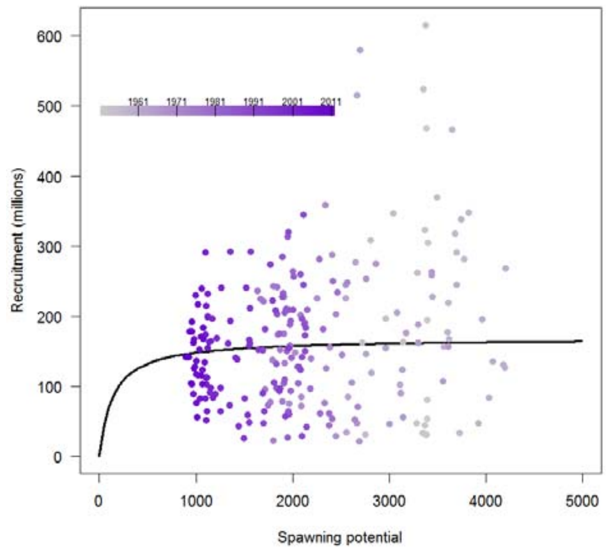


Figure 35. Estimates of reduction in spawning potential due to fishing (fishery impact = $\mathbf{1 - SB_t / SB_{t_{F=0}}}$) for the WCPO attributed to various fishery groups for the reference case.



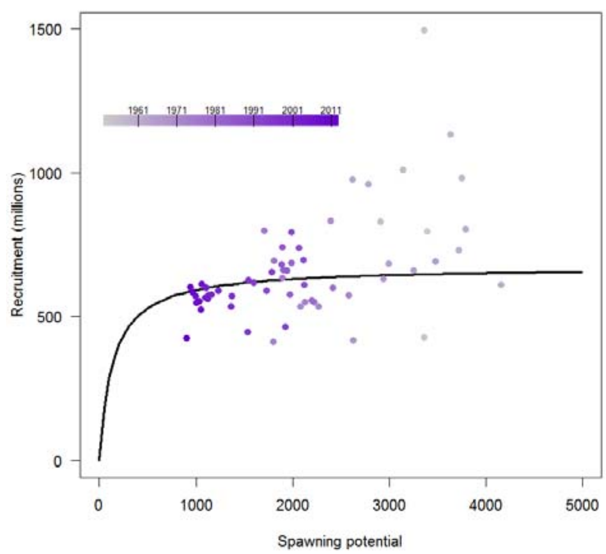


Figure 36. Estimated relationship between equilibrium recruitment and equilibrium spawning potential based on quarterly (top) and annual (bottom) values for the reference case.

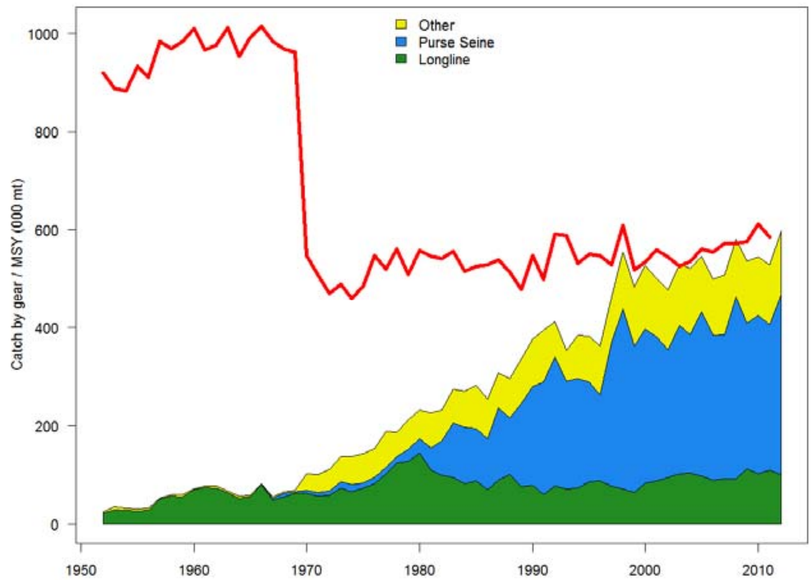


Figure 37. History of the annual estimates of *MSY* (red line) compared with annual catch split into three sectors for the reference case**.**

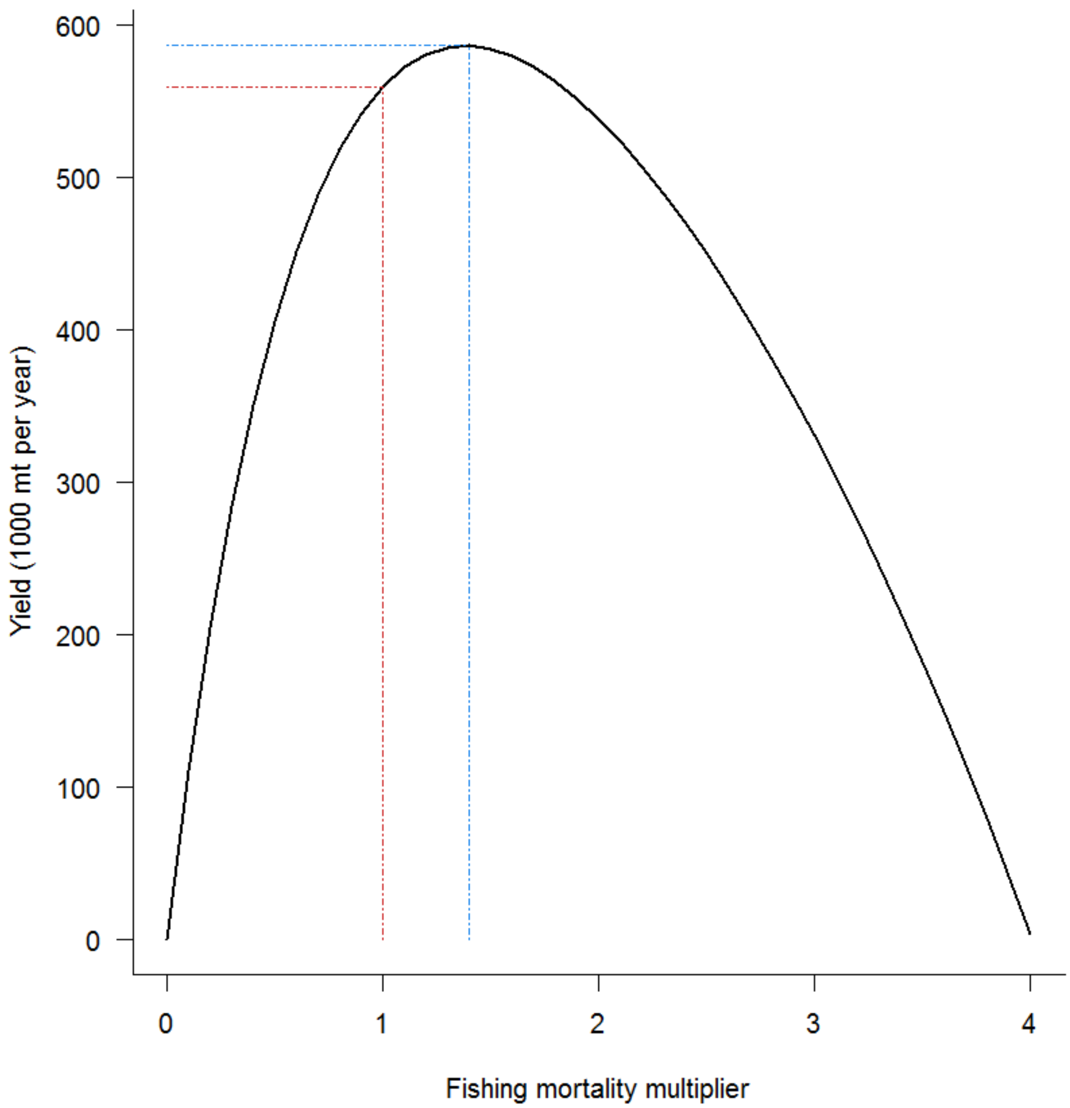


Figure 38. Estimated yield as a function of fishing mortality multiplier for the reference case. The red dashed line indicates the equilibrium yield at current fishing mortality and the blue dashed line indicates the MSY and the change in current fishing mortality required to achieve it.

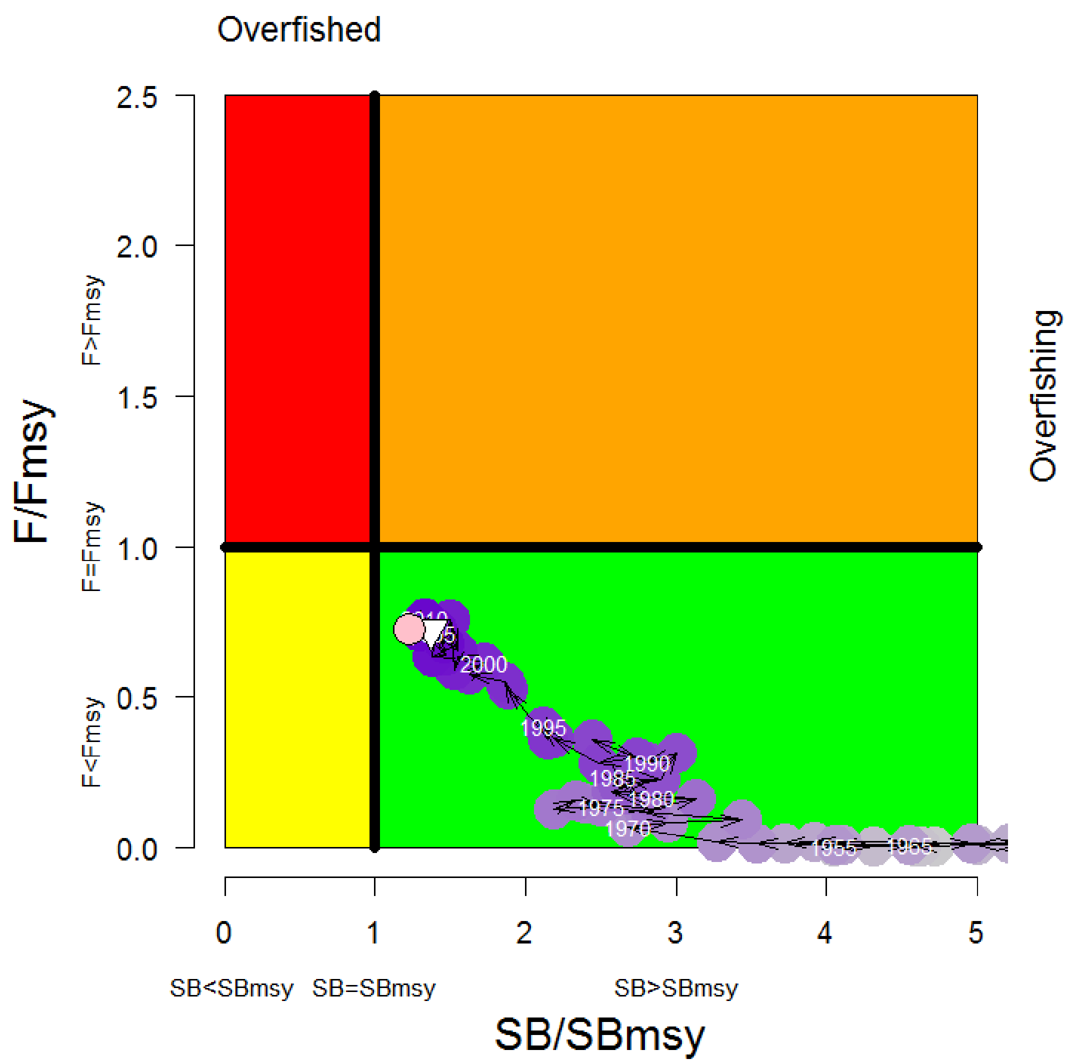


Figure 39. Temporal trend in annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points, for the period 1952–2011 from the reference case. The colour of the points is graduated from mauve to dark purple through time and the points are labelled at 5-year intervals. The white triangle represents the average for the current period and the pink circle the latest period as defined in Table 6.

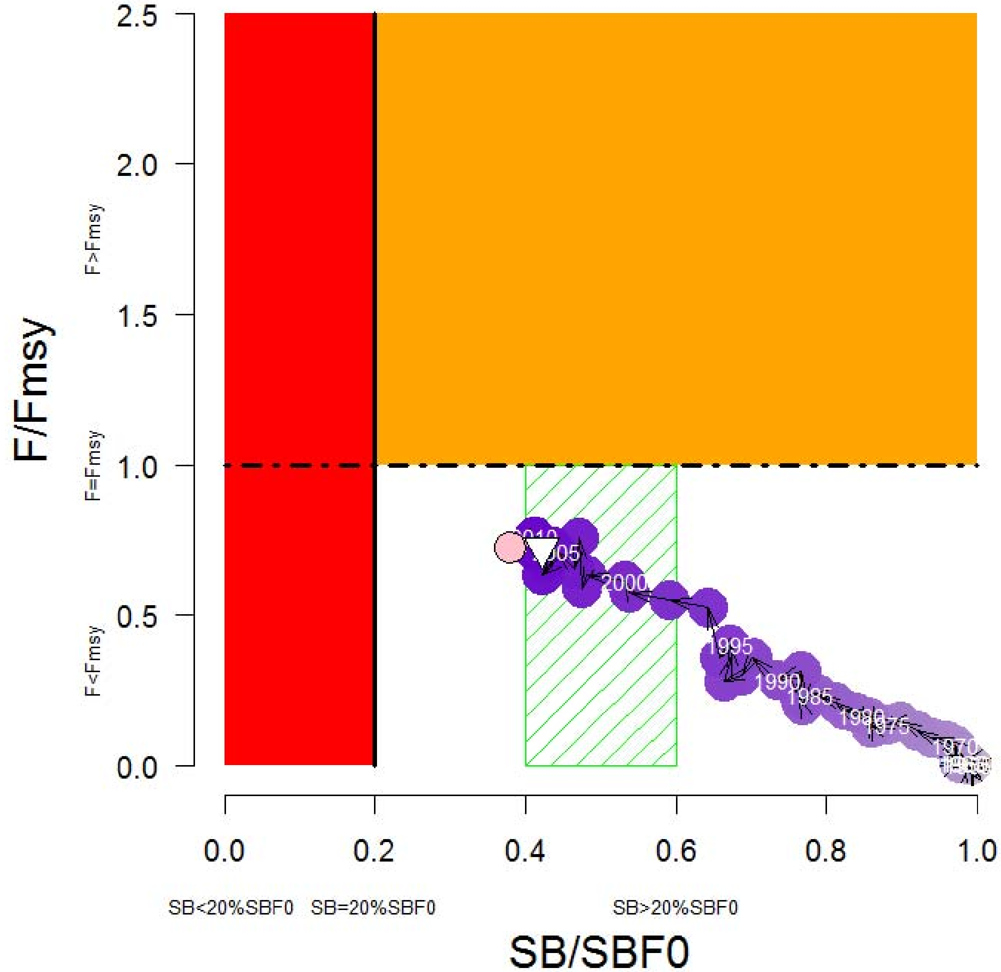
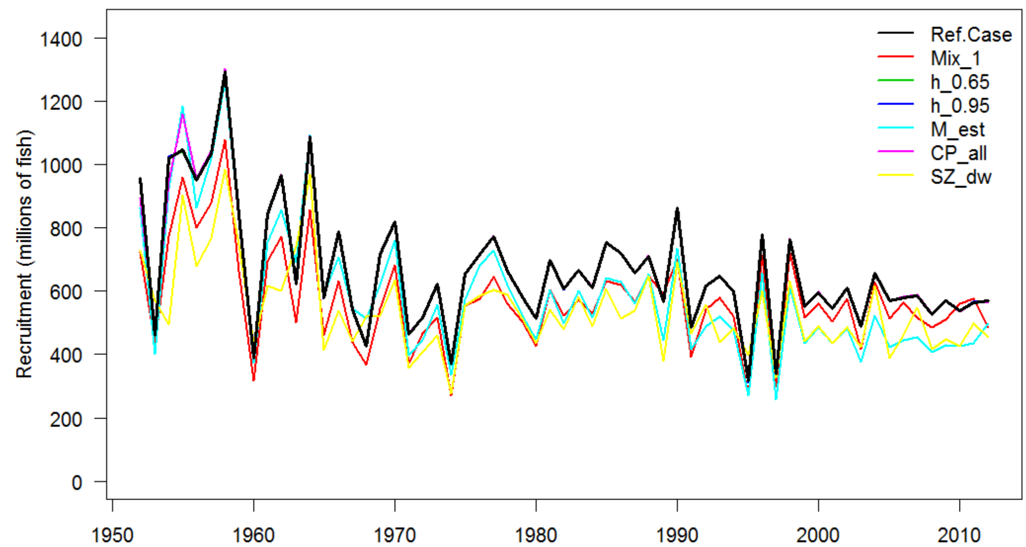


Figure 40. For discussion – a potential step towards displaying stock status with target and limit reference points. The red zone represents spawning potential levels lower than the agreed limit reference point which is marked with the solid black line. The orange region is for fishing mortality greater than F_{MSY} (F=F_{MSY} is marked with the black dashed line). The lightly shaded green rectangle covering 0.4-0.6$SB_{F=0}$ is the 'space' that WCPFC has asked for consideration of a TRP for skipjack.



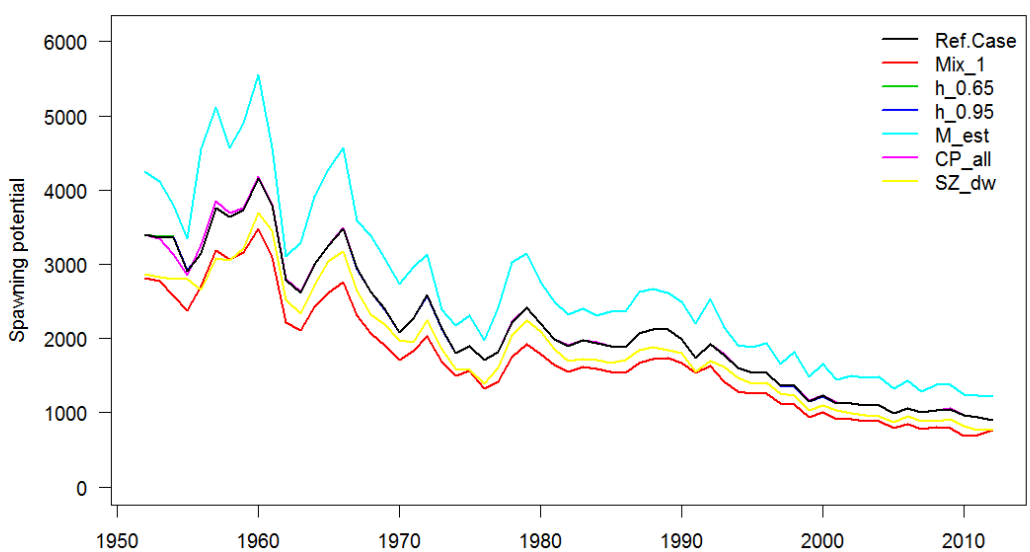


Figure 41. Estimated average recruitment (top) and spawning potential (bottom) for the WCPO obtained from the one-off sensitivity model runs to the reference case (see **Table 5** for details of each scenario).

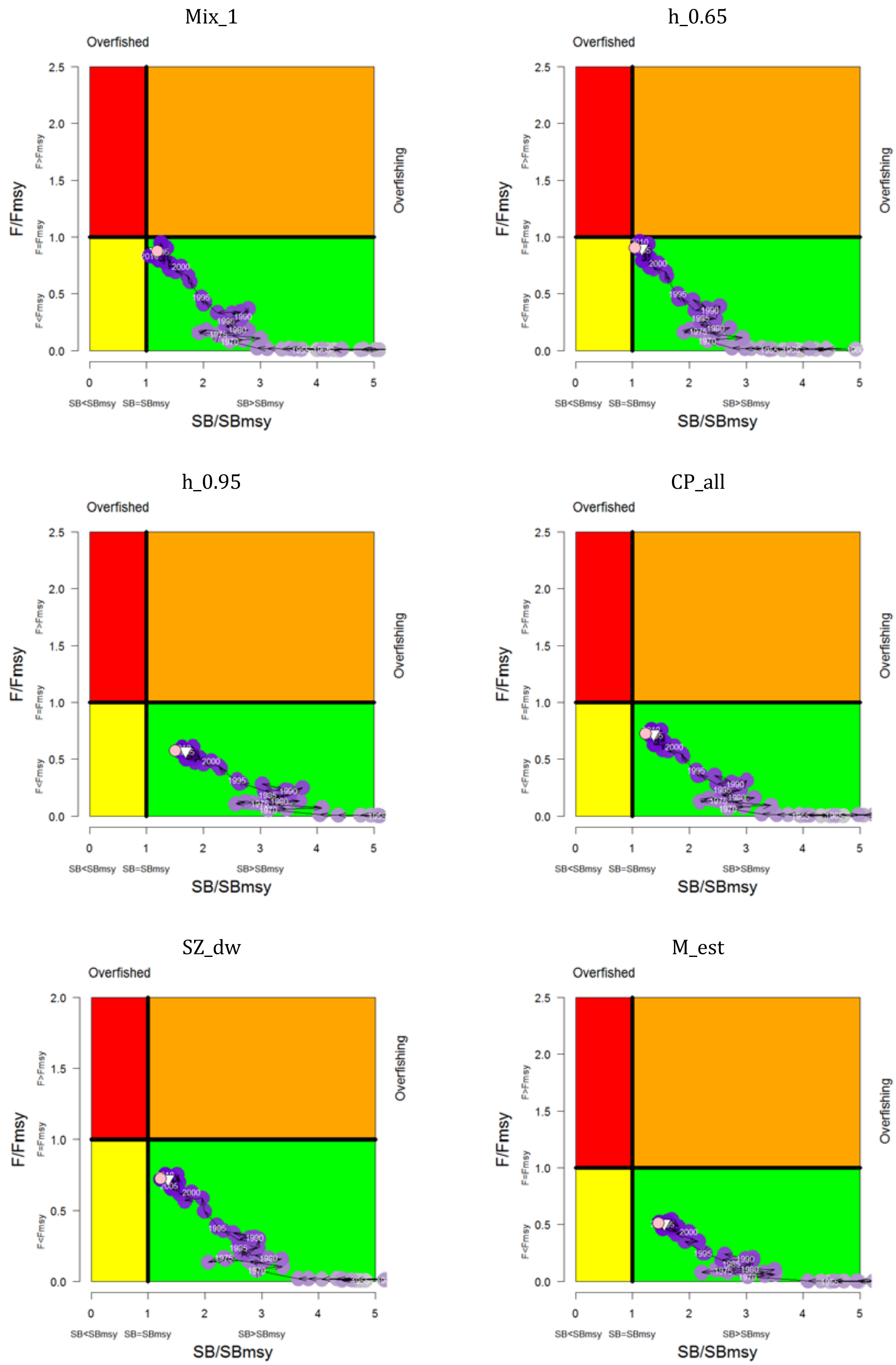


Figure 42. Temporal trend in annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points from the one-off sensitivity model runs to the reference case. The white triangle represents the average for the current period and the pink circle the latest period as defined in Table 6.

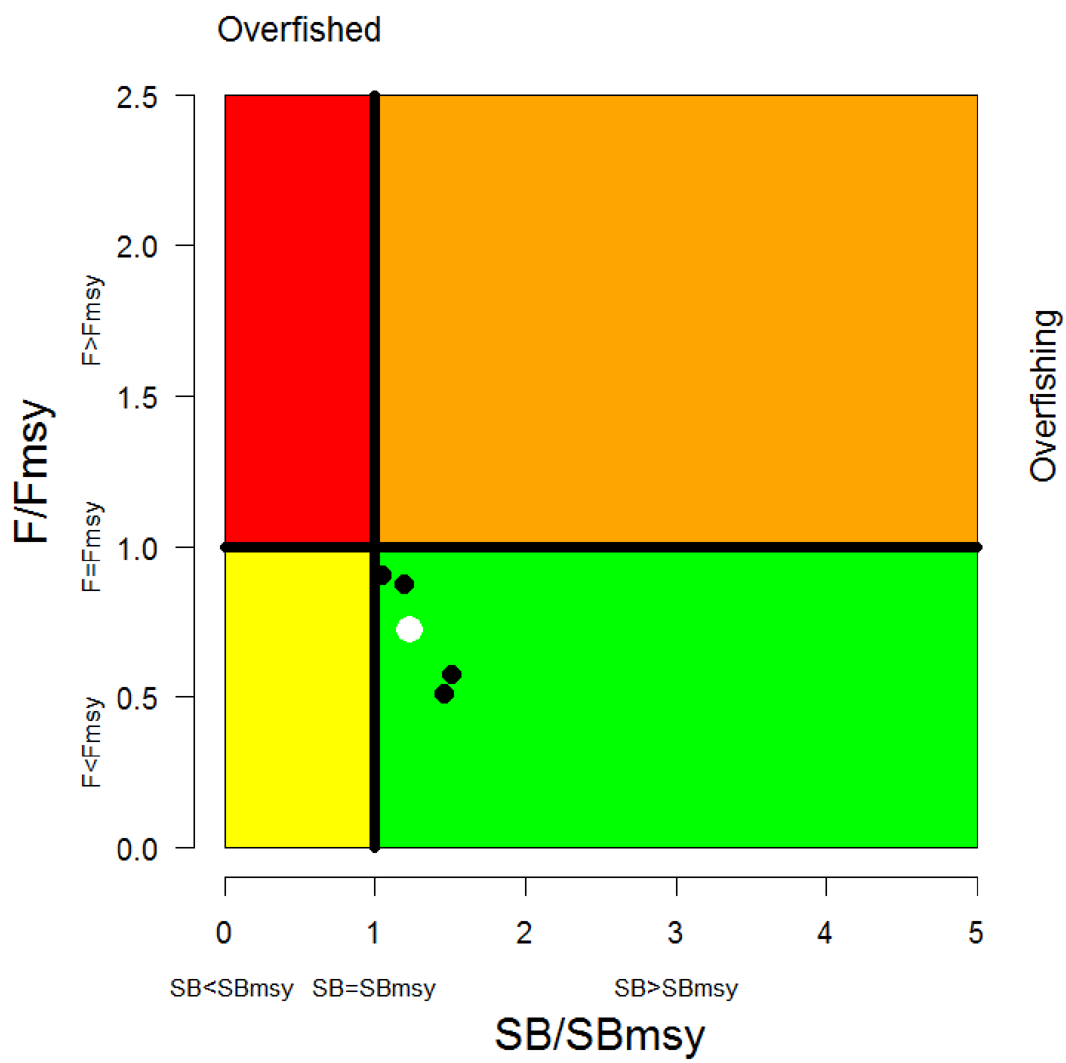


Figure 43. Stock status in terms of latest spawning biomass (SB_{latest}) relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points from the one-off sensitivity model runs (black circles) and the reference case model (white circle).

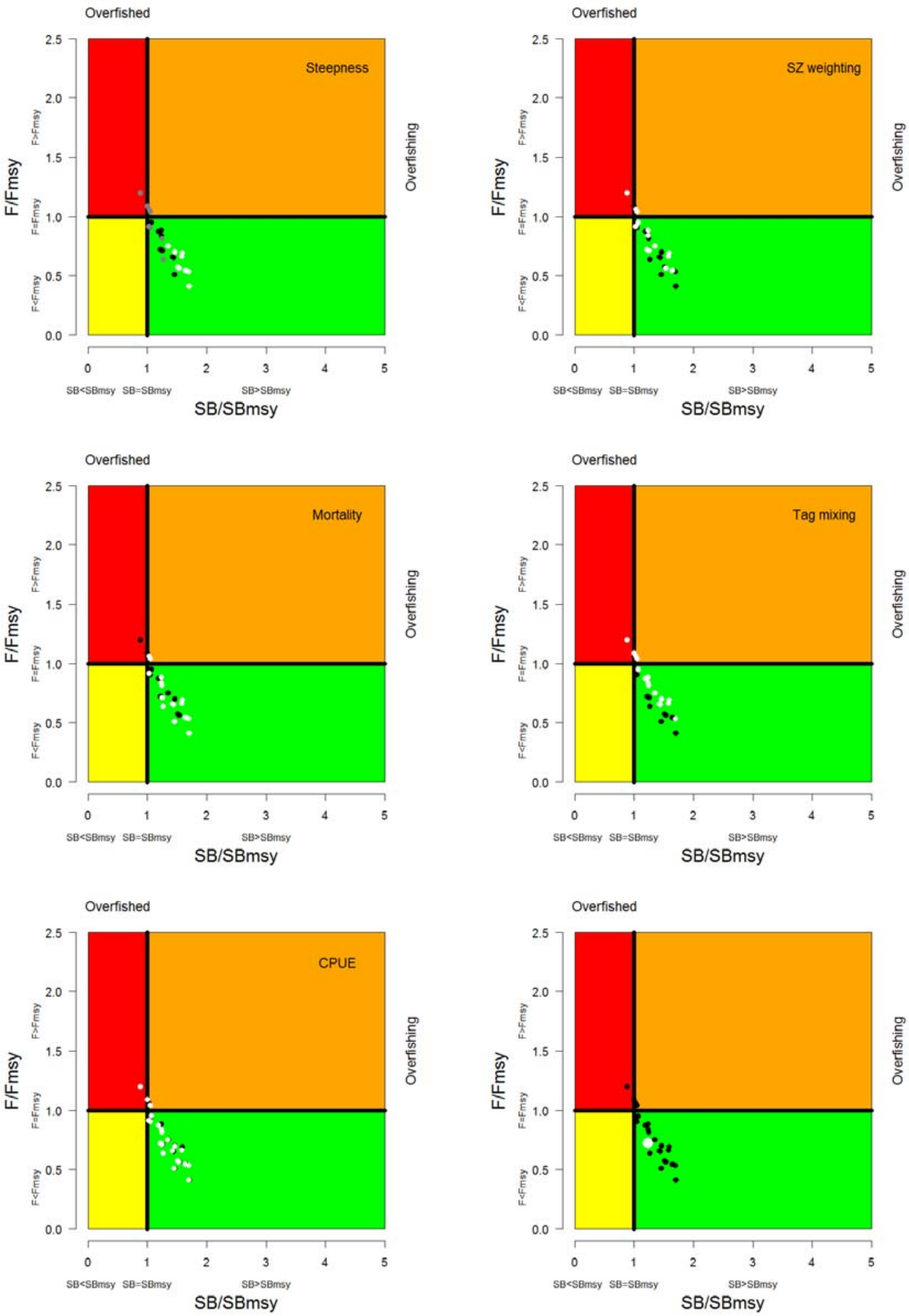


Figure 44. Plot of SB_{latest}/SB_{MSY} versus $F_{current}/F_{MSY}$ for the 48 model runs undertaken for the structural uncertainty analysis. The runs reflecting the reference case assumptions are denoted with black circles while the runs with the alternative assumption are denoted with white circles. For the steepness panel the labels are as follows: 0.95 (white), 0.65 (grey), and 0.8 (black). The lower right panel displays all 48 model runs in black, and the reference case model by the large white circle.

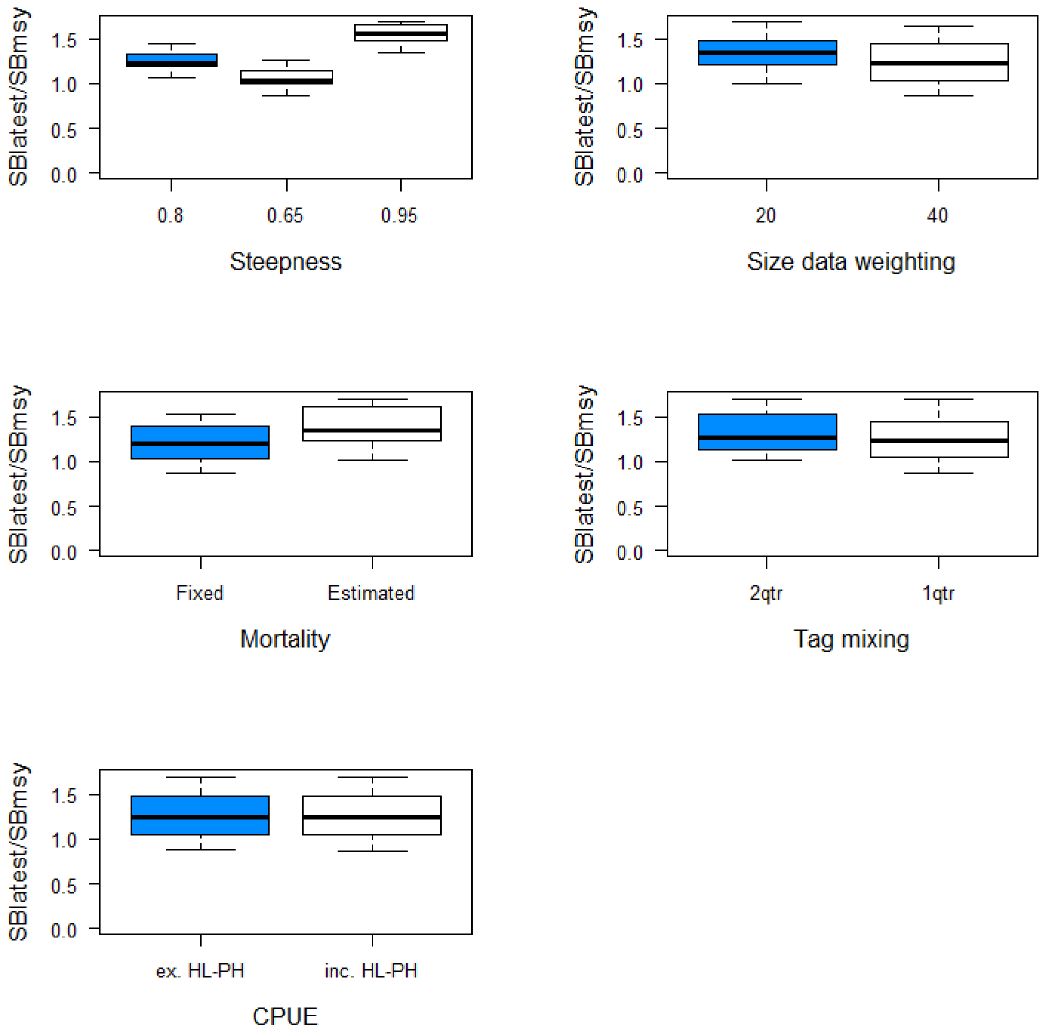


Figure 45. Box plots showing of the effects of the different factors within the structural uncertainty analysis grid on SB_{latest}/SB_{MSY}.

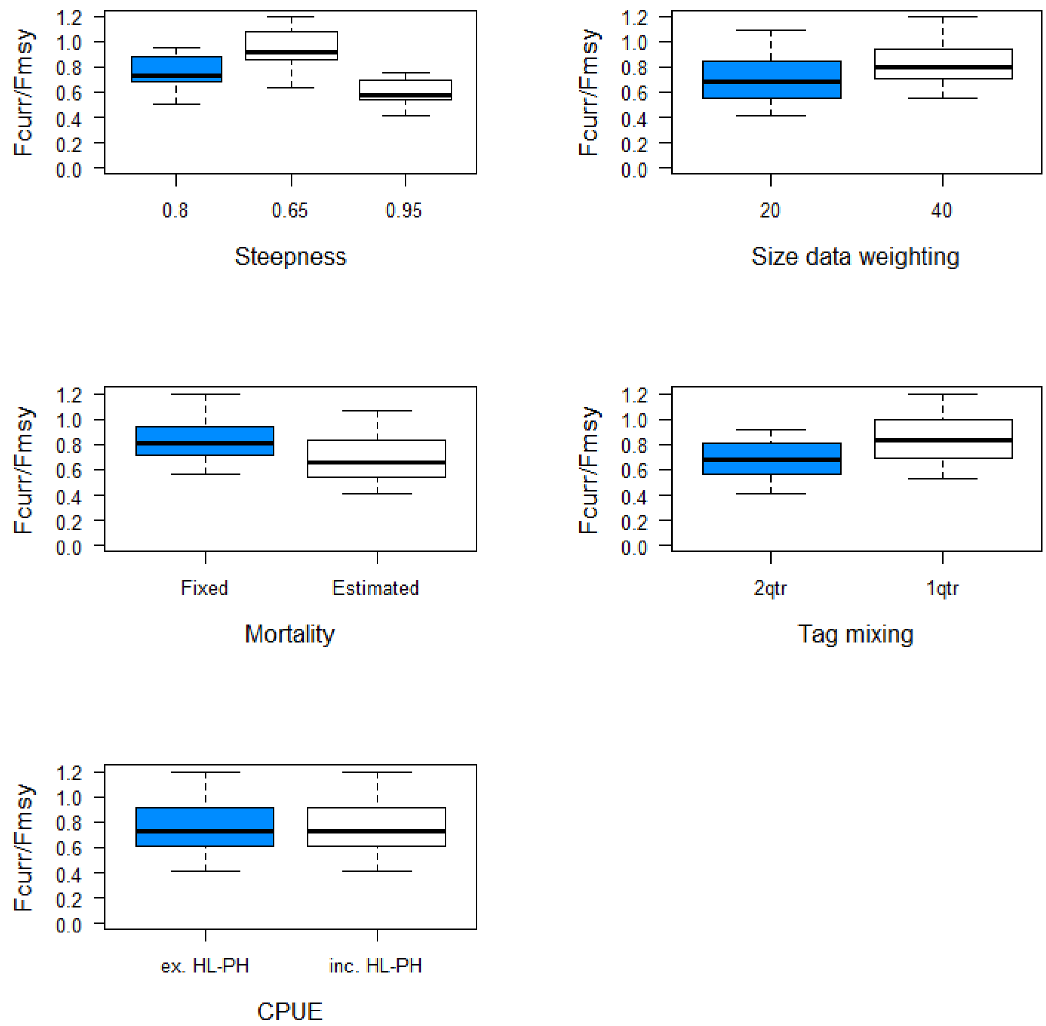


Figure 46. Box plots showing of the effects of the different factors within the structural uncertainty analysis grid on $F_{current}/F_{MSY}$.

10 ANNEX

10.1 Likelihood profile

To evaluate the information available in the observation data component on the model's estimate of scale, a maximum likelihood profile was calculated over a global scaling parameter estimated by the model. The profile reflected the loss of fit over all the data, i.e. the overall objective function value, caused by changing the population scale from that of the maximum likelihood estimated value. The total population scaling parameter (totpop) of MULTIFAN-CL was used to explore the range of population scale because it directly determines the level of recruitment and, hence, absolute biomass. The profile entailed fitting a set of models over a range of fixed totpop values above and below the maximum likelihood estimate.

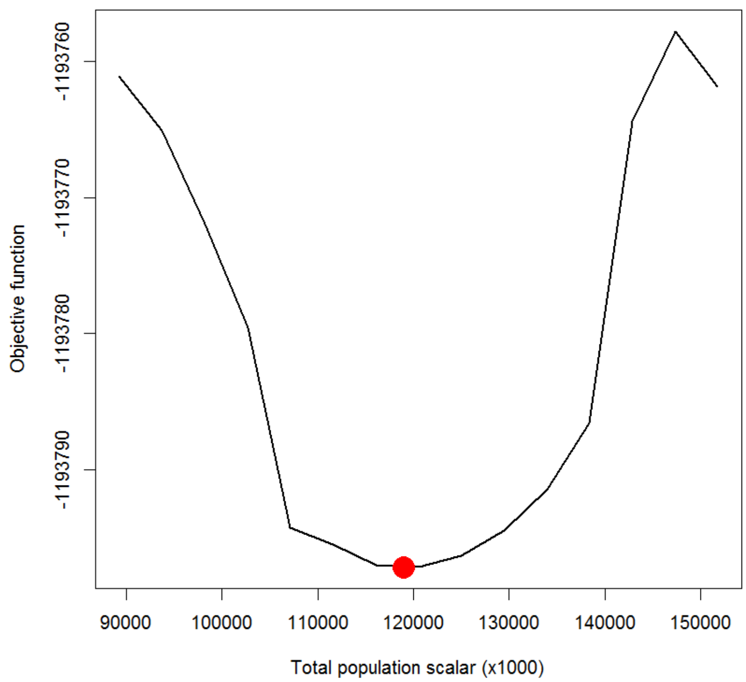


Figure 10.1.1 Profile of the marginal total negative log-likelihood in respect of the population scaling parameter, with the maximum likelihood estimate shown (red circle).

10.2 Retrospective analyses

10.2.1 Removal of recent years from 2014 updated data

Retrospective analysis involves rerunning the model by consecutively removing successive years of data to estimate model bias (Cadrin and Vaughn, 1997; Cadigan and Farrell, 2005). A series of models were fitted starting with the reference case model of the 2014 assessment, followed by models with the retrospective removal of all input data for the years 2012, 2011 and 2010 successively. In addition, a one-off model was run as a variant of the reference case that included the estimation of terminal recruitments in 2012. The models are described in Table 10.2.1 and a comparison of the recruitment and spawning biomass trajectories is shown in Figures 10.2.1 and 10.2.2, respectively.

Table 10.2.1. Description of model runs that explore retrospective fits to the reference case data input with successive removal of observations for each year from 2012 to 2009.

Model run	Description
run33	Full reference case input data time series; terminal recruitments not estimated.
run34	Full reference case input data time series; terminal recruitments estimated.
run34_retro2011	Exclude data for 2012 from reference case input data time series; terminal recruitments estimated.
run34_retro2010	Exclude data for 2011 and 2012 from reference case input data time series; terminal recruitments estimated.
run34_retro2009	Exclude data for 2010 to 2012 from reference case input data time series; terminal recruitments estimated.

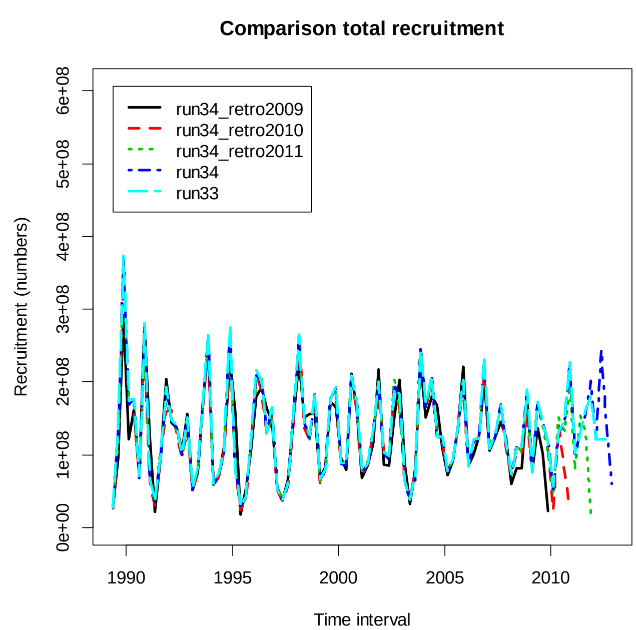


Figure 10.2.1. Recruitment estimates from a variant of the reference case where terminal recruitments were estimated (run34), and for retrospective analyses for the successive removal of data from the end of the observation time series from 2012 to 2010. Model runs are described in Table 10.2.1.

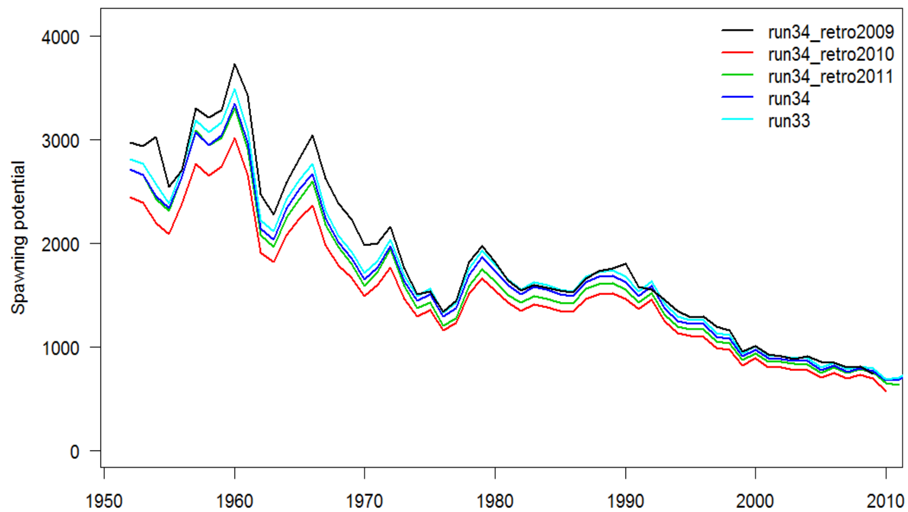


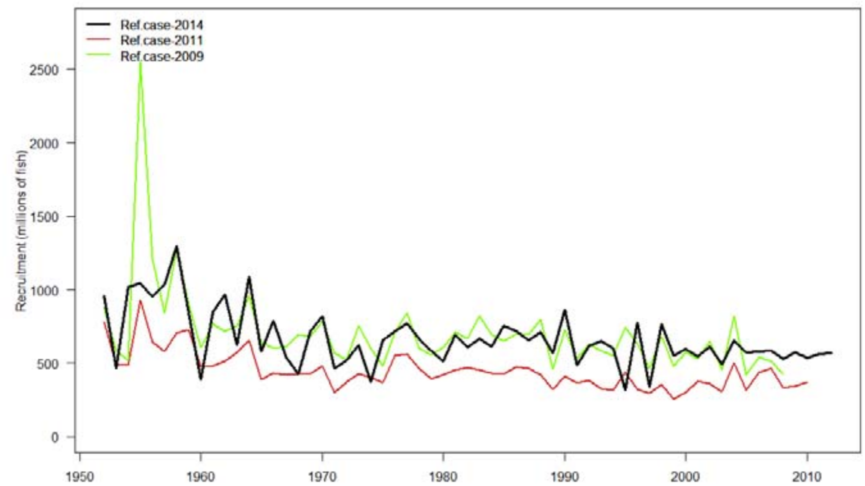
Figure 10.2.2. Annual spawning biomass estimates from a variant of the reference case where terminal recruitments were estimated (run34), and for a run where the terminal recruitments were assumed equal to the average level (run33), and for retrospective analyses for the successive removal of data from the end of the observation time series from 2012 to 2010. Model runs are described in Table 10.2.1.

10.2.2 Retrospective examination of previous assessments

The reference case model for the current (2014) assessment was compared retrospectively to those for the past two assessments done in 2011 and 2009. Key management quantities for the models are listed in Table 10.2.2, a comparison of the recruitment and spawning biomass trajectories is shown in Figure 10.2.3, and a comparison of the Kobe plots of estimated stock status relative to the MSY reference points is shown in Figure 10.2.4.

Table 10.2.2. Key management quantities for the reference case models used for the WCPO yellowfin tuna stock assessments in 2009, 2011, and the current assessment (2014).

Management quantity	Ref.case-2009	Ref.case-2011	Ref.case-2014
MSY	636800	538800	586400
$F_{current}/F_{MSY}$	0.58	0.77	0.72
$SB_{latest}/SB_{F=0}$	0.50	0.44	0.38



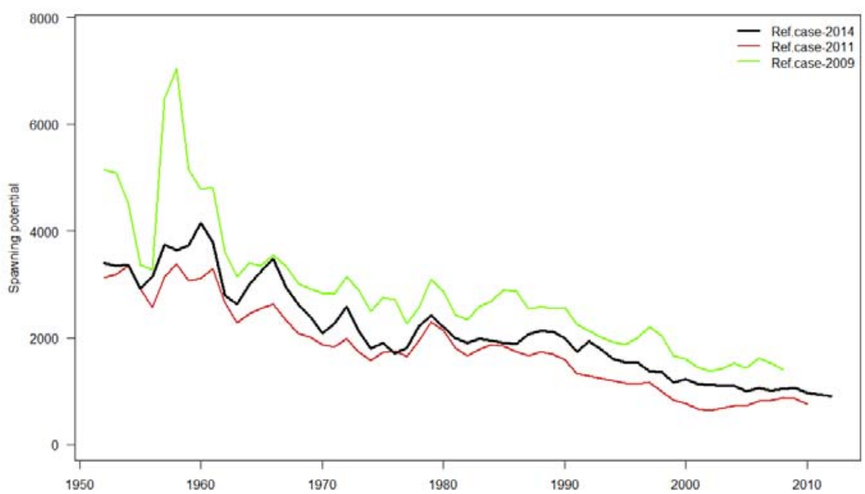


Figure 10.2.2. Annual recruitment (top) and spawning biomass (bottom) estimates from the reference case models used for the WCPO yellowfin assessments from 2009, 2011 and the current assessment (2014).

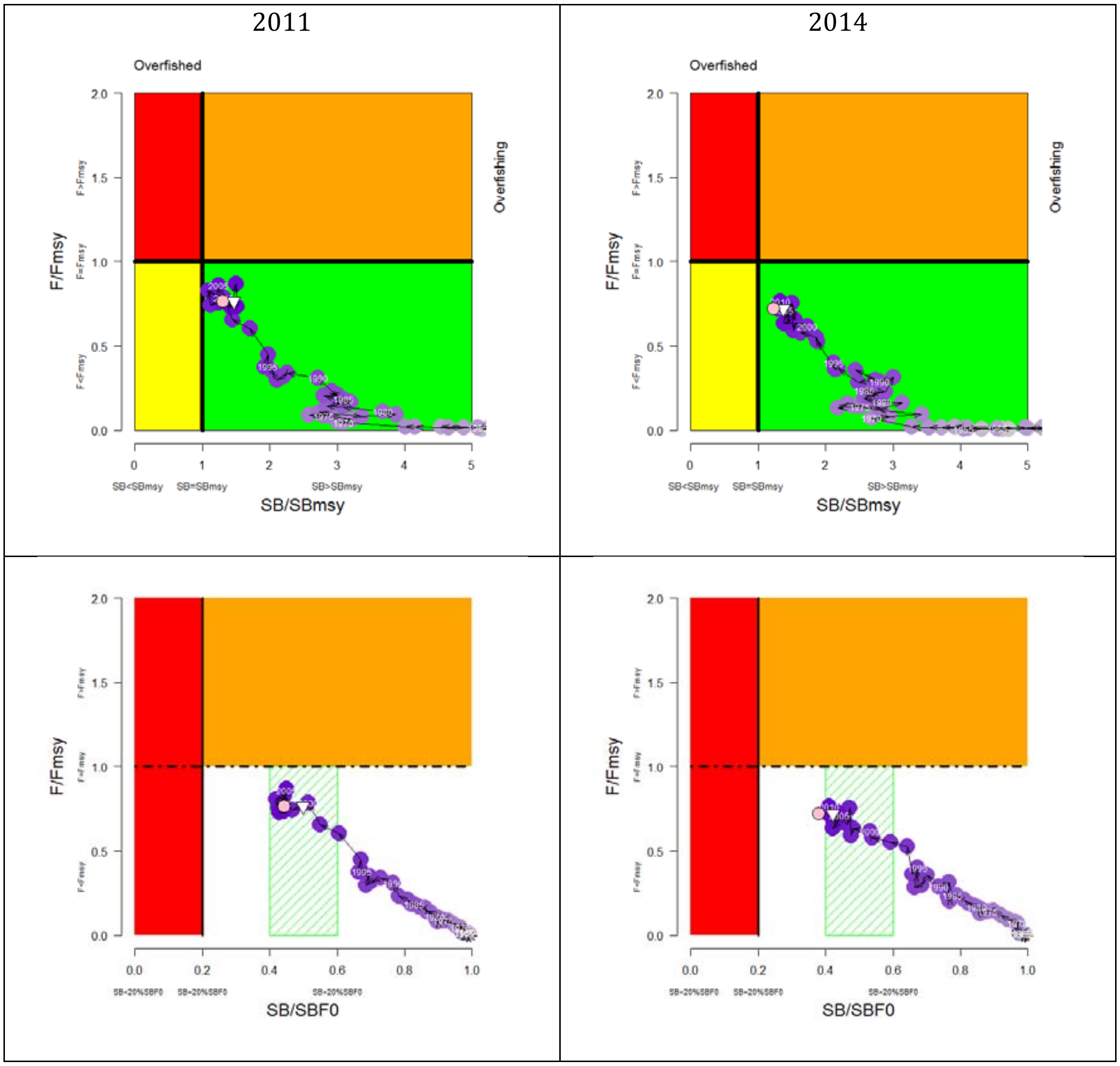


Figure 10.2.3 Comparison of the estimates of stock status in respect of spawning stock biomass relative to SB_{MSY} (top panels) and $SB_{F=0}$ (bottom panels), where the white triangle represents the average for the current period ($SB_{current}$) and the pink circle the latest period (SB_{latest}) as defined in Table 6 and for the reference case models used for the 2011 (left panels) and the current (2014, right panels) assessments of WCPO yellowfin tuna.

10.3 Stepwise model developments

Starting with the reference case model for the 2011 yellowfin tuna stock assessment, a series of stepwise developments were made towards a reference case model for the updated assessment for 2014 (Table 10.3.1). A comparison of the total population biomass trajectory illustrates the effects of the various developments on the estimate of absolute abundance over the model period (Figure 10.3.1).

Table 10.3.1. Summary of the stepwise development model runs undertaken starting with the 2011 yellowfin reference case assessment model leading up to the reference case for the 2014 assessment.

Run	Name	Description
2011	2011 reference case LLcpueOP_TWcpueR6_PTTP	Run from the 2011 assessment; Japanese longline operational CPUE for regions 1-5, Taiwanese CPUE for region 6, size data weighting n/20, corrected purse seine catch estimates, steepness = 0.8, excludes Japanese tag data.
2011_newMFCL	run36	The 2011 reference case model re-fitted to the input data (unchanged) using the latest release version 1.1.5.6 of the MULTIFAN-CL software.
2011_upd	run3	Run 2011_newMFCL with input data updated to 2012, Japanese LL CPUE spliced with indices from aggregate data for 2011-12, revised estimates of the tag reporting rate priors, tag releases scaled for initial mortality.
2014_oldCPUE	run10	Revised model structure and fisheries definitions, 9 regions, 33 fisheries, input updated CPUE data from model 2011_upd, longline size data rescaled relative to catch.
2014_newCPUE	run22	As per model 2014_oldCPUE, but with longline standardised CPUE from operational level data for all fleets.
2014_rvsCPUE	run39	As per 2014_newCPUE, but exclude CPUE indices from the fit for fisheries LL ALL 8 and PH HL 7, revised settings for effort deviates and catchabilities, and restricted the BH-SRR fit to a subset of the model period.
Ref.Case	run37	As per 2014_rvsCPUE, but with exclude estimation of terminal recruitment deviates in 2012.

Table 10.3.2. Estimates of management quantities for the stepwise development models. 'Current' is the average over the period 2006-2009 and 'latest' is 2010.

	2011	2011_newMFCL	2011_upd	2014_oldCPUE	2014_newCPUE	2014_rvsCPUE	Ref.Case
MSY (mt)	538800	464000	508800	716400	622800	578800	586400
C_{latest}/MSY	0.94	1.09	1.14	0.82	0.96	1.03	1.02
$F_{current}/F_{MSY}$	0.77	1.01	1.03	0.77	0.75	0.73	0.72
B_0	3740000	3252000	3416000	5194000	4515000	4240000	4319000
$B_{current}$	1881625	1452073	1291596	1763614	1827058	1928176	1994655
SB_0	2001000	1762000	1844000	2979000	2579000	2416000	2467000
SB_{MSY}	576000	508000	526000	880500	755400	712400	728300
$SB_{F=0}$	1693936	1594840	1572864	2136786	2146452	2327600	2368557
$SB_{current}$	844604	638499	545356	839531	898291	954411	998622
SB_{latest}	749703	464109	422950	909358	807299	864025	899496
$SB_{current}/SB_{F=0}$	0.5	0.4	0.35	0.39	0.42	0.41	0.42
$SB_{latest}/SB_{F=0}$	0.44	0.29	0.27	0.43	0.38	0.37	0.38
$SB_{current}/SB_{MSY}$	1.47	1.26	1.04	0.95	1.19	1.34	1.37
SB_{latest}/SB_{MSY}	1.3	0.91	0.8	1.03	1.07	1.21	1.24

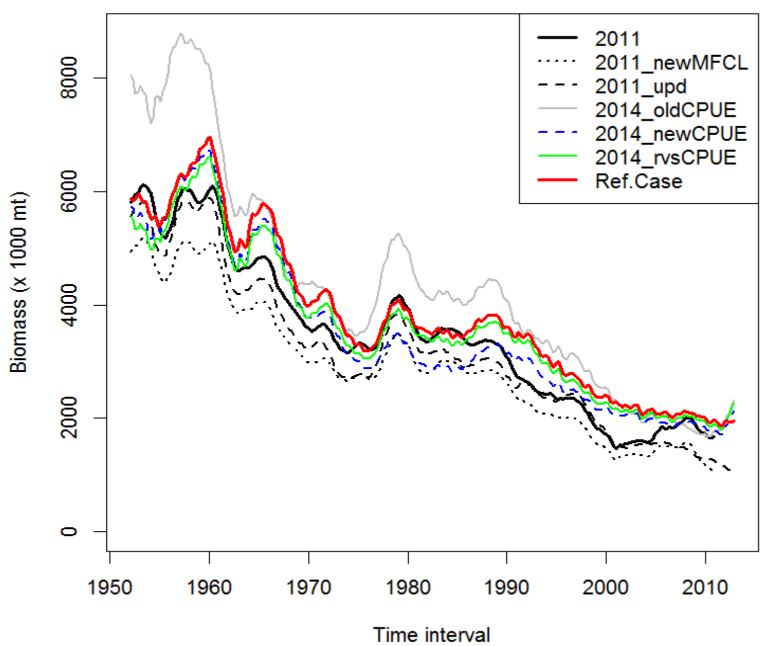


Figure 10.3.1. Estimated annual average spawning potential for the WCPO obtained from runs undertaken in the stepwise development from the 2011 reference case to the 2014 reference case. Model runs are as described in Table 10.3.1.

10.4 Input .ini file

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1001
# number of age classes
28
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0.2502986
# movement map
1 2 3 4
# diffusion coffs (per year)
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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 0 0 0
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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 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 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 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 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 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
# recruitment distribution by region
0.05 0.05 0.25 0.25 0.04 0.05 0.2 0.1 0.01
# The von Bertalanffy parameters
# Initial  lower bound  upper bound
# ML1
25 20 40
# ML2
150 140 200
# K (per year)
0.15 0 0.3
# Length-weight parameters
2.512e-05 2.9396
# sv(29)
0.9
# Generic SD of length at age
6 3 15
# Length-dependent SD
0.4 -1 1
# The number of mean constraints
0
```

10.5 Input doitall file

```
#!/bin/sh
cd $_CONDOR_SCRATCH_DIR
export PATH=.:$PATH
export ADTMP1=.

# Apply the recruitment functions changes to the PAR file.
# $1 Name of the PAR file.
# $2 New value.
function recruitmentConstraints {
    if [ -z $1 ]
    then
       echo "Needs filename as argument.";
       exit 1;
    elif [ -z $2 ]
    then
       echo "Needs new value argument.";
       exit 1;
    elif [ -f "$1" ]
    then
# Read line per line.
       while read LINE
       do
# Found the desired header.
           if [ "$LINE" == "# Seasonal growth parameters" ]
           then
              echo $LINE >> $1.new;
              for ((L=1 ; L < 2 ; L++))
              do
                     read LINE;
# Skip blank or comment line.
                     if [[ "$LINE" == "#" || "$LINE" == "" ]]
                     then
                     #echo "Found a matching line "$LINE;
```

```
                    L=`expr $L - 1`;
                    echo $LINE >> $1.new;
                    else
                    #echo "Processing line "$LINE;
                    I=0;
                    for VALUE in $LINE
                    do
                        I=`expr $I + 1`;
# Change the 29th value.
                        if [ $I -eq 29 ]
                        then
                           echo -n $2" " >> $1.new;
                        else
                           echo -n $VALUE" " >> $1.new ;
                        fi
                    done
                    echo "" >> $1.new;
                 fi
             done
# Write line AS IS.
           else
              echo $LINE >> $1.new;
           fi
       done < $1;
# Create a backup copie.
       mv $1 $1.bak;
# Move temporary file to target file.
       mv $1.new $1;
    fi;
}
nice $MFCL yft.frq yft.ini 00.par -makepar
###
#  ------------------------
#  PHASE 1 - initial par
#  ------------------------
#
if [ ! -f 01.par ]; then
  nice $MFCL yft.frq 00.par 01.par -file - <<PHASE1
  1 149 100       # recruitment penalties
  2 113 0  # old comment:  # estimate initpop/totpop scaling parameter
  2 177 1         # use old totpop scaling method
  2 32 1          # and estimate the totpop parameter
  2 116 70        # default value for rmax in the catch equations
  -999 49 20      # divide LL LF sample sizes by 20 (default)
  -999 50 20      # divide LL WF sample sizes by 20 (default=10)
  -20 50 100       # except for PS in area 1 - lower confidence in these weight
data
  -20 49 100       # except for PS in area 1 - lower confidence in these length
data
#  -18 50 100       # except for PH small fish fishery - lower confidence in these
weight data
#  -18 49 100       # except for PH small fish fishery - lower confidence in these
length data
  -25 50 100       # except for PH/ID PS fishery - lower confidence in these weight
data
  -25 49 100       # except for PH/ID PS fishery - lower confidence in these length
data
#  1 32 2          # sets control
  1 32 6          # sets control, but don't estimate growth
  1 111 4  # old comment:  # sets likelihood function for tags to negative binomial
- 2009 assessment used 4 (zero inflated).
  1 141 3         # sets likelihood function for LF data to normal
  1 173 8        # 1st n lengths are independent pars
  2 57 4          # sets no. of recruitments per year to 4
  2 69 1          # sets generic movement option (now default)
  2 93 4          # sets no. of recruitments per year to 4 (is this used?)
  2 94 2 2 95 20  # initial age structure based on Z for 1st 20 periods
  -999 26 2       # sets length-dependent selectivity option
```

```
  -9999 1 2
  2 96 12         # pool tags after 12 quarters at liberty
# sets non-decreasing selectivity for longline fisheries
 -999 57 3        # uses cubic spline selectivity
 -999 61 3        # with 3 nodes for cubic spline
  -5 57 3  # old comment:  # logistic selectivity for 3 TWCH fisheries
   -6 57 1
# grouping of fisheries with common selectivity
  -1 24 1
  -2 24 1
  -3 24 2
  -4 24 3
  -5 24 4
  -8 24 7
  -9 24 3
  -6 24 5
  -10 24 8
  -12 24 3
  -11 24 9
  -13 24 3
  -7 24 6
  -14 24 10
  -15 24 11
  -16 24 10
  -17 24 11
  -18 24 12
  -19 24 13
  -20 24 14
  -21 24 15
  -22 24 16
  -23 24 17
  -24 24 12
  -25 24 10
  -26 24 10
  -27 24 18
  -28 24 19
  -29 24 20
  -30 24 3
  -31 24 10
  -32 24 11
  -33 24 12
# grouping of fisheries with common catchability
  -1 29 1
  -2 29 1
  -3 29 2
  -4 29 1
  -5 29 3
  -8 29 1
  -9 29 1
  -6 29 4
  -10 29 5
  -12 29 1
  -11 29 6
  -13 29 1
  -7 29 1
  -14 29 7
  -15 29 8
  -16 29 9
  -17 29 10
  -18 29 11
  -19 29 12
  -20 29 13
  -21 29 14
  -22 29 15
  -23 29 16
  -24 29 17
  -25 29 18
  -26 29 19
```

```
  -27 29 20
  -28 29 21
  -29 29 22
  -30 29 1
  -31 29 23
  -32 29 24
  -33 29 25
  -1 60 1
  -2 60 1
  -3 60 2
  -4 60 1
  -5 60 3
  -8 60 1
  -9 60 1
  -6 60 4
  -10 60 5
  -12 60 1
  -11 60 6
  -13 60 1
  -7 60 1
  -14 60 7
  -15 60 8
  -16 60 9
  -17 60 10
  -18 60 11
  -19 60 12
  -20 60 13
  -21 60 14
  -22 60 15
  -23 60 16
  -24 60 17
  -25 60 18
  -26 60 19
  -27 60 20
  -28 60 21
  -29 60 22
  -30 60 1
  -31 60 23
  -32 60 24
  -33 60 25
# grouping of fisheries for tag return data
  -1 32 1
  -2 32 2
  -3 32 3
  -4 32 4
  -5 32 5
  -8 32 8
  -9 32 9
  -6 32 6
  -10 32 10
  -12 32 12
  -11 32 11
  -13 32 13
  -7 32 7
  -14 32 14
  -15 32 14
  -16 32 15
  -17 32 15
  -18 32 16
  -19 32 17
  -20 32 18
  -21 32 19
  -22 32 20
  -23 32 20
  -24 32 21
  -25 32 22
  -26 32 23
  -27 32 23
```

```
  -28 32 24
  -29 32 25
  -30 32 26
  -31 32 27
  -32 32 27
  -33 32 28
# effort dev bpoundary
  2 35 10
# sets penalties for effort deviations (negative penalties force effort devs
# to be zero when catch is unknown)
## use time varying effort weight for LL fisheries
   -1 66 1
   -2 66 1
   -4 66 1
   -9 66 1
  -12 66 1
  -13 66 1
# sets penalties for catchability deviations
   -18 15 1       # low penalty for PH.ID MISC.
   -24 15 1
  -25 15 0
  1 33 90         # maximum tag reporting rate for all fisheries is 0.9
  -26 15 0
  -27 15 1
  -31 15 1
  -32 15 1
  -33 15 1
  -7 66 1
  -8 66 0
  -30 66 0
  -7 49 20
  -8 49 20
  -30 49 20
  2 198 1
  -14 15 1
  -15 15 1
  -16 15 1
  -17 15 1
  -1 13 1
  -2 13 1
  -3 13 -3
  -4 13 1
  -5 13 -3
  -6 13 -3
  -7 13 1
  -8 13 1
  -9 13 1
  -10 13 -3
  -11 13 -3
  -12 13 1
  -13 13 1
  -14 13 -3
  -15 13 -3
  -16 13 -3
  -17 13 -3
  -18 13 3
  -19 13 -3
  -20 13 -3
  -21 13 -3
  -22 13 -3
  -23 13 -3
  -24 13 3
  -25 13 1
  -26 13 1
  -27 13 -3
  -28 13 -3
  -29 13 -3
  -30 13 1
```

```
  -31 13 -3
  -32 13 -3
  -33 13 3
  -26 66 1
  -9999 2 0
  -3 16 1
  -7 16 1
  -8 16 1
  1 400 4
PHASE1
fi
## reset steepness
recruitmentConstraints 01.par 0.80
###
#  ---------
#   PHASE 2
#  ---------
if [ ! -f 02.par ]; then
  nice $MFCL yft.frq 01.par 02.par -file - <<PHASE2
  2 144 100000    # increase penalty on catch from default of 10000
  2 35 10          # Set effdev bounds to +- 10 (need to do AFTER phase 1)
  -999 3 25       # all selectivities equal for age class 25 and older
  -999 4 4        # possibly not needed
  -999 21 4       # possibly not needed
  1 190 1         # write plot.rep
  1 1 200         # set max. number of function evaluations per phase to 100
  1 50 -2         # set convergence criterion to 1E+01
  -999 14 10      # Penalties to stop F blowing out
  -999 62 2       # add more nodes to cubic spline
#  -18 16 2        ## change for 2011 following BET
#  -18 3 12
#  -24 16 2
#  -24 3 12
PHASE2
fi
#  ---------
#   PHASE 3
#  ---------
if [ ! -f 03.par ]; then
  nice $MFCL yft.frq 02.par 03.par -file - <<PHASE3
  2 70 1          # activate parameters and turn on
  2 71 1          # estimation of temporal changes in recruitment distribution
  2 110 10       # set penalty weight to 10/10 default = 0.1
#  1 183 20        # penalties on devs for first 20 time periods
#  -100001 1 1000  # pen wt on region rec diffs in region 1
#  -100001 2 1000  # pen wt on region rec diffs in region 2
#  -100001 3 1000  # pen wt on region rec diffs in region 3
#  -100001 4 1000  # pen wt on region rec diffs in region 4
#  -100001 5 1000  # pen wt on region rec diffs in region 5
#  -100001 6 1000  # pen wt on region rec diffs in region 6
  2 178 1
PHASE3
fi
#  ---------
#   PHASE 4
#  ---------
if [ ! -f 04.par ]; then
  nice $MFCL yft.frq 03.par 04.par -file - <<PHASE4
  2 68 1          # estimate movement coefficients
PHASE4
fi
#  ---------
#   PHASE 5
#  ---------
if [ ! -f 05.par ]; then
  nice $MFCL yft.frq 04.par 05.par -file - <<PHASE5
  1 16 1          # estimate length dependent SD
PHASE5
```

```
fi
#  ---------
#   PHASE 6
#  ---------
if [ ! -f 06.par ]; then
  nice $MFCL yft.frq 05.par 06.par -file - <<PHASE6
  1 173 8         # estimate independent mean lengths for 1st 8 age classes
  1 182 10
  1 184 1
PHASE6
fi
#  ---------
#   PHASE 7
#  ---------
if [ ! -f 07.par ]; then
  nice $MFCL yft.frq 06.par 07.par -file - <<PHASE7
  -999 27 1       # estimate seasonal catchability for all fisheries
  -18 27 0        # except those where
  -19 27 1
  -24 27 0
  -25 27 1
  -29 27 0
  -33 27 0
PHASE7
fi
#  ---------
#   PHASE 8
#  ---------
if [ ! -f 08.par ]; then
  nice $MFCL yft.frq 07.par 08.par -file - <<PHASE8
  -3 10 1         # estimate
  -5 10 1         # catchability
  -8 10 0  # old comment:  # time-series
  -6 10 1         # for all
  -10 10 1         # non-longline
  -11 10 1        # fisheries
  -7 10 0
  -14 10 1
  -15 10 1
  -16 10 1
  -17 10 1
  -18 10 0
  -19 10 1
  -20 10 1
  -21 10 1
  -22 10 1
  -23 10 1
  -24 10 0
  -25 10 0
  -26 10 0
  -27 10 1
  -28 10 1
  -29 10 1
  -30 10 0
  -31 10 1
  -32 10 1
  -33 10 0
  -999 23 23      # and do a random-walk step every 23+1 months
PHASE8
fi
#  ---------
#   PHASE 9
#  ---------
if [ ! -f 09.par ]; then
  nice $MFCL yft.frq 08.par 09.par -file - <<PHASE9
  1 14 1          # estimate von Bertalanffy K
  1 12 1          # and mean length of age 1
PHASE9
```

```
fi
#  ---------
#   PHASE 10
#  ---------
if [ ! -f 10.par ]; then
  nice $MFCL yft.frq 09.par 10.par -file - <<PHASE10
# grouping of fisheries for estimation of negative binomial parameter a
  -999 43 0  # old comment:  # estimate a for all fisheries
  1 13 1     # estimate mean length of largest age class
  -999 44 0
PHASE10
fi
#  ---------
#   PHASE 11
#  ---------
if [ ! -f 11.par ]; then
  nice $MFCL yft.frq 10.par 11.par -file - <<PHASE11
  -100000 1 1     # estimate
  -100000 2 1     # time-invariant
  -100000 3 1     # distribution
  -100000 4 1     # of
  -100000 5 1     # recruitment
  -100000 6 1
  -100000 7 1
  -100000 8 1
  -100000 9 1
PHASE11
fi
#  ---------
#   PHASE 12
#  ---------
if [ ! -f 12.par ]; then
  nice $MFCL yft.frq 11.par 12.par -file - <<PHASE12
  2 145 -2
  1 149 0
  2 146 1
#  2 162 1 # estimate steepness
  2 162 0
  2 163 0
  2 147 1
  2 148 20       # Current is defined as 2004-2007
  2 155 4
  2 153 31
  2 154 16
  1 1 18000
  1 50 -3
  -999 14 0
  -999 55 1 # fishery impact
  2 193 1  # initial impact for depletion
  1 1 10000
  2 161 1
  2 199 188
  2 200 4
  2 171 1
PHASE12
fi
#cp plot.rep plot-12.rep
#cp length.fit length-12.fit
#cp weight.fit weight-12.fit
#  ---------
#   PHASE 13
#  ---------
#if [ ! -f 13.par ]; then
#  nice $MFCL yft.frq 12.par 13.par -file - <<PHASE13
#  -999 49 50
#  -999 50 50
#PHASE13
#fi
```