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

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Executive summary

Yellowfin tuna, an important component of tuna fisheries throughout the WCPO, are harvested with a diverse 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. However, there remains considerable uncertainty regarding the accuracy of the purse-seine catch and official catch statistics may significantly under-estimate actual catch levels. Reported catches have been corrected for the known sources of bias and the revised catches represent the primary catch data incorporated in the stock assessment.

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 (corrected catches). Purse seiners harvest the majority of the yellowfin tuna catch (68% in 2005-2009), while the longline fleet accounted for 13% of the catch in recent years. 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.

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. 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 and remaining at that level in subsequent years.

This paper presents the 2011 assessment of yellowfin tuna in the western and central Pacific Ocean. The assessment uses the stock assessment model and computer software known as MULTIFAN-CL. The yellowfin tuna model is age (28 age-classes) and spatially structured (6 regions) and the catch, effort, size composition and tagging data used in the model are classified by 24 fisheries and quarterly time periods from 1952 through 2010. The assessment included a range of model options and sensitivities that were applied to investigate key structural assumptions and sources of uncertainty in the assessment.

While the structure of the assessment model(s) was similar to the previous (2009) assessment, there were some substantial revisions to a number of key data sets, specifically the longline CPUE indices, catch and size data, purse-seine catch and size data, and the configuration of the Indonesian and Philippines domestic fisheries. Cumulatively, these changes resulted in a substantial change in the key results from the 2009 assessment, reducing the overall level of biomass and the estimates of *MSY*, $B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$, while increasing the estimate of $F_{current}/\tilde{F}_{MSY}$ Overall, the current models represent a considerable improvement to the fit to the key data sets compared to 2009 indicating an improvement in the consistency among the main data sources, principally the longline CPUE indices and the associated length and weight frequency data.

The current assessment represents the first attempt to integrate the tagging data from the recent PTTP. The model diagnostics indicate a relatively poor fit to these data compared to the data from earlier tagging programmes, particularly for fish of the older age classes and/or longer periods at liberty. For all model options, there was a positive bias in the model's prediction of the number of tags recovered from older fish, indicating that estimated exploitation rates for recent years were higher than observed directly from the tag recoveries. This indicates a degree of conflict between the tagging data and the other key data sources, specifically the longline CPUE indices and, to a lesser extent, the longline size data. Consequently, the inclusion of PTTP data set in the model yields a rather more optimistic assessment (when contrasted with models that exclude these data).

The main conclusions of the current assessment are as follows.

1. For all analyses, there are strong temporal trends in the estimated recruitment series. Initial recruitment was relatively high but declined during the 1950s and 1960s. Recruitment remained relatively constant during the 1970s and 1980s, declined steadily from the early 1990s and then recovered somewhat over the last decade. Recent recruitment is estimated to be lower than the long-term average (approximately 85%).

2. Trends in biomass are generally consistent with the underlying trends in recruitment. 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. 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, principally from the Japanese fleet. This data enables a number of factors to be incorporated within the analysis to account for temporal trends in the catchability of the fleet.

3. Refinement in the approach applied to process the longline size frequency data (length and weight data) has resulted in a more coherent trend in these data over the model period. As a result, there has been a substantial improvement in the fit to both the size frequency data and the CPUE indices compared to recent assessments.

4. There is considerable conflict between the tagging data (principally from the PTTP) and the other key sources of data included in the model, primarily the CPUE indices. The inclusion of the PTTP tagging data results in a the estimation of a substantially lower level of fishing mortality, particularly for the both the younger age classes vulnerable to the purse-seine associated fishery (age classes 3-4) and the older age classes (age classes > 9) vulnerable to the unassociated purse-seine fishery. The resulting assessment is more optimistic when the PTTP tags are incorporated in the model. Further auxiliary analysis of the PTTP tagging data are required to resolve the conflict between these key sources of data.

5. Fishing mortality for adult and juvenile yellowfin tuna is estimated to have increased continuously since the beginning of industrial tuna fishing. A significant component of the increase in juvenile fishing mortality is attributable to the Philippines and Indonesian surface fisheries, which have the weakest catch, effort and size data. There has been recent progress made in the acquisition of a large amount of historical length frequency data from the Philippines and these data were incorporated in the assessment. However, there is an ongoing need to improve estimates of recent and historical catch from these fisheries and maintain the current fishery monitoring programme within the Philippines. Previous analyses have shown that the current stock status is relatively insensitive to the assumed level of catch from these fisheries, although yield estimates from the fishery vary in accordance to the assumed levels of historical catch. Therefore, improved estimates of historical and current catch from these fisheries are important in the determination of the underlying productivity of the stock.

6. The ratios $B_t / B_{t,F=0}$ provide a time-series index of population depletion by the fisheries. Depletion has increased steadily over time, reaching a level of about 50-55% of unexploited biomass (a fishery impact of 45-50%) in 2006–2009. This represents a moderate level of stock-wide depletion although the stock remains considerably higher than the equivalent equilibrium-based reference point ($\widetilde{B}_{MSY} / \widetilde{B}_0$ of approximately 0.35–0.40). However, depletion is considerably higher in the equatorial region 3 where recent depletion levels are approximately 0.30 for total biomass (a 70% reduction from the unexploited level). Impacts are moderate in region 4 (37%), lower (about 15–25%) in regions 1, 5, and 6 and minimal (9%) in region 2. If stock-wide over-fishing criteria were applied at the level of our model regions, we would conclude that region 3 is fully exploited and the remaining regions are under-exploited.

7. The attribution of depletion to various fisheries or groups of fisheries indicates that the associated purse-seine fishery and Philippines/Indonesian domestic fisheries have the highest impact, particularly in region 3, while the unassociated purse seine fishery has a moderate impact. These

fisheries are also contributing to the fishery impacts in all other regions. Historically, the coastal Japanese pole-and-line and purse-seine fisheries have had a significant impact on biomass levels in their home region (1). In all regions, the longline fishery has a relatively small impact, less than 5%.

8. For the most plausible range of models, the fishing mortality based reference point $F_{current}/\tilde{F}_{MSY}$ is estimated to be 0.56–0.90 and on that basis conclude that **overfishing is not occurring**. The corresponding biomass based reference points $B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$ are estimated to be above 1.0 (1.25–1.60 and 1.34–1.83, respectively) and, therefore, the stock is **not in an overfished state**. 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 approaching the *MSY* based fishing mortality and biomass thresholds.

9. The western equatorial region accounts for the most of the WCPO yellowfin catch. In previous assessments, there have been concerns that the stock status in this region (region 3) might differ from the stock status estimated for the entire WCPO. A comparison between the results from the WCPO models and a model encompassing only region 3 yielded very similar results, particularly with respect to stock status. Nonetheless, there appear to be differences in the biological characteristics of yellowfin tuna in this region that warrant further investigation.

10. The estimates of *MSY* for the principal model options (480,000–580,000 mt) are comparable to the recent level of (estimated) catch from the fishery (550,000 mt). Further, under equilibrium conditions, the predicted yield estimates ($Y_{Fcurrent}$) are very close to the estimates of *MSY* indicating that current yields are at or above the long-term yields available from the stock. Further, while estimates of current fishing mortality are generally below F_{MSY}, any increase in fishing mortality would most likely occur within region 3 — the region that accounts for most of the catch. This would further increase the levels of depletion that is occurring within that region.

11. The current assessment investigated the impact of a range of sources of uncertainty in the current model and the interaction between these assumptions. Nonetheless, there remains a range of other assumptions in the model that should be investigated either internally or through directed research. 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 examine in detail the time-series of size frequency data from the fisheries, which may lead to refinement in the structure of the fisheries included in the model; 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.

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 and 2009). 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.

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 ($B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$) and recent fishing mortality to the fishing mortality at MSY ($F_{current}/\tilde{F}_{MSY}$). Likelihood profiles of these ratios are used to describe their uncertainty.

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.

The Center for Independent Experts (CIE) conducted a review of the 2009 yellowfin tuna assessment. Overall, the review was supportive of the current assessment approach. A separate document has been compiled to address the specific comments of the reviewers (SPC-OFP 2011).

As in previous years, a Pre-assessment Workshop (PAW) was held prior to the commencement of the current stock assessment (OFP 2009). 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 Biology

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 (Figure 1). 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).

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 2). 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) (Figure 2) and growth increments from tag release/recovery data (Figure 3). 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) (Figure 2).

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.

2.2 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. However, there remains considerable uncertainty regarding the accuracy of the purse-seine catch and reported catches may significantly under-estimate actual catch levels (Lawson 2009 and 2010, Lawson & Sharples 2011). In recent years, 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) 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 unless otherwise noted. For the last decade, the corrected annual catch estimates are substantially higher than the uncorrected catch - the average annual corrected purse seine catch was approximately 110,000 mt higher than the uncorrected catch for 2005-2009. The lower, uncorrected catches (S_BEST) were incorporated in the stock assessment as an alternative catch scenario.

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. Purse seiners harvest the majority of the yellowfin tuna catch (68% in 2005-2009), while the longline fleet accounted for 13% of the catch in recent years. 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. 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 and remaining at that level in subsequent years (excluding the catches from the purse seine fleets operating beyond archipelagic waters).

Figure 6 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 7).

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. The details of these data and their stratification are described below.

3.1 Spatial stratification

The geographic area considered in the assessment is the WCPO, defined by the coordinates 40°N–40°S, 120°E–150°W. Within this overall area, a six-region spatial stratification was adopted for the assessment (Figure 6). The rationale for this stratification was to separate the tropical area, where both surface and longline fisheries occur year-round, from the higher latitudes, where the longline fisheries occur more seasonally. The spatial stratification is also designed to minimise the spatial heterogeneity in the magnitude and trend in longline CPUE (Langley 2006b) and the size composition of the longline catch (Langley 2006c). The stratification for the assessment is equivalent to that used in the 2009 assessment.

3.2 Temporal stratification

The time period covered by the assessment is 1952–2010. Within this period, data were compiled into quarters (Jan–Mar, Apr–Jun, Jul–Sep, Oct–Dec). The time period covered by the assessment includes almost all the significant post-war tuna fishing in the WCPO.

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). Twenty five fisheries have been defined for this analysis on the basis of region, gear type, nationality and, in the case of purse seine, set type (Table 1).

There is a single principal longline fishery in each region (LL ALL 1–6) and two additional Chinese/Taiwanese longline fisheries (LL TW-CH) fishing in regions 3 and 4. The separation of these fisheries from the general longline fisheries in those regions was required because of the different size composition of yellowfin tuna (and hence different selectivity) taken by the Chinese/Taiwanese fleet. This difference is thought to be related to operational characteristics (shallow night sets, as opposed to deep day sets).

Similarly, the Papua New Guinea longline fishery (LL PG 3), the eastern Australian longline (LL AU 5) fishery, Hawaiian longline fishery (LL HW 2, 4), and an aggregate of the Pacific Island domestic longline fisheries (LL PI 6) were included as separate fisheries in the model (Table 1).

A spatio-temporal analysis of size data from the Japanese longline fishery revealed that yellowfin caught within PNG waters, principally the Bismarck Sea, were consistently smaller than the fish caught in the remainder of Region 3 (Langley 2006c). Historically, this area accounted for a significant component of the total longline catch from Region 3 and, given the apparent difference in size selectivity; it was decided to separate this component of the fishery (LL BMK 3) from the principal longline fishery in Region 3 (LL ALL 3).

In the two equatorial regions, the purse-seine catch and effort (days searching and fishing) data were apportioned into two separate fisheries: effort on associated schools of tuna (log, anchored FAD, and drifting FAD sets) (PS ASS) and effort on unassociated schools (free schools) (PS UNS). The western equatorial region also includes a pole-and-line fishery that includes the catch and effort data from the Japanese distant-water pole-and-line fleet and the domestic pole-and-line fisheries (Solomon Islands and, historically, PNG) (PL ALL 3). Catches of yellowfin from this fishery peaked in the late 1970s–early 1980s (at about 8,000 mt per annum) but have been negligible since 2000.

The domestic fisheries of the Philippines were grouped into two separate fisheries largely based on the size of fish caught: a hand-line fishery catching large fish (PH HL 3) and a surface fishery (ring net, small-scale purse-seine, etc) catching smaller fish (PH MISC 3). In previous assessments, the Indonesian domestic fishery was combined with the Philippines surface fishery. However, there is considerably greater uncertainty associated with the recent catch from the Indonesian fishery and it was decided to disaggregate the composite fishery to enable a more comprehensive investigation of the uncertainty related to the Indonesian catch. The Indonesian surface fishery includes catch by pole-and-line, troll, gillnet, and other small-scale methods (ID MISC 3).

The assessment includes the yellowfin catch from the seasonal purse-seine (PS JP 1) and pole-and-line (PL JP 1) fisheries operated by the Japanese coastal fleet within MFCL region 1. Catches of yellowfin by the Japanese coastal surface fleet peaked at about 15,000 mt in the mid 1980s and steadily decline over the subsequent period to about 5,000 mt in recent years.

Two significant changes were made to the fishery definitions from the 2009 assessment. The first change was to transfer the catch (and associated effort) from the locally based longline fleets of Indonesia, the Philippines, FSM, and the Marshall Islands from the LL ALL fisheries in regions 3 and 4 to the corresponding LL TW-CH fisheries. This change follows a reconfiguration of the longline fisheries in the 2010 bigeye WCPO stock assessment (Harley et al. 2010) on the basis that the size composition (and therefore selectivity) of the catch by the locally based longline fleets was more comparable to the catch of the TW-CH longline fisheries than the Japanese distant-water and offshore fleets.

The second significant change was the restructuring of the purse-seine fisheries from the Philippines and Indonesian fleets. In previous assessments, these fisheries were included as a component of the Philippines and Indonesian domestic fisheries (PH MISC 3 and ID MISC 3). However, differences in the spatial distribution of the purse seine catch and the length composition of the associated catch relative to the other gear types warranted the additional resolution of these fisheries. The Philippines and Indonesian industrial purse-seine fishery operating to the east of 130° E longitude is included within the generic purse seine fisheries within region 3 (PS ASS 3 and PS UNS 3), while the purse seine fisheries operating within the national archipelagic waters were retained within the respective domestic fisheries (PH MISC 3 or ID MISC 3). A new fishery (PS PHID 3) was defined for the domestic purse-seine fisheries that operate beyond the national archipelagic waters and to the east of about 125° E longitude (see Williams 2011a, Fig. 6).

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 (Figure 9). This is consistent with the form in which the catch data are recorded for these fisheries.

Total catches included in the model are lower than the summation of total reported catches from the WCPFC due to the difficulties in spatially separating some of the aggregated catch estimates. For 1990–2007, model catches represent about 95% of the total WCPFC reported catch, with most of the discrepancy due to the catches from the “other” fisheries and longline fisheries. Historical (pre 1970) catches for all gears other than longline were not available for inclusion in the model data set (Figure 4). Total catches from 2010 are not considered complete due to late or incomplete reporting of catches from a number of the purse-seine and longline fleets.

As outlined in Section 2.2, two alternative sets of purse-seine catch data were used in the assessment. The first set consisted of uncorrected catches extracted from the OFP database of reported catches aggregated by 1° latitude, 1° longitude, month and flag. Recent studies have shown that these catch estimates are likely to substantially under-estimate the actual catch of yellowfin due to inaccurate reporting of the species catch composition on logsheets (Hampton and Williams 2011) and biases in the observer sampling procedures (grab sampling) (Lawson 2009 and 2010, Lawson & Sharples 2011). To address these biases, the catch data were corrected using a three-species disaggregation of the total purse seine catch using observer sampling data corrected for selection bias of grab sampling using the results of paired grab and spill samples. This resulted in considerably higher estimates of yellowfin catch particularly from associated sets (Figure 8). There remains a high level of uncertainty associated with these new estimates; however, on balance, the corrected catches are considered to be more reliable than the uncorrected catches. The corrected catches were used as the principal catch series in the assessment, while the uncorrected catches were incorporated in a sensitivity analysis (see below).

Effort data for the Philippines and Indonesian surface fisheries were unavailable. Where effort data are absent, the model directly computes fishing mortality consistent with the observed catch using a Newton-Raphson procedure.

Effort data units for purse seine fisheries are defined as days fishing and/or searching allocated to set types based on the proportion of total sets attributed to a specified set type (associated or unassociated sets) in logbook data. Similarly, effort data for the pole-and-line fisheries were defined as days fishing and/or searching.

For the principal longline fisheries (LL ALL 1–6), effective (or standardised) effort was derived from Japanese operational-level longline data using generalized linear models (GLM) and a delta-lognormal approach (Hoyle and Okamoto 2011). Use of operational level data permitted the analyses to a) compensate for some aspects of changing effort concentration in different areas through time, b) remove swordfish-targeted effort from the time series before 1976, and c) to compensate for changes in fishing power associated with individual vessels during the period after 1976. Alternative indices were derived from Japanese longline data aggregated at the 5 degree square and year-quarter level (Langley et al 2005, Hoyle and Okamoto 2011).

For region 6, limited operational data were available from a consistent set of Japanese vessels from the early 1970s onwards and, hence, no operational CPUE indices were available through this period. However, operational level CPUE indices were derived from logsheet data collected from the Taiwanese fleet operating in region 6 during 1964-2010, principally targeting albacore tuna (Chang et al. 2010). Trends in the Taiwanese delta-lognormal CPUE indices were comparable to the Japanese operational indices during the overlapping period. These indices were considered to represent the best available indices for region 6 due to the broad spatial and temporal coverage and the availability of associated information regarding target activity (gear configuration) and fishing vessel identifier.

The technique for standardising longline effort was also applied to determine the relative scaling of longline effort between regions. These scaling factors incorporated both the size of the region and the relative catch rate to estimate the relative level of exploitable longline biomass between regions (see Langley et al. 2005). The scaling factors were derived from the Japanese longline CPUE data from 1960–86 (Hoyle & Langley 2007).

The scaling factors allowed trends in longline CPUE among regions to be comparable indicators of exploitable biomass among regions. For each of the principal longline fisheries, the GLM standardised CPUE index was normalised to the mean of the GLM index from 1960–86 — the equivalent period for which the region scaling factors were derived. The normalised GLM index was then scaled by the respective regional scaling factor to account for the regional differences in the relative level of exploitable longline biomass between regions. Standardised effort was calculated by dividing the quarterly catch by the quarterly (scaled) CPUE index.

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

Time-series of catch-per-unit-effort (CPUE) for all fisheries are shown in Figure 10. The GLM standardised CPUE indices for the principal longline fisheries are presented in Figure 11.

Within the model, effort for each fishery was normalised to an average of 1.0 to assist numerical stability. The principal 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 among the fisheries.

3.5 Length-frequency 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). Each length-frequency observation consisted of the actual number of yellowfin tuna measured. A graphical representation of the availability of length (and weight) samples is provided in Figure 13. The data were collected from a variety of sampling programmes, which can be summarized as follows:

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.

Indonesia: Limited size data were obtained for the Indonesian domestic fisheries from the former IPTP database.

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 is 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.

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. The bias correction resulted in a decline in the overall length of the fish in the length samples from the associated purse-seine fisheries (PS ASS 3 and 4) and an increase in the length of fish in the samples from the unassociated purse-seine fishery in region 4 (PS UNA 4) (Figure 14). Insufficient data were available to correct the length samples from the period before 1996 and hence these data were excluded from the current assessment.

Longline: The majority of the historical data were collected by port sampling programmes for Japanese longliners unloading in Japan and from sampling aboard Japanese research and training vessels. For each temporal stratum, the composite length distribution for the fishery was derived following the approach described below. In recent years, length data from other longline fleets have been collected by OFP and national port sampling and observer programmes in the WCPO.

Japan coastal: Length data from the Japanese coastal purse-seine and pole-and-line fleets were provided by 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 NRIFS) 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.

Length data from the Japanese distant-water and offshore longline fleets were principally available aggregated in spatial strata of 10 degrees of latitude by 20 degrees of longitude. In previous assessments, quarterly length frequency distributions were derived for the principal longline fisheries weighted by the spatial distribution of the quarterly catch from the individual fishery. However, there is considerable spatial variation in the yellowfin tuna catch from the longline within the individual MFCL regions and changes in the spatial distribution of the longline catch have influenced the composite regional-specific length compositions.

For the current assessment, a new approach was applied to standardise the size frequency data to reduce the influence of spatial changes in the distribution of catch and sample collection (Hoyle & Langley 2011). The objective of this approach was to generate size frequency distributions that were more consistent with the underlying size distribution of the population within a region (mediated by the long-term average selectivity of the fishery).

The following procedure was applied to generate an aggregated year/quarter length composition for a specific region longline fishery from the Japanese length frequency data.

i. The average CPUE (number of fish per 100 hooks) for the Japanese longline fishery during 1960-1986 was determined for each of the 10*20 lat/long stratum that comprises a region (typically 6-9 cells per region). The CPUEs were applied to determine the relative weighting of the size data in each stratum. A maximum sample size was set at 1000 fish and the strata were assigned an individual sample size relative to the CPUE of the strata. The individual sample sizes for all strata in a region sum to 1000.

ii. The year/quarter samples (length measurements) from each 10*20 lat/long stratum were scaled to represent the individual sample size associated with the stratum.

iii. The rescaled numbers of fish (in each length interval) sampled from each stratum were combined, thereby, weighting the samples by the relative abundance of fish in each stratum.

These protocols result in samples from strata with a higher abundance of yellowfin having more influence in the composite length composition. Conversely, in a year/quarter where samples are only available from strata with lower yellowfin abundance a composite length composition will be generated, although the overall sample size will be lower and hence the individual length composition will have a lower influence on the model. The same approach was applied to derive the weight frequency compositions from the Japanese weight frequency data (Section 3.6).

The new approach enabled a larger proportion of the length samples to be retained within the model data set compared to the previous approach where samples were excluded if insufficient data were available from the strata where most of the catch was taken. For example, in previous assessments virtually all length samples collected from LL ALL 1 and LL ALL 2 from 1970 onwards were excluded from the model data set (Langley et al. 2009). In the current formulation, these data are retained but are assigned a lower effective sample size as most of the more recent samples were collected from areas within the regions that have a lower abundance of yellowfin (Table 3 and Figure 15).

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.

3.6 Weight-frequency data

A large data set of individual fish weights from the Japanese longline fisheries is available for inclusion in the assessment. For many other longline fleets, "packing list" data are available from export documentation, and these data are progressively being processed and incorporated into the assessment database. For this assessment, the available weight data (apart from those provided by Japan) originated from vessels unloading in various ports around the region from where tuna are exported, including Guam, Palau, FSM, Marshall Islands, Fiji, Papua New Guinea, Hawai'i, and eastern Australian ports. Weights samples from the Japanese coastal purse-seine fishery were also provided by NRIFSF.

All weight data were recorded as processed weights (usually recorded to the nearest kg). Processing methods varied among fleets requiring the application of fishery-specific conversion factors to standardise the processed weight data to whole fish weights. 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. For the principal longline fisheries, the weight data were aggregated following the spatially weighted approach described for the length data (see above). As for the length data, the new approach to processing the weight data resulted in a considerable increase in the number of samples being included in the model data set (compared to the 2009 assessment) (Table 4 and Figure 15).

The new protocol applied to the length and weight frequency data also resulted in a considerable improvement in the consistency of the size data between the two data sets. For each region, trends in average fish length and weight were generally consistent over the model period (Figure 16 and Figure 17).

3.7 Tagging data

A considerable amount of tagging data was available for incorporation into the MULTIFAN-CL analysis. Previous assessments have incorporated yellowfin tuna tag releases and returns from the OFP's Regional Tuna Tagging Project conducted during 1989−1992, a small number of releases in the Coral Sea and tag releases in the Hawaiian handline fishery (1996–2001). The tag release effort was spread throughout the tropical western Pacific, between approximately 120°E and 170°W (see Kaltongga 1998 for further details) (Table 5).

Two additional tag data sets were available for inclusion in the current assessment: 1) tag data from the recent Pacific Tuna Tagging Programme (PTTP) undertaken in mainly in the western tropical Pacific from Indonesia to the Gilbert Islands of Kiribati and 2) tagging conducted by NRIFSF in the north-western subtropical Pacific (region 1) over the last decade (Table 5).

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. Alternative model options were considered using three sets of the tagging data, including all tag data, excluding both the PTTP tags and the NRIFSF tags, or excluding the NRIFSF tags.

The complete data set includes a total of 127,227 releases which were classified into region/quarter 115 tag release groups. A total of 14,766 tag returns could be assigned to the fisheries included in the model. 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.

The returns from each length class of each tag release group were then 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.

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 fishery dynamics; (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) are given in Hampton and Fournier (2001) and Kleiber et al (2003) and are not repeated here. Rather, brief descriptions of the various processes are given, including information on structural assumptions, estimated parameters, priors and other types of penalties used to constrain the parameterisation. For convenience, these descriptions are summarized in Table 9. In addition, we describe the procedures followed for estimating the parameters of the model and the way in which stock assessment conclusions are drawn using a series of reference points.

4.1 Population dynamics

The model partitions the population into six spatial regions and 28 quarterly age-classes. 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). The last age-class comprises a "plus group" in which mortality and other characteristics are assumed to be constant. For the purpose of computing the spawning biomass, we assume a fixed maturity schedule (Table 9) consistent with the observations of Itano (2000). The population is "monitored" in the model at quarterly time steps, extending through a time window of 1952–2010. The main population dynamics processes are as follows:

4.1.1 Recruitment

Recruitment is the appearance of age-class 1 fish in the population. Yellowfin tuna spawning does not follow a clear seasonal pattern in the tropics but occurs sporadically when food supplies are plentiful (Itano 2000). We have 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 six 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 only a slight 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. The recommendations of the PAW also included a model option that estimated the value of steepness internally in the model. In this case, a beta-distributed prior was assumed on steepness of the SRR with a lower bound at 0.2, a mode = 0.85, and standard deviation = 0.16 (Figure 18) (equivalent to previous assessments).

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 (see Table 9). These processes are assumed to be regionally invariant.

As noted above, the population is partitioned into 28 quarterly age-classes. The number of older age classes allows for the possibility of significantly older and possibly larger fish in the early years of the fishery when exploitation rates were very low.

Previous analyses assuming a standard von Bertalanffy growth pattern indicated that there was substantial departure from the model, particularly for sizes up to about 80 cm. 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 through movement coefficients connecting 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. There are seven inter-regional boundaries in the model with movement possible across each in both directions. Four seasonal movements were allowed, each with their own movement coefficients. Thus there is a need for $2 \times 7 \times 4 = 56$ movement parameters. The seasonal pattern of movement persists from year to year with no allowance for longer-term variation in movement. A previous (2004) assessment had included the estimation of age-specific movement. However, there are limited data available to estimate these parameters and for the current assessment movement coefficients were 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 Reproductive potential

Reproductive output at age, which is used to derive spawning biomass, was recalculated for the 2009 assessment (Hoyle et al. 2009). The calculations were based on data collected in the WCPO, and based on relative reproductive potential rather than (as previously) the relative biomass of both sexes above the age of female maturity. The calculations used an approach 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 female 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 19). 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.

4.1.6 Natural mortality

Natural mortality (*M*) was held fixed at pre-determined age-specific levels. Natural mortality at age was recalculated for the 2009 assessment using an approach previously applied to bigeye (Watters and Maunder 2001; Harley and Maunder 2003) and yellowfin (Maunder and Watters 2001) tunas in the EPO, and to albacore (Hoyle 2008) and bigeye (Hoyle and Nicol 2008) tunas in the WCPO. The 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. Details of the calculations are provided in Hoyle et al. (2009).

Previous WCPO yellowfin assessments have applied a natural mortality ogive calculated using EPO data (Maunder and Watters 2001). The revised schedule has a slightly lower level of natural mortality for the 11–14 age classes. The externally-estimated *M*-at-age is shown in Figure 20.

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. In previous assessments, we have modelled selectivity with separate age-specific coefficients (with a range of 0–1), but constraining the parameterisation with smoothing penalties. This has the disadvantage of requiring a large number of parameters to describe selectivity. In this assessment, we have used a method based on a cubic spline interpolation to estimate age-specific selectivity. 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.

Selectivity is assumed to be fishery-specific and time-invariant. Selectivity coefficients for "main" longline fisheries LL ALL 1 and LL ALL 2 (northern fisheries) were constrained to be equal, as were LL ALL 3–6 (equatorial and southern fisheries) and the Chinese/Taiwanese fisheries (LL TW-CH 3 and 4). For the two latter fisheries, selectivity was parameterised using a logistic functional form rather than the cubic spline method. For all fisheries, the selectivity for the last four age-classes, for which the mean lengths are very similar, was constrained to be equal.

The Chinese/Taiwanese longline fisheries (LL TW-CH 3 and 4) have 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 LL 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.

4.2.2 Catchability

Catchability was allowed to vary slowly over time (akin to a random walk) for all purse seine fisheries, the Philippines and Indonesian fisheries, the Australian, Taiwanese/Chinese, Hawaii, PNG (LL PNG 3 & LL BMK 3) and other Pacific-Island longline fisheries, 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 the Philippines and Indonesian surface fisheries (PH MISC 3, ID MISC 3 and PS PHID 3), no effort estimates were available. In the absence of effort data, MFCL estimates partial fishing mortalities 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.

The "main" longline fisheries were grouped for the purpose of initial catchability, and time-series variation was assumed not to occur in this group. 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.

Catchability for all fisheries apart from the Philippines and Indonesian fisheries (in which the data were based on annual estimates) was allowed to vary seasonally.

4.2.3 Effort deviations

Effort deviations, constrained by prior distributions of zero mean, were used to model the random variation in the effort – fishing mortality relationship. For the Philippines handline fishery, the purse seine fisheries and the Australian, Hawaii and Taiwanese-Chinese longline fisheries, the variance was set at a moderate level (approximating a CV of 0.2).

The region-specific longline CPUE indices represent the principal indices of stock abundance in the assessment model. Hence, the extent that the model can deviate from the CPUE indices is moderated by the penalty weights assigned to the standardised effort series for the longline fisheries. However, the precision of the CPUE indices varies temporally and among regions and, therefore, it is appropriate to implement a relative weighting on the individual effort observations. The CPUE indices from the region 3 longline fishery are 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.

The CPUE indices from region 3 were assumed to have an average coefficient of variation (CV) of 0.2 for the period with the most comprehensive data set (1960-86). A CV was then calculated for each effort observation from LL 3 by scaling the actual CV of the individual CPUE indices (from the GLM) relative to the mean of the CVs for individual observations from 1960-86. Similarly, the individual CVs of the CPUE indices from the other regions were scaled relative to the region 3 base period. The resulting scaled CVs were transformed to an effort penalty for each longline CPUE observation. The higher effort penalties associated with less precise CPUE indices means that these indices are less influential in the assessment model.

The relative precision of the region-specific longline CPUE indices varies depending on the CPUE data sets (aggregated vs. operational). The aggregated CPUE indices from regions 2, 5 and 6 were assigned a considerably lower precision than the corresponding operational CPUE indices (Table 6). For the Japanese operational indices, the precision of the CPUE indices for region 6 were considerably lower than for the other regions, principally from 1980 onwards (Figure 12). The low precision of these CPUE indices was one of the main reasons for applying the Taiwanese CPUE indices from region 6 in the reference model (Table 6).

This approach represented a refinement on the approach used in the 2009 assessment whereby the penalty on the effort deviates for each region was set at a level that corresponded to an average CV of 0.2 over the entire model period and allowing for temporal variation in the CV (in proportion to the standard error of the individual indices).

4.3 Dynamics of tagged fish

4.3.1 Tag mixing

In general, the population dynamics of the tagged and untagged populations are governed by the same model structures and parameters. An obvious exception to this is recruitment, which for the tagged population is simply the release of tagged fish. 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. 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 desensitises 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 principal, 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 as the composition and operation of individual fisheries change. Consequently, the inclusion of the tagging data from the PTTP necessitated facilitating the estimation of fishery tag reporting rates that are specific to the individual tagging programmes. This flexibility in the estimation of tag reporting rates has been accommodated in recent developments to MFCL.

For each tagging programme, reporting rates were estimated for each of the fisheries that account for most of the tag recoveries, most notably the two equatorial purse seine fisheries, the domestic fisheries of Philippines and Indonesia, the equatorial pole-and-line fishery, Australian and Hawaiian domestic longline fisheries and the domestic Japanese fisheries. Limited numbers of tags have been recovered from the from the broad-scale longline fisheries (LL ALL 1-6 and TW-CN 3 & 4) and a single tag reporting rate, independent of tagging programme, was estimated for these fisheries.

For the estimation of the RTTP reporting rates, a relatively informative priors was provided for the Philippines and Indonesian domestic fisheries and the purse seine fisheries, as independent estimates of reporting rates for these fisheries were available from tag seeding experiments and other information (Hampton 1997). The external estimates of reporting rate for the purse-seine fisheries were modified by the estimates of average tag loss and tagger-specific mortality of tagged fish (Hoyle 2011). For the PTTP, informative priors were formulated for the two equatorial purse seine fisheries based on Hoyle (2011).

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.

4.4 Observation models for the data

There are 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 are 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 are 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 is 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 the longline fisheries derived using the protocols described in Section 3.5 are considered to represent more reliable indicators of the trends in the size composition of the population over time (compared to previous years). On this basis, the size data were considered to be moderately informative and were given an according weighting in the likelihood function; 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 is 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 means that these data are likely to be more influential than in previous assessments. The influence of the Japanese longline size data was explored using lower (n/50) and higher (n/10) effective sample sizes within the suite of model sensitivities.

A log-likelihood component for the tag data was computed using a negative binomial distribution in which fishery-specific variance parameters were estimated from the data. 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. 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 Principal model runs

Following the recommendations of the PAW, an initial set of model options was considered that contrasted the two sets of longline CPUE indices derived from either the aggregated data (LLcpueAG) or the operational data (LLcpueOP). However, the operational data were limited for region 6 and CPUE indices for 1980 onwards were either unavailable or poorly determined. This led to the inclusion of the Taiwanese longline CPUE index as the principal CPUE for region 6 (TWcpueR6). The CPUE indices derived from the operational data are considered preferable to the aggregated CPUE indices as they explicitly incorporate temporal changes in the fleet structure – a key factor in influencing the efficiency of the fishing fleet over time.

The current assessment is the first time that tagging data from the PTTP are available for inclusion in the assessment models. To investigate the influence of these data the alternative CPUE options were compared with tagging data sets that excluded (RTTP) or included (PTTP) the available data from the PTTP.

Of the six principal model options, the model that included the Japanese (regions 1-5) and Taiwanese (region 6) CPUE indices and the PTTP tagging data was selected as the reference case (LLcpueOP_TWcpueR6_PTTP) on the basis that the model included the preferred CPUE indices and the complete set of tagging data (excluding Japanese tag releases). This model was used to illustrate the key diagnostics that are common to many of the model options considered. The model also served as the basis for the range of sensitivity analyses conducted.

4.6 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 was performed by an efficient optimization using exact derivatives with respect to the model parameters. Estimation was conducted in a series of phases, the first of which used arbitrary starting values for most parameters. A bash shell script, *doitall.yft*, documenting the phased procedure is provided in Appendix A. Some parameters were assigned specified starting values consistent with available biological information. The values of these parameters are provided in the *yft.ini* file (Appendix B)[3].

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[3] 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. (2003).

The Hessian matrix computed at the mode of the posterior distribution was used to obtain estimates of the covariance matrix, which was used in combination with the Delta method to compute approximate confidence intervals for parameters of interest.

4.7 Stock assessment interpretation methods

Several ancillary analyses are conducted in order to interpret the results of the model 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 integrated into the model, and therefore confidence intervals for quantities of interest are available using the Hessian-Delta approach.

4.7.1 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, 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.

4.7.2 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 ($\widetilde{SB}_{MSY}$) 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. The confidence intervals of these metrics were estimated using a likelihood profile technique.

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 2006–2009. The last year in which a complete set of catch and effort data is available for all fisheries is 2009. We do not include 2010 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 (1952–2010). 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.

4.8 Comparison with the 2009 assessment

There are five main differences in the input data and structural assumptions of the current assessment compared to the base-case from the 2009 assessment (CPUElow_samplehigh_Qincr).

i. Fixing the steepness parameter (*h*) of the SRR at 0.8 in the reference case rather than 0.75 as used in the 2009 assessment.

ii. Incorporation of CPUE indices derived from operational catch and effort data from the Japanese (regions 1-5) and Taiwanese (region 6) longline fishery. By comparison, in 2009 CPUE indices were derived from Japanese aggregated catch and effort data and were corrected for long-term changes in catchability based on an external analysis.

iii. A modified approach to determining the individual effort deviation penalties applied to the longline standardised effort series.

iv. A reassignment of the catches for the local longline fisheries in Micronesia from the principal longline fisheries in region 3 and 4 (LL3 and LL4) to the corresponding TW-CN longline fishery. This follows changes to the bigeye stock assessment model on the basis that the size composition of the catch from these local fleets is more comparable to the size composition of the TW-CN longline catch.

v. A revised protocol for deriving the length- and weight size compositions for the principal longline fisheries.

vi. The correction of the purse-seine length frequency data to account for sampling bias and the exclusion of length data from the fisheries prior to 1996 (bias correction not available) (Lawson 2011).

vii. A revision of the corrected (spill sample) purse-seine fishery catch estimates (Lawson and Sharples 2011). The main difference was in PS ASS 3 where the time series of corrected catches were approximately 10% lower than the corrected catches in the 2009 assessment.

viii. Refinement to the Philippines and Indonesian fishery definitions, including the definition of a new fishery encompassing the Philippines and Indonesian purse-seine fleets operating east of about 125° E and outside of archipelagic waters.

ix. Inclusion of the PTTP tagging data.

For comparison to the 2009 stock assessment, a step-wise sequence of models was formulated that modified the 2009 base-case model to sequentially incorporate each of the changes identified above, with the exception of the inclusion of the PTTP tag data. The sequence of models encompassed the model period of the 2009 assessment (1952-2008) (Table 7).

4.9 Sensitivity analyses

The sensitivity analyses focussed on a number of key model uncertainties. Initially, the sensitivities were examined as a single change to the reference model (LLcpueOP_TWcpueR6_PTTP) although a more comprehensive analysis of the range of sensitivities was undertaken to investigate the interactions between the various sensitivities (see below).

The key uncertainties identified in the current assessment are the assumed level of steepness of the SRR, catch history of the purse-seine fisheries, and the relative weighting of the LL ALL 1-6 length and weight frequency data (Table 10).

The reference model assumed a value of 0.80 for the steepness of the SRR; model sensitivities included alternative values of 0.65 and 0.95.

As noted above, corrected catches from the purse-seine fisheries (PS ASS, PS UNA 3 & 4) are substantially higher than previously reported, principally for the associated fisheries. However, the current estimates are based on limited sampling data and are considered preliminary. The sensitivity of the model results to the assumed level of purse-seine catch was examined by comparing the base model results to a model with the purse-seine catches determined using the previous methodology ("*PSold*"). The overall level of purse-seine catch in the alternative catch history is approximately 50% of the recent level of catch from the associated fisheries, while the unassociated catches are comparable between the two data sets (Figure 8).

The reference model assumed that the LL ALL 1-6 length and weight frequency data were relatively influential, assigning an effective sample size of 0.2 times the number of fish in the individual samples (n/20). The relative influence of the size frequency data was increased (n/10) and decreased (n/50) in separate model sensitivities.

The interactions between the each of the principal models and the various model sensitivities were assessed by conducting model runs that combined the various model options described above. This represented a grid of 18 combinations of the following factors: the relative weighting of the LL ALL size frequency data (n/10, n/20, and n/50), steepness of the SRR (0.65, 0.80, or 0.95) and purse-seine catch history (corrected or uncorrected catch). 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 (principally related to the estimation of growth).

5 Results

5.1 Comparison with 2009 assessment

A range of preliminary model runs were conducted to examine the impact of the key changes in the current assessment compared to the 2009 assessment (as described in Section 4.8). The structural assumptions of the model are largely unchanged from the 2009 assessment, with the exception of a reconfiguration of the Philippines and Indonesian fisheries; however, there have been some large changes to many of the key data sets, specifically the longline CPUE indices, Japanese longline size frequency data, corrected purse-seine catches, and the purse seine length frequency data.

The introduction of each of these changes in the key data sets has resulted in a more pessimistic stock assessment, reducing the overall biomass level and, correspondingly, the estimate of *MSY* (estimated for the average 2004-2007 fishery selectivity, consistent with the 2009 assessment) (Figure 21 and Table 8). Almost all of these changes have also resulted in a decline in the spawning biomass based reference point $SB_{current}/\widetilde{SB}_{MSY}$ and an increase in the fishing mortality rate relative to F_{MSY} ($F_{current}/\widetilde{F}_{MSY}$) (Table 8). The exception is the inclusion of the revised corrected purse-seine catch history.

The reconfiguration of the Philippines and Indonesian fisheries also resulted in a more pessimistic stock status. Overall, the suite of changes in the assessment resulted in the 2004-2007 stock status changing from $SB_{current}/\widetilde{SB}_{MSY}$ from 1.90 to 1.24 with the comparable steepness assumption of 0.8, while $F_{current}/\widetilde{F}_{MSY}$ increased from 0.53 to 0.94 (Table 8).

The inclusion of the additional catch, effort and size data from 2009 and 2010 resulted in a decrease in $F_{current}/\widetilde{F}_{MSY}$ for 2004-2007 from 0.94 to 0.86, while the inclusion of the PTTP tags reduced $F_{current}/\widetilde{F}_{MSY}$ further (0.77) and increased the estimate of *MSY* (Table 8). The overall level of biomass estimated from these two current models is more comparable to the 2009 base case model (see below).

5.2 Current assessment

As noted in the previous section, there are marked differences in the results of some the model options compared to 2009 "base case" assessment. These differences are essentially driven by changes in the input data rather than the underlying model assumptions. The current assessment investigates the influence of the key data sets in the model, principally the longline CPUE indices, longline size data and the inclusion of the tagging data from the PTTP. The impacts of a range of key model assumptions are also investigated. Summary results are presented for all model options; however, a single model option "LLcpueOP_TWcpueR6_PTTP" was selected for a more detailed analysis in preference to other model options (and denoted the "reference case"). In addition, a separate model was configured for the core area of the yellowfin fishery (region 3) and the results from this model were contrasted with the reference model enabling some insight into some of the influential structural assumptions of the model.

The main stock assessment-related results are summarised for all analyses in the relevant sections (below).

5.3 Fit statistics and convergence

A summary of the fit statistics for all model options is presented in Table 12**Error! Reference source not found.**. The fit statistics are not directly comparable among most of the principal model runs and sensitivities due to differences in the input data and structural assumptions. Consequently, the fit statistics alone do not provide a criterion for selecting an individual model or set of models in preference to other models.

5.4 Fit diagnostics (reference case)

We can assess 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:

- The log total catch residuals by fishery are shown in Figure 22. The residuals are small and, for most fisheries, generally show even distributions about zero. This reflects the high penalty applied to the catch deviations in the model likelihood.
- For most fisheries, there is a reasonable fit to the length data for the longline fisheries as revealed from a comparison of the observed and predicted length data aggregated over time (Figure 23). However, for some of the longline fisheries (LL TW-CH 4, and LL HW 4) there is a systematic lack of fit – the model over-estimates the proportion of fish in the larger length classes and, correspondingly, under-estimates the proportion of fish in the smaller length classes.
- Some of the discrepancies between the observed and predicted length data appear to be due to temporal trends in the fit to the size data over time. For the region 4 longline fisheries, most of the lack of fit is apparent from 2000 onwards; the observed lengths from the LL TW-CH 4 fishery are lower than predicted, while the observed lengths from the LL 4 fishery are higher than predicted (Figure 24). The other principal longline fisheries also exhibit periods with a systematic lack of fit to the length data. Most notable is the lack of fit to the smaller length of fish sampled from the LL 3 from the mid 1990s onwards. This is evident in the pattern of positive residuals for the smaller length classes (90–110 cm FL) during this period (Figure 25).
- There is a general lack of fit to the individual length samples from the LL ALL 2 fishery (Figure 24). However, there is considerable variability in the individual samples and the samples were assigned a relatively low sample size due to the unrepresentative nature of the individual samples. Hence, the model has sufficient freedom to deviate from the individual length observations.
- For the principal purse-seine fisheries, there is a good fit to the aggregated length data, with the exception of the unassociated purse-seine fishery in region 4 (PS UNS 4) (Figure 23). For this fishery, the model under-estimates the observed length composition for most of the individual samples (Figure 24). This systematic lack of fit to the length data suggests the current assumption of a common selectivity between the PS UNS 3 and 4 fisheries may not be valid.
- There is now relatively comprehensive sampling available for the two Philippines domestic fisheries (PH MISC 3 and PH HL 3) and the model produces a reasonable fits these data (Figure 23 and Figure 24). However, a number of the other domestic fisheries either have limited samples available (ID MISC 3 and PS IDPH 3) and/or there is considerable variability among the individual length observations (PS IDPH 3, PS JP 1 and PL JP 1) (Figure 24). The length data from the PS JP 1 fishery are particularly problematic as they reveal a rapid temporal shift in the size of fish caught during the mid 1980s. This is indicative of a significant change in the operation of the fishery and should be accommodated by defining separate two separate fisheries (pre- and

post 1985). A sensitivity analysis was conducted to investigate the impact of such a change in the structure of the fisheries.

- For most of the longline fisheries, there is a good fit to the aggregated weight frequency data (Figure 26). However, there are several fisheries (LL PG 3 and LL AU 5) with a strong modal structure in the weight distribution for which the model does not reliably predict the size composition, particularly the proportion of fish in the mode of the weight frequency distribution (at about 20–25 kg). The model also tends to over-estimate the size of fish in the LL 3 fishery (Figure 26). This lack of fit is principally attributable to two periods when the observed fish weights were considerably lower (throughout the 1970s and from the mid 1990s to mid 2000s) (Figure 27). This is evident in the pattern of the residuals from the model fit to these data (Figure 28).

- There is a systematic lack of fit to the weight frequency data from the LL 6 fishery with the observed weight composition of the catch being consistently larger than the model predictions (Figure 26 and Figure 27). The weight frequency data from the fishery were assigned a relatively low sample size and consequently the model is able to deviate from these weight frequency observations due to the common selectivity among the principal longline fisheries (LL 3-6).

- Overall, the model predicts a decline (of approximately 3-5kg) in the weight composition of the catch from most of the main longline fisheries over the entire model period. This is generally consistent with the observed decline in the weight of fish sampled from the catch for those regions where samples are available for the entire period (LL 1-4) (Figure 26).

- The fit of the model to the tagging data compiled by calendar time is shown in Figure 29. There are two main tag recovery periods; recoveries associated with the RTTP during 1993–94 and recoveries associated with the PTTP during 2007–2010. There is a very good fit to the observed recoveries from the RTTP (Figure 29). The model also fits the general trend in the number of recoveries from the PTTP, although there is considerably more variability in the number of recoveries between successive quarters than predicted by the model (Figure 29).

- Temporal trends in observed and predicted tag recoveries were examined for the four main fishery groupings that accounted for most of the PTTP tag recoveries (Figure 30). For the PS PHID 3 fishery, predicted tag returns by quarter were generally higher than observed, although for three quarter (in late 2009 and early 2010) the model under-estimated the number of recoveries. There was also a marked lack of fit to the tag recoveries from the ID MISC 3 fishery for the two quarters with the largest number of returns. For the purse-seine fishery in region 3 (combining both PS ASS and PS UNS for the purpose of tag recoveries) the model predictions of quarterly tag recoveries were broadly consistent with the observations, although in most quarters the number of tags predicted was generally greater than observed. Tag recoveries were relatively low in the region 4 purse seine fishery and the predicted number of recoveries were broadly comparable, with the exception of the single quarter when a relatively large number of tags were recovered (Figure 30).

- The fit of the model to the aggregated tagging data compiled by time at liberty is shown in Figure 31.This is an over-estimation of tag returns for about 6−11 quarters at liberty (Figure 31). The model also over-estimates the recovery of fish at liberty for longer periods (greater than 12 quarters), although the number of observations is small. The source of this discrepancy was investigated by examining the age-specific tag recoveries of PTTP from the two purse-seine tag groups (Figure 32). Both groups exhibited an age specific bias in the tag recoveries that was consistent with the recoveries by period at liberty. For age classes 6-10 the predicted recovery number of tag recoveries was consistently higher than observed (Figure 32). For both fisheries, the model under-estimated the number of recoveries from age class 4.

- The overall consistency of the model with the observed effort data can be examined in plots of effort deviations against time for each fishery. If the model is coherent with the effort data, we would expect an even scatter of effort deviations about zero. On the other hand, if there was an obvious trend in the effort deviations with time, this may indicate that a trend in catchability had occurred and that this had not been sufficiently captured by the model. Of particular interest are the effort deviations for the LL ALL 1–6 longline fisheries, which were constrained to have the same average catchability and to have no year-to-year variation (i.e., catchability deviations were assumed to be zero) (Figure 33).

- For LL ALL 3 and 6, the very low effort deviations during the early period is an artefact of the lack of standardised effort data for the period. During this period, the model has freedom to estimate deviates from the notional level of effort and thereby fit the observed catch from these two fisheries (Figure 33).
- Overall, the effort deviations for the main longline fisheries are relatively low and do not exhibit any systematic trends over the model period (Figure 33) indicating that the model estimates of longline exploitable biomass trends are consistent with the longline CPUE indices. One notable exception is the recent decline in the effort deviates for LL ALL 4 indicating that the decline in the CPUE indices has been considerably higher than predicted by the model. This suggests a conflict between the CPUE indices and other key data (seemingly the size composition data from the longline fisheries).

5.5 Model parameter estimates (reference case unless otherwise stated)

5.5.1 Growth

The estimated growth curve is shown in Figure 34. The non-von Bertalanffy growth of juvenile yellowfin is clearly evident, with near-linear growth in the 50–100 cm size range. The estimated growth pattern from the reference model is similar to that observed in the otolith length-increment data (Figure 35) (Lehodey and Leroy 1999). However, growth increments derived from tag data are generally lower than predicted by the estimated growth curve, particularly for shorter-term release periods (Figure 35).

The mean length at age estimates for the reference case are very similar to the values derived for the 2009 base case, although the estimates of variance of length at age are somewhat greater. Compared to the reference model, the growth parameter estimates for the Region3 model considerably with a higher *k*, a lower value of length at maximum age (139.74 vs. 150.86 cm) and lower variability of length at age. However, these estimates of growth for region 3 differ considerably from the 2007 stock assessment which estimated growth rates for the 2–7 age classes that were substantially lower than the growth rates estimated for the WCPO model.

5.5.2 Natural mortality

As for recent assessments, natural mortality was not estimated in any of the analyses and a fixed age-specific mortality function was applied (see Figure 20). This issue may be re-visited in future assessments using biologically reasonable functional forms for *M*-at-age.

5.5.3 Movement

The model estimates very large movements of fish southward from region 1 to region 3 in the second quarter (21% of all fish moving) and third quarter (40%) of the year and from region 5 to region 3 in the first quarter (14%) (Figure 36). There is an estimated reciprocal movement of 6% of the fish between region 3 and region 4 in the first quarter and a further 6% movement of fish from region 4 to region 3 in the third quarter. Movement rates between all other adjacent regions are low (less than 3%) 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 tags over the main recovery period (Figure 37). Most tag releases within region 3 and region 4 were recovered within the region of release although there was also a transfer of tags between the two regions. The predicted tag movements from region 4 to region 3 are generally consistent with the observed tag recoveries, although the model tended to over-estimate the transfer of tags from region 3 to region 4 (Figure 37). The model also predicted the observed movement of tags from region 5 to region 3. In the reference model, there were limited tag releases and recoveries to inform the model regarding the movement of fish among the other combinations of regions.

The large movements of fish from region 1 to region 3 are comparable to previous assessments. An alternative model was investigated that incorporated the recent Japanese tagging data (LLcpueOP_TWcpueR6_PTTP_JPPS_JPtags). This model also estimated large movement coefficients from region 1 to region 3. However, this is not inconsistent with the observed recovery of some Japanese tags from region3 (Table 5).

The distribution of regional biomass by source region derived from a simulation using the movement coefficients is presented in Figure 38. The simulation indicates that most biomass within a region is sourced from recruitment within the region, particularly for regions 1, 2, 5 and 6. The high movement rates from region 1 to region 3 results in a substantial proportion (about 15%) of the region 3 biomass originating from recruitment in region 1. Recruitment in region 1 is also estimated to contribute to the biomass in region 4, sourced via region 3.

The mixing between the equatorial regions results in a significant proportion of biomass (45%) in the eastern region (region 4) being sourced from recruitment in the western region (region 3) (Figure 38).

5.5.4 Selectivity

Estimated selectivity coefficients are generally consistent with expectation with longline fisheries principally selecting larger, older fish and the associated purse-seine sets (FAD and log sets) catching smaller yellowfin (Figure 39). Unassociated purse-seine sets generally catch substantially larger fish than associated sets and are estimated to have full selectivity for the older age classes. The selectivity of the combined Philippines and Indonesia purse-seine fishery (PS PHID 3) represents a composite of the PS ASS 3 and PS UNS 3 fisheries.

Limited size data are available for the Indonesian surface fishery (ID MISC 3) and the model estimates that catches from this fishery are comprised of young fish (the 2–3 age classes).

The Philippines surface fishery (PH MISC 3), the Japanese coastal pole-and-line fishery (PL JP 1) and the equatorial pole-and-line fishery (PL ALL 3) principally catch small fish; however, there are also some observations of larger fish in the catch that result in a high selectivity of older fish also.

For the Japanese purse-seine fishery (PS JP 1), there is an apparent shift in the size composition of the catch from large fish to small fish in the mid 1980s (see Figure 24). The reference model assumes a single selectivity for the entire period with a high selectivity for older fish. The model option that incorporated the recent Japanese tagging data (LLcpueOP_TWcpueR6_PTTP_JPPS_JPtags) also estimated separate selectivities for the two time periods, resulting in a considerable improvement in the fit to the length frequency data from the fishery.

For the principal longline fisheries LL ALL 3–6, 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 TW-CH fisheries. The functional form of the (common) selectivity of the latter fisheries is constrained to have full selectivity for the oldest age classes. The historical distant-water longline fishery in PNG waters (LL BMK 3) has a higher selectivity for younger fish (age classes 6–8) than the principal longline fishery in the region (LL ALL 3).

5.5.5 Catchability

Time-series changes in catchability are evident for several fisheries (Figure 40). Catchability in the principal longline fisheries (LL ALL 1–6) has been assumed to be constant over time. There is evidence of a strong increase in catchability in the purse seine fisheries up to the early 2000s, although catchability for the associated purse-seine fisheries (PS ASS 3 and 4) is predicted to have declined over the more recent years.

The catchability of the Japanese purse-seine fishery (PS JP 1) is estimated to have declined from the mid 1980s onwards corresponding to the apparent change in the size composition of the catch.

5.5.6 Tag-reporting rates

Estimated tag-reporting rates by fishery are shown in Figure 41. Tag reporting rates for individual method fisheries are likely to differ among tagging programmes and hence, specific tag reporting rates were estimated for each tagging programme for the main fisheries that recover tags. 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.

For both the RTTP and PTTP, the estimates of reporting rate for the purse seine fisheries in region 3 and 4 were estimated to be higher than the mode of their prior distributions and tended to vary considerably between regions. The estimates for the longline fisheries are highly variable, ranging from near zero to the upper limit allowed (0.9). However, the estimated reporting rates from the longline fisheries are based on a very small number 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 (PL ALL 3), a fishery that accounted for a moderate number of tag recoveries, is estimated at the upper bound on the reporting rate (0.9). Most of the reporting rate estimates for the Philippines and Indonesian domestic fisheries are relatively high, particularly for the PS PHID 3 fishery (Figure 41).

5.6 Stock assessment results

5.6.1 Recruitment

The reference case recruitment estimates (aggregated by year for ease of display) for each region and the WCPO are shown in Figure 42. Overall recruitment is highest within region 3, while moderate levels of recruitment also occur within regions 1, 4 and 5. The regional estimates display large interannual variability and variation on longer time scales. Recruitment is estimated to be high in most regions during the 1950s. Recruitment in region 3 remains relatively high during the 1960s and 1970s, declines through the 1980s and remains low through the 1990s before recovering to the higher level during the 2000s (Figure 42).

The recruitment trend in region 3 strongly influences the trend of the aggregate WCPO recruitment estimates; total recruitment was very high during the 1950s and relatively low during the 1990s. Recent (2001−10) WCPO recruitment is estimated to be 85% of the long-term average (Figure 42).

A comparison of WCPO recruitment estimates for the six principal model options, including the reference model is provided in Figure 43. The model options all exhibit a trend in overall recruitment that is comparable to the reference model, although the overall magnitude of recruitment is lower for the model option with the aggregated CPUE indices and incorporating PTTP tags (LLcpueAG_PTTP).

5.6.2 Biomass

The estimated total and spawning biomass for each region is presented in Figure 44 and Figure 45. Biomass is estimated to have declined relatively steadily over the model period with most of the decline occurring within regions 3 and, to a lesser extent, region 4. The other regions account for a small proportion of the WCPO biomass throughout the model period. Over the last decade (2001-10), regions 3 and 4 have accounted for 50% and 30% of the total yellowfin biomass, respectively.

The trends in biomass are more variable among the other regions (1, 2, 5 and 6) (Figure 46), generally reflecting the differences in the CPUE trends from the main longline fisheries (LL ALL 1−6) (Figure 47). There are some discrepancies between the CPUE trends and the temporal trend in the longline exploitable biomass, most notably in region 4 over the last decade with the CPUE indices exhibiting a greater decline than the exploitable biomass (Figure 47).

The comparison of biomass trends for the principal model options is shown in Figure 48a. The trends in biomass are comparable for the six model options and all models estimate a similar level of biomass during the last 10-15 years. However, the historical level of biomass varies among model options with the LLcpueAG model options having a significantly lower level of biomass during the 1950s. This may be attributable to the lack of operational CPUE indices for the principal region (3) prior to 1959 resulting in the models having greater freedom to fit the other sources of data (the larger fish in the longline size data) during the early period.

The range of model sensitivities exhibited similar trends in total biomass to the reference model (Figure 48b). However, the level of spawning biomass estimated from the single region 3 model was considerably higher than and the spawning biomass within region 3 from the reference model. The discrepancy between the region 3 model and the WCPO model was considerably reduced when the constraints related to LL ALL 3 selectivity (common among LL ALL 3-6) and the purse seine selectivities (common between PS ASS 3 & 4 and PS UNS 3 & 4) were removed (model _splitSelectR3) (Figure 49).

5.6.3 Fishing mortality

Average fishing mortality rates for juvenile and adult age-classes increase strongly from 1970 for all the model options and are at the highest level in the most recent years (Figure 50). The reference model and most of the key sensitivities all estimate comparable levels of fishing mortality for juvenile and adult age-classes throughout the model period. Recent fishing mortality rates are somewhat lower for the *splitSelectR3* model option.

For the reference model, recent exploitation rates are high on the youngest age classes due to the impact of the associated purse-seine fishery and the Philippines and Indonesian fisheries in region 3 (PS ASS 3, PH MISC 3, ID MISC 3 and PS PHID 3) (Figure 51 and Figure 52). There is also a high exploitation rate on the older age classes (6–16 age classes), largely attributable to the equatorial purse-seine fisheries. Overall, there has been a substantial decline in the proportion of old (greater than age class 10) fish in the population since the mid 1970s (Figure 52). Amongst the regions, recent exploitation rates were highest in region 3 and comparatively low in all other regions (Figure 51).

The recent age specific fishing mortality is estimated to be considerably higher for the model options that exclude the PTTP tag data, particularly for the age classes vulnerable to the associated (age classes 3-4) and unassociated purse seine fisheries (age classes 8-20) (Figure 53).

5.6.4 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. The two trajectories are plotted in Figure 54. It is evident that the impact has been substantial in region 3 and moderate in region 4, with the impact increasing steadily from the early 1980s. Impacts on total biomass are relatively low (9%) in region 2 and moderate (15-25%) in regions 1, 5 and 6.

Overall, the impact of fishing has reduced the current total biomass in region 3 to about 42% of the unexploited level, while the current total WCPO biomass is at about 53% of unexploited levels (Figure 56) sustained by the lower impacts outside of the equatorial regions. Fishery impacts have reduced the total biomass in region 4 to about 63% of unexploited levels. Fishery impacts on the spawning biomass are considerably higher than for total biomass, with spawning biomass in region 3 and WCPO spawning biomass at about 30% and 44% of the unexploited levels, respectively (Figure 55 and Figure 57).

A comparison of relative impact of fishing on the entire WCPO biomass from a range of model options is presented in Figure 58. Overall fishery impacts are comparable for all model options with the exception of the *splitSelectR3* model which estimates slightly lower impacts in the most recent years.

It is possible to classify the fishery impact on the spawning biomass ($1 - SB_t / SB_{0t}$) or total biomass ($1 - B_t / B_{0t}$) to specific fishery components in order to see which types of fishing activity have the largest impact on spawning biomass (Figure 59) and total biomass (Figure 60). Within each region, the relative impacts of specific fisheries on spawning and total biomass are comparable. In region 3, the Philippines/Indonesian domestic fisheries and the associated purse-seine fishery have the greatest impact. The unassociated purse seine fishery (PS UNS 3) has a moderate impact.

In region 4, the purse seine fishery is responsible for most of the impact, while the Philippines/Indonesian fisheries accounts for about 20% of the impact due to the direct movement of fish from region 3 to region 4. Similarly, while the direct fishery impacts are moderately low in regions 1, 2 and 5, the high impacts on the stock in region 3 are reducing the movement of fish to these adjacent regions. Within region 1, there are the additional impacts of the pole-and-line and purse-seine fisheries (PL JP 1 & PS JP 1) which were highest during the 1970s and 1980s.

It is noteworthy that in all regions, the longline fishery has a relatively small impact, less than 5%. In the sub-equatorial regions, the longline fishery tends to have a larger share of the impact, but overall impacts are much smaller.

The recent overall fishery-specific impacts on total biomass in the WCPO are broadly consistent with the proportional impacts within region 3; low impact from the longline fishery, moderate impact from the unassociated purse-seine fishery and highest impacts from the associated purse-seine and Philippines/Indonesian domestic fisheries.

5.6.5 Yield analysis

Symbols used in the following discussion are defined in Table 13. The yield analyses conducted in this assessment incorporate the SRR (Figure 61) into the equilibrium biomass and yield computations. 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. However, 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 through sensitivity analyses. For comparison with previous assessments, steepness was also estimated for the *_hEST* model run, yielding an estimate of 0.51 (similar to the estimates from previous assessments).

Equilibrium yield and biomass (spawning and total) are computed as a function of multiples of the 2006–2009 average fishing mortality-at-age (Figure 62). For the reference case, a maximum yield (*MSY*) of 538,800 mt per annum is achieved at *fmult* = 1.31; i.e. at 131% of the current level of fishing effort (Table 15). This represents that the ratio of $F_{current} / \tilde{F}_{MSY}$ is equal to 0.77 (approximately 1/1.31)**Error! Reference source not found.**. On this basis, current exploitation rates re approximately 77% 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 520,400 mt ($Y_{Fcurrent}$) to 538,800 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 SRR. For the reference model, recent recruitment is estimated to have been at approximately 85% of the long-term average level. If future recruitments remain at about the current level then lower yields can be anticipated from the stock.

Recent catches ($C_{current}$) were higher than the equilibrium yield ($Y_{Fcurrent}$) indicating that during the recent period the stock biomass was higher than the equilibrium level. Under equilibrium conditions the spawning ($SB_{Fcurrent}$) and total biomass ($B_{Fcurrent}$) is estimated at 0.39 and 0.47 of the corresponding unexploited biomass level (SB_0 and B_0).

Estimates of yield were broadly comparable for most of the model options considered with *MSY* estimates of 480,000-580,000 mt (Table 15, Table 16 and Table 17). The exceptions were the lower yield estimates associated with model option that estimated steepness (h = 0.51) and the higher *MSY* estimated from the models that estimated separate selectivities for the region 3 fisheries (*_splitSelectR3*) or incorporated the higher value of steepness.

Similarly, estimates of $F_{current}/\tilde{F}_{MSY}$ were generally comparable (0.70-0.85) for most model options, including the core region 3 model. However, model options with lower values of steepness (h = 0.65 and estimated steepness) estimated fishing mortality levels that approach or exceed F_{MSY} ($F_{current}/\tilde{F}_{MSY}$ of 0.91 and 1.23) (Table 16 and Figure 63). Conversely, the model option with a higher value of steepness (0.95) is more optimistic ($F_{current}/\tilde{F}_{MSY}$ of 0.54) (Table 16), while the *splitSelectR3* model also estimates a lower value of $F_{current}/\tilde{F}_{MSY}$ (0.56) than the reference case (Figure 63).

For the all of the model options, the recent average stock status is estimated to have been above the biomass based MSY reference points ($B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$ > 1). However, in the last year of the model (2010) the biomass based reference points are consistently lower than for the recent (2006-2009) period and for some models B_{latest}/B_{MSY} and SB_{latest}/SB_{MSY} approach 1.0 or, in the case of the model with steepness estimated, decline below 1.0 (Table 15, Table 16 and Table 17). The decline in biomass in the last year appears to be attributable to recent low recruitment; however, the stock status for the terminal year is considered to be poorly determined and is not sufficiently reliable to form the basis of management advice.

Overall, model options that included the PTTP tagging data tended to be more optimistic (lower $F_{current}/\tilde{F}_{MSY}$ and higher $SB_{current}/S\tilde{B}_{MSY}$ and *MSY*) than the corresponding model that excluded the tagging data (Table 15).

For a selection of contrasting model options, the reference points $F_t/\tilde{F}_{MSY}$, $B_t/\tilde{B}_{MSY}$ and $SB_t/S\tilde{B}_{MSY}$ were computed for each year (t) included in the model (1952–2010). These computations incorporated the overall fishery selectivity in year t. This enables trends in the status of the stock relative to these two reference points to be followed over the model period (Figure 64 and Figure 65). Prior to 1980, exploitation rates and total and adult biomass remained at high levels relative to $\tilde{B}_{MSY}$ and $S\tilde{B}_{MSY}$. Over the next 25 years, fishing mortality rates steadily increased and the biomass level declined relative to $\tilde{B}_{MSY}$ and $S\tilde{B}_{MSY}$. Nonetheless, throughout the model period, including the most recent years, the biomass level is estimated to have remained above the $\tilde{B}_{MSY}$ and $S\tilde{B}_{MSY}$ levels, while fishing mortality rates have remained below $F_t/\tilde{F}_{MSY}$ (Figure 64 and Figure 65**Error! Reference source not found.**). Only the model sensitivity with the low value of steepness (0.65) has resulted in a recent stock status approaching the *MSY* based thresholds.

The full grid of model options, encompassing the combinations of data assumptions and sensitivities, attempts to encompass the main sources of uncertainty associated with the stock assessment model. The distribution of the fishing mortality ($F_{current}/\tilde{F}_{MSY}$) and biomass ($SB_{current}/S\tilde{B}_{MSY}$) based reference points occupies a broad domain, with steepness being the most influential factor in the range of assumptions considered (Figure 66). Only model options with the low value of steepness yielded results that approached or exceeded the F_{MSY} reference point. Model options estimated recent biomass to have been above the $S\tilde{B}_{MSY}$ level (Figure 66).

As noted above, the determination of the *MSY*-based reference points is highly dependent on the assumed relationship between recruitment and spawning biomass. Further, the formulation of the *MSY*-based reference points assumes that the relationship between recruitment and spawning biomass is a stock-wide (WCPO) process; i.e., recruitment in a specific region is a function of the total spawning biomass and the overall average recruitment distribution rather than the spawning biomass in the specific region. Under this set of assumptions, the calculation of *MSY*-based reference points is not influenced by differential levels of depletion of regional stock biomass — it is assumed that a region where the spawning biomass is heavily depleted can be sustained by the recruitment from the total spawning biomass in the wider stock area. This assumption warrants further consideration for a stock that occupies a geographic area as large as the WCPO.

There are considerable differences in the estimated levels of depletion of the spawning biomass among the six regions of the WCPO, with the highest level of depletion occurring in region 3 and relatively low impacts in the other regions. One of the rationales for conducting a stock assessment limited to the core region was to determine whether the stock assessment conclusions were robust at the two spatial scales. While there were differences in the regional specific level of biomass estimated by the reference model and the region 3 model, the estimated *MSY* based stock status indicators were comparable between the two models (Table 17).

6 Discussion and conclusions

This assessment of yellowfin tuna for the WCPO applied a similar modelling approach to that used in the 2009 assessment. However, while the model's data structure was similar to the previous assessment there were some substantial revisions to a number of key data sets, specifically:

- Incorporation of CPUE indices derived from operational catch and effort data from the Japanese (regions 1-5) and Taiwanese (region 6) longline fishery. By comparison, in 2009 CPUE indices were derived from Japanese aggregated catch and effort data and were corrected for long-term changes in catchability based on an external analysis.
- A modified approach to determining the individual effort deviation penalties applied to the longline standardised effort series.
- A reassignment of the catches for the local longline fisheries in Micronesia from the principal longline fisheries in region 3 and 4 (LL3 and LL4) to the corresponding TW-CN longline fishery. This follows changes to the bigeye stock assessment model on the basis that the size composition of the catch from these local fleets is more comparable to the size composition of the TW-CN longline catch.
- A revised protocol for deriving the length- and weight size compositions for the principal longline fisheries.
- The correction of the purse-seine length frequency data to account for sampling bias and the exclusion of length data from the fisheries prior to 1996 (bias correction not available).
- A revision of the corrected (spill sample) purse-seine fishery catch estimates. The main difference was in PS ASS 3 where the time series of corrected catches were approximately 10% lower than the corrected catches in the 2009 assessment.
- Inclusion of the PTTP tagging data.

In addition, there were a number of structural changes to the assessment model, most notably the refinement to the Philippines and Indonesian fishery definitions, including the definition of a new fishery encompassing the Philippines and Indonesian purse-seine fleets operating east of about 125° E and outside of archipelagic waters. For the reference model(s), the assumed value of steepness was increased slightly (from 0.75 in 2009 to 0.80).

Cumulatively, these changes caused in a substantial change in the key results from the 2009 assessment reducing the overall level of biomass and the estimates of *MSY*, $B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$, while increasing the estimate of $F_{current}/\tilde{F}_{MSY}$ Overall, the current models represent a considerable improvement to the fit to the key data sets compared to 2009 indicating an improvement in the consistency among the main data sources, principally the longline CPUE indices and the associated length and weight frequency data.

The current stock assessment investigated a wide range of potential model options and sensitivities. These models integrated catch, effort, length-frequency, weight-frequency and tagging data into a coherent analysis that is broadly consistent with other information on the biology and fisheries. Overall, the model diagnostics indicate a reasonable fit to the various sources of data; however, they also highlight some inconsistencies among the various sets of input data and model assumptions.

The current assessment represents the first attempt to integrate the tagging data from the recent PTTP. The model diagnostics indicate a relatively poor fit to these data compared to the data from earlier tagging programmes, particularly for fish of the older age classes and/or longer periods at liberty. For all model options, there was a positive bias in the model's prediction of the number of tags recovered from older fish, indicating that estimated exploitation rates for recent years were higher than observed directly from the tag recoveries. This indicates a degree of conflict between the tagging data and the other key data sources, specifically the longline CPUE indices and, to a lesser extent, the longline size data. Consequently, the inclusion of PTTP data set in the model yields a rather more optimistic assessment (when contrasted with models that exclude these data).

A range of additional model options were investigated to explore the possible source of bias in the model fit to the PTTP data set, specifically model options that allow more flexibility in the age-based processes that influence tag recoveries (such as purse seine selectivity assumptions, estimation of alternative age-specific natural mortality and growth). However, none of these model options resulted in a substantial improvement in the fit to the tagging data set. It is likely that the lack of fit to the tagging data results because of (i) spatial patterns in tagged fish dispersal that cannot be predicted by the model because the coarse six-region spatial structure is inadequate; and (ii) the likelihood that substantial numbers of tagged fish that were recaptured in 2010 have not yet been returned to SPC.

Key uncertainties also remain regarding the reliability of the level of catch from the purse-seine associated and unassociated fisheries – differences in the relativity of the level of catch from these two fisheries will affect the underlying expectation of tags recovered from the composite purse seine fishery. The model also attempts to fit the tagging data by increasing the estimated reporting rate for the purse seine fishery from the initial prior value. Limited information is also available regarding the fishery-specific reporting rates of tags for various key sectors of the fishery. Improved information regarding tag reporting rates is fundamental to maximising the information content from the tagging programme, particularly in the application of these data to estimate stock abundance.

A single model option also included an additional set of tags released by Japanese researchers within region 1 during the last decade. It was envisaged that these tags could be informative regarding the movement of fish from region 1 to region 3 and constrain the high associated movement coefficients obtained from previous assessments. While most of the tag recoveries occurred in region 1, a small number of tags were also recovered from the purse-seine fishery in region 3. In the absence of information regarding the tag reporting rate from that fishery, the model estimated a very low reporting rate that was consistent with the high level of movement previously estimated from region 1 to region 3. Consequently, the Japanese tagging data were uninformative in the model and the assessment results were very similar to the reference model.

Comparing the model results from the reference model with a model configured solely for region 3 provides a useful approach to investigate some of the key structural assumptions of the models, particularly the assumption of a common selectivity among the principal longline fisheries in regions 3-6 and the shared selectivities between the region 3 and 4 purse-seine associated and unassociated fisheries. The smaller size of fish caught by the LL ALL 3 fishery suggests that the former assumption may not be valid and releasing the selectivity constraint for the fishery resulted in a lower selectivity for the older age classes and a substantial improvement to the fit to the length and weight frequency data (although a deterioration in the fit to the tagging data).

One interpretation of this result is that there is an actual difference in the selectivity at age between the LL ALL 3 fishery and the other longline fisheries. An alternative interpretation is that the model uses selectivity to account for regional differences in the growth of yellowfin tuna. The region 3 model estimates a considerably different growth pattern with a substantially lower length at maximum age compared to the WCPO wide assessment models. Thus, the lower selectivity of the older age classes may be the model's mechanism to compensate for the smaller size of fish in the older ages classes compared to the other regions. Further research is required to resolve the extent of differences in the growth rate of yellowfin tuna among the regions.

The key source of uncertainty associated with the estimates of stock status is attributable to the assumed nature of the stock recruitment relationship. The assumed value of steepness of 0.80 is considered to represent a reasonable default value for tuna stocks (Harley 2011) and there is little, if any, reliable information available for the WCPO yellowfin tuna stock to justify deviating from the default assumption. A model option was undertaken that attempted to estimate the value of steepness. The resulting low (0.51) value of steepness is driven by the confounded declining trend in biomass and recruitment over the model period. It is not considered that the estimates of spawning biomass and recruitment are sufficiently robust to inform the model regarding the nature of the stock-recruitment relationship.

To address the uncertainty associated with stock-recruitment relationship, a range of values of steepness were included within the model sensitivities. It is considered that the range (0.65-0.95) encompasses the plausible range of steepness values for the yellowfin tuna stock (Harley 2011). For the range of models that incorporated the default value of steepness (0.80), the model estimated $F_{current}/\tilde{F}_{MSY}$ to be 0.56–0.90 and $B_{current}/\tilde{B}_{MSY}$ and $SB_{current}/S\tilde{B}_{MSY}$ are estimated to be above 1.0 (1.25–1.60 and 1.34–1.83, respectively). The alternative values of steepness lead to contrasting outcomes regarding the stock status. The higher value (0.95) of steepness yields a more optimistic stock status and estimates considerably higher potential yields for the stock. For the low (0.65) value of steepness, the stock is estimated to be approaching the *MSY* based fishing mortality and biomass thresholds.

The estimates of *MSY* for the six principal models (480,000−580,000 mt) are comparable to the recent level of (estimated) catch from the fishery (550,000 mt). Further, under equilibrium conditions, the predicted yield estimates ($Y_{Fcurrent}$) are very close to the estimates of *MSY* indicating that current yields are at or above the long-term yields available from the stock. It is important to note that the total catches included in the stock assessment model differ considerably from the reported catches (average 2005-08 of 473,000 mt, source WCPFC Yearbook 2009). The large difference is attributable to the model incorporating the corrected purse-seine catches which are not yet included in the official WCPFC catch figures (but are included for comparison in Williams (2011b)).

The main conclusions of the current assessment are as follows.

1. For all analyses, there are strong temporal trends in the estimated recruitment series. Initial recruitment was relatively high but declined during the 1950s and 1960s. Recruitment remained relatively constant during the 1970s and 1980s, declined steadily from the early 1990s and then recovered somewhat over the last decade. Recent recruitment is estimated to be lower than the long-term average (approximately 85%).

2. Trends in biomass are generally consistent with the underlying trends in recruitment. 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. 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, principally from the Japanese fleet. This data enables a number of factors to be incorporated within the analysis to account for temporal trends in the catchability of the fleet.

3. Refinement in the approach applied to process the longline size frequency data (length and weight data) has resulted in a more coherent trend in these data over the model period. As a result, there

has been a substantial improvement in the fit to both the size frequency data and the CPUE indices compared to recent assessments.

4. There is considerable conflict between the tagging data (principally from the PTTP) and the other key sources of data included in the model, primarily the CPUE indices. The inclusion of the PTTP tagging data results in a the estimation of a substantially lower level of fishing mortality, particularly for the both the younger age classes vulnerable to the purse-seine associated fishery (age classes 3-4) and the older age classes (age classes > 9) vulnerable to the unassociated purse-seine fishery. The resulting assessment is more optimistic when the PTTP tags are incorporated in the model. Further auxiliary analysis of the PTTP tagging data are required to resolve the conflict between these key sources of data.

5. Fishing mortality for adult and juvenile yellowfin tuna is estimated to have increased continuously since the beginning of industrial tuna fishing. A significant component of the increase in juvenile fishing mortality is attributable to the Philippines and Indonesian surface fisheries, which have the weakest catch, effort and size data. There has been recent progress made in the acquisition of a large amount of historical length frequency data from the Philippines and these data were incorporated in the assessment. However, there is an ongoing need to improve estimates of recent and historical catch from these fisheries and maintain the current fishery monitoring programme within the Philippines. Previous analyses have shown that the current stock status is relatively insensitive to the assumed level of catch from these fisheries, although yield estimates from the fishery vary in accordance to the assumed levels of historical catch. Therefore, improved estimates of historical and current catch from these fisheries are important in the determination of the underlying productivity of the stock.

6. The ratios $B_t / B_{t,F=0}$ provide a time-series index of population depletion by the fisheries. Depletion has increased steadily over time, reaching a level of about 50-55% of unexploited biomass (a fishery impact of 45-50%) in 2006–2009. This represents a moderate level of stock-wide depletion although the stock remains considerably higher than the equivalent equilibrium-based reference point ($\tilde{B}_{MSY} / \tilde{B}_0$ of approximately 0.35–0.40). However, depletion is considerably higher in the equatorial region 3 where recent depletion levels are approximately 0.30 for total biomass (a 70% reduction from the unexploited level). Impacts are moderate in region 4 (37%), lower (about 15–25%) in regions 1, 5, and 6 and minimal (9%) in region 2. If stock-wide over-fishing criteria were applied at the level of our model regions, we would conclude that region 3 is fully exploited and the remaining regions are under-exploited.

7. The attribution of depletion to various fisheries or groups of fisheries indicates that the associated purse-seine fishery and Philippines/Indonesian domestic fisheries have the highest impact, particularly in region 3, while the unassociated purse seine fishery has a moderate impact. These fisheries are also contributing to the fishery impacts in all other regions. Historically, the coastal Japanese pole-and-line and purse-seine fisheries have had a significant impact on biomass levels in their home region (1). In all regions, the longline fishery has a relatively small impact, less than 5%.

8. For the most plausible range of models, the fishing mortality based reference point $F_{current} / \tilde{F}_{MSY}$ is estimated to be 0.56–0.90 and on that basis conclude that **overfishing is not occurring**. The corresponding biomass based reference points $B_{current} / \tilde{B}_{MSY}$ and $SB_{current} / S\tilde{B}_{MSY}$ are estimated to be above 1.0 (1.25–1.60 and 1.34–1.83, respectively) and, therefore, the stock is **not in an overfished state**. 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 approaching the *MSY* based fishing mortality and biomass thresholds.

9. The western equatorial region accounts for the most of the WCPO yellowfin catch. In previous assessments, there have been concerns that the stock status in this region (region 3) might differ

from the stock status estimated for the entire WCPO. A comparison between the results from the WCPO models and a model encompassing only region 3 yielded very similar results, particularly with respect to stock status. Nonetheless, there appear to be differences in the biological characteristics of yellowfin tuna in this region that warrant further investigation.

10. The estimates of *MSY* for the principal model options (480,000–580,000 mt) are comparable to the recent level of (estimated) catch from the fishery (550,000 mt). Further, under equilibrium conditions, the predicted yield estimates ($Y_{Fcurrent}$) are very close to the estimates of *MSY* indicating that current yields are at or above the long-term yields available from the stock. Further, while estimates of current fishing mortality are generally below F_{MSY}, any increase in fishing mortality would most likely occur within region 3 — the region that accounts for most of the catch. This would further increase the levels of depletion that is occurring within that region.

11. The current assessment investigated the impact of a range of sources of uncertainty in the current model and the interaction between these assumptions. Nonetheless, there remains a range of other assumptions in the model that should be investigated either internally or through directed research. 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 examine in detail the time-series of size frequency data from the fisheries, which may lead to refinement in the structure of the fisheries included in the model; 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 six-region MULTIFAN-CL analysis of yellowfin tuna.

Fishery	Nationality	Gear	Region
1. LL ALL 1	Japan, Korea, Chinese Taipei	Longline	1
2. LL ALL 2	Japan, Korea, Chinese Taipei	Longline	2
3. LL HW 2	United States (Hawaii)	Longline	2
4. LL ALL 3	All, except CT-Offshore, CN, FSM, MH, PH, ID, and PNG	Longline	3
5. LL TW-CH 3	CT-Offshore, CN, FSM, MH, PH, and ID	Longline	3
6. LL PG 3	Papua New Guinea	Longline	4
7. LL ALL 4	All except CT-Offshore, CN, FSM, MH, PH, ID, and US	Longline	4
8. LL TW-CH 4	CT-Offshore, CN, FSM, MH, PH, and ID	Longline	4
9. LL HW 4	United States (Hawaii)	Longline	4
10. LL ALL 5	All excl. Australia	Longline	5
11. LL AU 5	Australia	Longline	5
12. LL ALL 6	Japan, Korea, Chinese Taipei	Longline	6
13. LL PI 6	Pacific Island Countries/Territories	Longline	6
14. PS ASS 3	All	Purse seine, log/FAD sets	3
15. PS UNS 3	All	Purse seine, school sets	3
16. PS ASS 4	All	Purse seine, log/FAD sets	4
17. PS UNS 4	All	Purse seine, school sets	4
18. PH MISC 3	Philippines	Miscellaneous (small fish), including purse seine within PH archipelagic waters.	3
19. PH HL 3	Philippines, Indonesia	Handline (large fish)	3
20. PS JP 1	Japan	Purse seine, all sets	1
21. PL JP 1	Japan	Pole-and-line	1
22. PL ALL 3	All, except Indonesia	Pole-and-line	3
23. LL BMK 3	All excl. PNG, Chinese Taipei & China within PNG waters	Longline	3
24. ID MISC 3	Indonesia	Miscellaneous (small fish), including purse seine within ID archipelagic waters.	3
25. PS PHID 3	Philippines and Indonesia	Purse seine in waters east of about 125°E (and outside of PH and ID archipelagic waters).	3

Table 2. Annual catch by fishery for 2009 and the average for 2005-2009. The two alternative catch histories for the industrial purse-seine fisheries are presented using corrected and uncorrected catches (in brackets). The catches from 2010 are not presented as they were considered to be incomplete.

Fishery	**Annual catch (mt)**	
	Avg. 2005-2009	2009
1. LL ALL 1	2,870	2,698
2. LL ALL 2	455	371
3. LL HW 2	253	168
4. LL ALL 3	8,549	6,490
5. LL TW-CH 3	24,330	28,511
6. LL PG 3	710	868
7. LL ALL 4	11,712	12,459
8. LL TW-CH 4	2,723	1,871
9. LL HW 4	718	296
10. LL ALL 5	8,177	10,062
11. LL AU 5	1,776	1,308
12. LL ALL 6	2,217	6,083
13. LL PI 6	5,314	5,449
14. PS ASS 3	136,725 (65,804)	125,439 (69,273)
15. PS UNS 3	119,250 (89,101)	102,227 (78,579)
16. PS ASS 4	22,983 (14,649)	34,390 (15,116)
17. PS UNS 4	31,123 (29,443)	16,348 (16,442)
18. PH MISC 3	58,213	59,317
19. PH HL 3	19,520	13,761
20. PS JP 1	3,073	2,571
21. PL JP 1	2,736	3,381
22. PL ALL 3	278	64
23. LL BMK 3	1,992	3,447
24. ID MISC 3	22,792	21,627
25. PS PHID 3	70,352	47,397
Total	558,840 (448,026)	506,603 (407,190)

Table 3. The number of length frequency samples and the average effective sample size for the length frequency data for the principal longline fishery in each region for each of the principal model options.

	Region					
	1	2	3	4	5	6
Number of samples	132	124	176	190	95	161
Model option						
n/20	29	14	34	22	27	8
n	589	273	673	450	544	156

Table 4. The number of weight frequency samples and the average effective sample size for the weight frequency data for the principal longline fishery in each region for each of the principal model options.

	Region					
	1	2	3	4	5	6
Number of samples	190	180	213	190	121	119
Model option						
n/20	29	14	34	22	27	8
n	589	273	673	450	544	156

Table 5. Summary of the number of tag release periods (yr/qtr), number of tags released and number of tags recaptured by tagging programme and MFCL region. Only tags included in the assessment model are included.

Programme		**Region**						**Total**
		1	**2**	**3**	**4**	**5**	**6**	
RTTP	n. groups	-	-	13	5	4	3	25
1989-1992	n. release	-	-	30,957	2,837	4,454	1,173	39,421
	n. recapture	2	1	4,003	134	45	-	4,185
Coral Sea	n. groups	-	-	-	-	1	-	1
1995	n. release	-	-	-	-	255	-	255
	n. recapture	-	-	-	-	1	-	1
Hawaii	n. groups	-	11	-	19	-	-	30
1995-2001	n. release	-	3,528	-	4,839	-	-	8,367
	n. recapture	6	5	-	18	-	-	29
PTTP	n. groups	-	-	14	3	4	-	21
2005-2009	n. release	-	-	58,855	2,744	4,878	-	66,477
	n. recapture	3	-	9,694	319	4	1	10,021
Japan	n. groups	38	-	-	-	-	-	38
1999-2008	n. release	12,707	-	-	-	-	-	12,707
	n. recapture	516	-	14	-	-	-	530

Table 6. Average assumed CV for the effort deviations for the principal longline fishery in each region for each of the principal model options.

Model option	Region					
	1	2	3	4	5	6
CPUE AG	0.266	0.656	0.194	0.305	0.68	0.606
CPUE OP	0.158	0.217	0.225	0.268	0.217	0.437
CPUE OP, TW R6	0.158	0.217	0.225	0.268	0.217	0.204

Table 7. Summary of the step-wise changes from the 2009 assessment to the format of the reference case of the current assessment.

Run	**Description**
CPUElow_samplehigh_Qincr	Reference case from 2009 assessment, steepness fixed at 0.75
Step 1, steepness 0.8	Fixed steepness at 0.80.
Step 2, cpueOP	LL CPUE indices from Japanese operational data for regions 1-5, TW operational CPUE indices for region 6.
Step 3, Tmp_eff_devwt	Temporal weighting on effort deviate penalties associated with standardized effort for principal longline fisheries.
Step 4, LLcatches_R3	Transfer of LL catch from components of the longline fleet in LL 3 to TW-CN longline fishery (specifically FM, FM, ID, GU, PH, PW, MI).
Step 5, JPLL_sz_rwtd	Apply area based reweighting of the JP LL length and weight freq. data.
Step 6, spill_SZ_corr	Removal of PS length data prior to 1996 and replace with corrected size data for 1996 onwards.
Step 7, spill_CATCH_rev	Revised spill sample corrected PS catches for industrial PS fisheries (14-17).
Step 8, 2011_fishery	2011 reference case, excluding 2009 and 2010 data. Includes additional PS/ID fishery beyond archipelagic waters and final configuration of fisheries..
LLcpueOP_TWcpueR6_RTTP	Reference case for 2011 assessment, excluding PTTP tags.
LLcpueOP_TWcpueR6_PTTP	Reference case for 2011 assessment, including PTTP tags.

Table 8. A comparison of the key MSY based reference points between the 2009 base case model and the step-wise changes in the data sets for the current assessment. For comparison, the 2009 reference period of 2004-07 is used to determine the reference points. The *LLcpueOP_TWcpueR6_RTTP* and *LLcpueOP_TWcpueR6_PTTP* models include the data from 2009 and 2010.

Run	*MSY*	$SB_{current}/S\tilde{B}_{MSY}$	$F_{current}/\tilde{F}_{MSY}$
CPUElow_samplehigh_Qincr	636,800	1.78	0.58
Step 1, steepness 0.8	682,400	1.90	0.53
Step 2, cpueOP	580,000	1.62	0.69
Step 3, Tmp_eff_devwt	638,000	1.50	0.70
Step 4, LLcatches_R3	598,000	1.73	0.64
Step 5, JPLL_sz_rwtd	531,200	1.46	0.79
Step 6, spill_SZ_corr	491,600	1.30	0.92
Step 7, spill_CATCH_rev	459,200	1.31	0.82
Step 8, 2011_fishery	446,000	1.24	0.94
LLcpueOP_TWcpueR6_RTTP	482,400	1.28	0.86
LLcpueOP_TWcpueR6_PTTP	527,600	1.33	0.77

Table 9. Main structural assumptions of the yellowfin tuna assessment model(s) and details of estimated parameters, priors and bounds.

Category	Assumptions	Estimated parameters (ln = log transformed parameter)		Prior		Bounds	
				μ	σ	Low	High
Observation model for total catch data	Observation errors small, equivalent to a residual SD on the log scale of 0.07.	None		na	na	na	na
Observation model for length-frequency data	Normal probability distribution of frequencies with variance determined by effective sample size and observed frequency. Effective sample size dependent on the individual model option (see Table 10).	None		na	na	na	na
Observation model for weight-frequency data	Normal probability distribution of frequencies, variance determined by effective sample size and observed frequency. Effective sample size dependent on the individual model option (see Table 10).	None		na	Na	na	na
Observation model for tagging data	Tag numbers in a stratum have negative binomial probability distribution, with estimated variance parameters for fishery groups.	Variance parameters		-	-	0	100
Tag reporting	Purse seine reporting rates constrained to be equal within regions. All reporting rates constant over time. Reporting rate priors vary among individual tagging programmes.					0.001	0.9
Tag mixing	Tags assumed to be randomly mixed at the model region level two quarters following the quarter of release.	None		na	Na	na	na
Recruitment	Occurs as discrete events at the start of each quarter. Spatially-aggregated recruitment is weakly related to spawning biomass in the prior quarter via a Beverton-Holt SRR (fixed value of steepness) .The spatial distribution of recruitment in each quarter is allowed to vary with a small penalty on deviations from the average spatial distribution.	Average spatially aggregated recruitment (ln)		-	-	-20	20
		Spatially aggregated recruitment deviations (ln)		SRR	0.7	-20	20
		Average spatial distribution of recruitment		-	-	0	1
		Time series deviations from average spatial distribution (ln)		0	1	-3	3
Initial population	A function of the initial recruitment and equilibrium age structure in each region, which is in turn assumed to arise from the total mortality estimated for 1952–56 and movement rates.	Initial recruitment scaling (ln)		-	-	-8	8
Age and growth	28 quarterly age-classes, with the last representing a plus group. Juvenile age-classes 1-8 have independent mean lengths constrained by	Mean length age class 1		-	-	20	40
		Mean length age class 28		-	-	140	200

	a small penalty for deviation from the von Bertalanffy growth curve; adult age-class mean lengths constrained by VB curve. SD of length-at-age are log-linearly related to the mean length-at-age. Mean weights (W_j) computed internally by estimating the distribution of weight-at-age from the distribution of length-at-age and applying the weight-length relationship $W = aL^b$ (a= 2.512e-05, b= 2.9396, source N. Miyabe, NRIFSF).	von Bertalanffy *K*		-	-	0	0.3
		Independent mean lengths		0	0.7		
		Length-at-age SD		-	-	3	8
		Dependency on mean length (ln)		-	-	-1.00	1.00
Selectivity	Constant over time. Coefficients for the last 4 age-classes are constrained to be equal. Longline fisheries LL ALL 1–2 and LL ALL 3–6 share selectivity parameters. Purse-seine fisheries share selectivity among regions. For all fisheries, selectivity parameterised with 5-node cubic spline, except Taiwanese/Chinese longline selectivities with logistic function (non decreasing with age).	Selectivity coefficients (5 cubic spline nodes or 2 logistic parameters per fishery)		-	-	0	1
Catchability	Constant over years and among regions for longline fisheries (effort data are scaled to reflect different region sizes). Seasonal variation for all fisheries apart from Philippines and Indonesian fisheries. Non-longline fisheries and the Australian, Taiwanese/Chinese, and LL BMK 3 longline fisheries have structural time-series variation, with random steps (catchability deviations) taken every 2 years.	Average catchability coefficients (ln)		-	-	-15	1
		Seasonality amplitude (ln)		0	2.2	-	-
		Seasonality phase		-	-	-	-
		Catchability deviations PH/ID (ln)		0	0.7	-0.8	0.8
		Catchability deviations other (ln)		0	0.1	-0.8	0.8
Fishing effort	Variability of effort deviations constrained by a prior distribution with (on the log scale) mean 0 and average SD determined by iterative reweighting (or fixed at 0.2) for LL ALL 1–6 with temporal variation in SD. SD 0.22 for other fisheries at the average level of effort for each fishery. SD inversely proportional to the square root of effort.	Effort deviations LL 1, 2, 4, 7, 10, 12 (ln)		0	0.16	-6	6
		Effort deviations PH, ID (ln)		0	0.22	-6	6
		Effort deviations other (ln)		0	0.22	-6	6
Natural mortality	Age-dependent but constant over time and among regions. All parameters are specified (see Figure 20).	Average natural mortality (ln)		-	-	-	-
		Age-specific deviations (ln)		-	-	-	-
Movement	Age-independent and variant by quarter but constant among years. No age-dependent variation.	Movement coefficients		0	0.32	0	3
		Age-dependent component (ln)		0	0.32	-4	4
Maturity	Age-dependent and specified.	None		na	na	0	1

Table 10. Summary of the range of model options investigated. The reference case is shaded.

Run	CPUE Regions 1-5	CPUE Region6	LL 1-6 size data	PTTP tags	Japan tags	PS catch	Steepness	PS JP 1 split	Region 3 LL & PS selectivity split
LLcpueAG_PTTP	AG	AG	n/20	Yes	No	Corrected	0.80	No	No
LLcpueAG_RTTP	AG	AG	n/20	No	No	Corrected	0.80	No	No
LLcpueOP_PTTP	OP	OP	n/20	Yes	No	Corrected	0.80	No	No
LLcpueOP_PTTP_ TWcpueR6_dwtSize50	OP	TW	n/**50**	Yes	No	Corrected	0.80	No	No
LLcpueOP_PTTP_ TWcpueR6_h65	OP	TW	n/20	Yes	No	Corrected	**0.65**	No	No
LLcpueOP_PTTP_ TWcpueR6_h95	OP	TW	n/20	Yes	No	Corrected	**0.95**	No	No
LLcpueOP_PTTP_ TWcpueR6_hEST	OP	TW	n/20	Yes	No	Corrected	**Estimated**	No	No
LLcpueOP_PTTP_ TWcpueR6_JPSize	OP	TW	n/**10**	Yes	No	Corrected	0.80	No	No
LLcpueOP_PTTP_ TWcpueR6_PSold	OP	TW	n/20	Yes	No	**Uncorrected**	0.80	No	No
LLcpueOP_PTTP_ TWcpueR6_splitSelectR 3	OP	TW	n/20	Yes	No	Corrected	0.80	No	**Yes**
LLcpueOP_RTTP	OP	OP	n/20	No	No	Corrected	0.80	No	No
LLcpueOP_TWcpueR6 _PTTP	OP	TW	n/20	Yes	No	Corrected	0.80	No	No
LLcpueOP_TWcpueR6 _PTTP_JPPS_JPtags	OP	TW	n/20	Yes	**Yes**	Corrected	0.80	**Yes**	No
LLcpueOP_TWcpueR6 _RTTP	OP	TW	n/20	No	No	Corrected	0.80	No	No
Region3	OP	-	n/20	Yes	No	Corrected	0.80	No	No

Table 11. Average assumed CV for the effort deviations for the principal longline fishery in each region for each of the principal model options.

Model option	Region					
	1	2	3	4	5	6
CPUE AG	0.266	0.656	0.194	0.305	0.68	0.606
CPUE OP	0.158	0.217	0.225	0.268	0.217	0.437
CPUE OP, TW R6	0.158	0.217	0.225	0.268	0.217	0.204

Table 12. Details of objective function components for various model options**.**

Run	npars	Total	Catch	Length freq.	Weight freq	Tag	Penalties
LLcpueAG_PTTP	6285	-1,351,061.2	128.3	-446,903.0	-914,082.1	5,820.2	3,975.5
LLcpueAG_RTTP	6262	-1,354,308.1	132.4	-447,602.5	-914,223.1	3,213.5	4,171.5
LLcpueOP_PTTP	6285	-1,349,676.4	138.7	-447,472.9	-914,111.5	6,631.2	5,138.2
LLcpueOP_PTTP_ TWcpueR6_dwtSize50	6284	-1,223,896.4	133.2	-411,288.6	-823,628.1	6,017.4	4,869.7
LLcpueOP_PTTP_ TWcpueR6_h65	6285	-1,349,641.2	137.8	-447,303.4	-914,193.7	6,441.2	5,277.0
LLcpueOP_PTTP_ TWcpueR6_h95	6285	-1,349,637.3	137.7	-447,303.8	-914,193.8	6,441.8	5,280.8
LLcpueOP_PTTP_ TWcpueR6_hEST	6286	-1,349,642.0	137.9	-447,302.9	-914,193.1	6,440.3	5,275.9
LLcpueOP_PTTP_ TWcpueR6_JPSize	6285	-1,440,736.1	137.8	-472,250.2	-980,736.5	6,512.7	5,600.0
LLcpueOP_PTTP_ TWcpueR6_PSold	6285	-1,349,281.8	60.1	-447,311.1	-914,209.1	6,450.1	5,728.3
LLcpueOP_PTTP_ TWcpueR6_splitSelectR3	6300	-1,350,053.5	133.6	-447,462.6	-914,413.8	6,372.1	5,317.2
LLcpueOP_RTTP	6262	-1,353,266.0	138.2	-447,567.9	-914,162.4	3,282.0	5,044.1
LLcpueOP_TWcpueR6 _PTTP	6291	-1,349,639.5	136.6	-447,240.1	-914,193.7	6,409.0	5,248.7
LLcpueOP_TWcpueR6 _PTTP_JPPS_JPtags	6328	-1,350,308.5	136.5	-448,598.5	-914,182.8	7,082.4	5,253.9
LLcpueOP_TWcpueR6 _RTTP	6262	-1,352,974.1	138.5	-447,528.2	-914,174.6	3,236.7	5,353.4
Region3	2443	-495,308.5	106.2	-207,615.2	-293,140.8	3,965.6	1,375.8

Table 13. Description of symbols used in the yield analysis. For the purpose of this assessment, 'current' is the average over the period 2006-2009 and 'latest' is 2010.

Symbol	Description
$C_{current}$	Average annual catch over a recent period[4]
C_{latest}	Catch in the most recent year
$F_{current}$	Average fishing mortality-at-age[5] for a recent period
F_{MSY}	Fishing mortality-at-age producing the maximum sustainable yield (MSY[6])
$Y_{F_{current}}$	Equilibrium yield at $F_{current}$
$Y_{F_{MSY}}$	Equilibrium yield at F_{MSY}. Better known as MSY
$C_{current}/MSY$	Average annual catch over a recent period relative to MSY
C_{latest}/MSY	Catch in the most recent year relative to MSY
F_{mult}	The amount that $F_{current}$ needs to be scaled to obtain F_{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_{MSY}	Equilibrium total biomass that results from fishing at F_{MSY}
B_{MSY}/B_0	Equilibrium total biomass that results from fishing at F_{MSY} relative to B_0
$B_{current}$	Average annual total biomass over a recent period
B_{latest}	Total annual biomass in the most recent year
$B_{F_{current}}$	Equilibrium total biomass that results from fishing at $F_{current}$
$B_{current_{F=0}}$	Average annual total biomass over a recent period in the absence of fishing
$B_{latest_{F=0}}$	Total biomass predicted to exist in the absence of fishing
SB_0	Equilibrium unexploited total biomass[7].
$B_{current}/B_0$	Average annual total biomass over a recent period relative to B_0
B_{latest}/B_0	Total annual biomass in the most recent year relative to B_0
$B_{F_{current}}/B_0$	Equilibrium total biomass that results from fishing at $F_{current}$relative to B_0
$B_{current}/B_{MSY}$	Average annual total biomass over a recent period relative to B_{MSY}
B_{latest}/B_{MSY}	Total annual biomass in the most recent year relative to B_{MSY}
$B_{F_{current}}/B_{MSY}$	Equilibrium total biomass that results from fishing at $F_{current}$relative to B_{MSY}
$B_{current}/B_{current_{F=0}}$	Average annual total biomass over a recent period / the biomass in the absence of fishing
$B_{latest}/B_{latest_{F=0}}$	Total annual biomass in the most recent year / the biomass in the absence of fishing
$Crit_{age}$	The age at which harvest would maximize the yield per recruit
$Crit_{length}$	The length at which harvest would maximize the yield per recruit
$Mean_{age}$	The mean age of the catch over a recent period
$Mean_{length}$	The mean length of the catch over a recent period
Y_{lost}	The proportion of the maximum yield per recruit lost by the mean age at harvest

[4] Some recent period used for the purpose of averaging fishing mortality or other quantities. Typically excludes the most recent year due to uncertainty, but covers the preceding four years, e.g. 2006-2009.

[5] This age-specific pattern is dependent on both the amount of fishing and the mix of fishing gears, e.g. relative catches of small and large fish

[6] MSY and other MSY-related quantities are linked to a particular fishing pattern and the MSY will change, for example, based on changes in the relative catches of small and large fish

[7] Similar quantities as above for total biomass can also be calculated for spawning biomass and are not repeated here

Table 14. Some performance statistics for the model runs described in Table 10.

Run	MSY	$F_{current}$ $/F_{MSY}$	SB_{curren} $/SB_{MSY}$	*steepness*	Obj. Fnt value	npars	gradient
LLcpueAG_PTTP	490,400	0.71	1.83	0.80	1,351,061.2	6,285	0.0522
LLcpueAG_RTTP	483,600	0.73	1.77	0.80	1,354,308.1	6,262	0.0008
LLcpueOP_PTTP	580,000	0.67	1.55	0.80	1,349,676.4	6,285	0.0008
LLcpueOP_PTTP_ TWcpueR6_dwtSize50	563,600	0.76	1.44	0.80	1,223,896.4	6,284	0.0881
LLcpueOP_PTTP_ TWcpueR6_h65	498,000	0.91	1.28	0.65	1,349,641.2	6,285	0.0169
LLcpueOP_PTTP_ TWcpueR6_h95	644,800	0.54	1.92	0.95	1,349,637.3	6,285	0.0009
LLcpueOP_PTTP_ TWcpueR6_hEST	411,600	1.23	1.09	0.51	1,349,642.0	6,286	0.0149
LLcpueOP_PTTP_ TWcpueR6_JPSize	534,000	0.78	1.46	0.80	1,440,736.1	6,285	0.0008
LLcpueOP_PTTP_ TWcpueR6_PSold	498,400	0.69	1.44	0.80	1,349,281.8	6,285	0.0055
LLcpueOP_PTTP_ TWcpueR6_splitSelectR3	661,600	0.56	1.71	0.80	1,350,053.5	6,300	0.0667
LLcpueOP_RTTP	525,200	0.85	1.37	0.80	1,353,266.0	6,262	0.0009
LLcpueOP_TWcpueR6 _PTTP	538,800	0.77	1.47	0.80	1,349,639.5	6,291	0.0034
LLcpueOP_TWcpueR6 _PTTP_JPPS_JPtags	563,200	0.72	1.53	0.80	1,350,308.5	6,328	0.1014
LLcpueOP_TWcpueR6 _RTTP	493,600	0.90	1.34	0.80	1,352,974.1	6,262	0.0009
Region3	422,000	0.78	1.48	0.80	495,308.5	2,443	0.0009

Table 15. Estimates of management quantities for the reference model and the other principal models. For the purpose of this assessment, 'current' is the average over the period 2006-2009 and 'latest' is 2010.

	LLcpueOP_ TWcpueR6_ PTTP	LLcpueOP_ TWcpueR6_ RTTP	LLcpueAG_ RTTP	LLcpueAG_ PTTP	LLcpueOP_ RTTP	LLcpueOP_ PTTP
$C_{current}$	551,120	551,488	552,149	552,206	551,518	551,405
C_{latest}	507,100	508,329	510,666	509,019	508,499	507,526
$Y_{F_{current}}$	520,400	490,800	461,600	463,200	518,000	541,600
$Y_{F_{MSY}}$ or MSY	538,800	493,600	483,600	490,400	525,200	580,000
$Y_{F_{current}}/MSY$	0.97	0.99	0.95	0.94	0.99	0.93
$C_{current}/MSY$	1.02	1.12	1.14	1.13	1.05	0.95
C_{latest}/MSY	0.94	1.03	1.06	1.04	0.97	0.88
F_{MSY}	0.09	0.09	0.09	0.10	0.09	0.09
F_{mult}	1.31	1.11	1.37	1.40	1.18	1.48
$F_{current}/F_{MSY}$	0.77	0.90	0.73	0.71	0.85	0.67
B_0	3,740,000	3,539,000	3,554,000	3,272,000	3,802,000	4,071,000
B_{MSY}	1,419,000	1,331,000	1,325,000	1,250,000	1,427,000	1,556,000
B_{MSY}/B_0	0.38	0.38	0.37	0.38	0.38	0.38
$B_{current}$	1,881,625	1,659,417	2,097,799	1,997,012	1,778,774	2,145,588
B_{latest}	1,677,832	1,376,045	1,801,125	1,850,084	1,456,755	1,946,310
$B_{F_{current}}$	1,770,000	1,463,000	1,716,000	1,646,000	1,652,000	2,101,000
$B_{current_{F=0}}$	3,563,564	3,465,036	3,860,895	3,534,867	3,561,909	3,811,311
$B_{latest_{F=0}}$	3,211,918	3,055,172	3,443,764	3,247,133	3,115,217	3,480,963
SB_0	2,001,000	2,035,000	2,045,000	1,546,000	2,183,000	2,313,000
SB_{MSY}	576,000	608,600	610,300	412,900	654,100	699,300
SB_{MSY}/SB_0	0.29	0.30	0.30	0.27	0.30	0.30
$SB_{current}$	844,604	816,181	1,078,664	757,126	892,923	1,083,099
SB_{latest}	720,650	622,039	874,746	668,586	667,403	937,864
$SB_{F_{current}}$	775,500	688,500	851,600	610,800	791,300	1,036,000
$SB_{current_{F=0}}$	1,935,073	2,038,110	2,266,114	1,680,906	2,095,056	2,206,409
$SB_{latest_{F=0}}$	1,760,226	1,789,523	2,008,576	1,570,367	1,812,905	1,994,684
$B_{current}/B_0$	0.50	0.47	0.59	0.61	0.47	0.53
B_{latest}/B_0	0.45	0.39	0.51	0.57	0.38	0.48
$B_{F_{current}}/B_0$	0.47	0.41	0.48	0.50	0.43	0.52
$B_{current}/B_{MSY}$	1.33	1.25	1.58	1.60	1.25	1.38
B_{latest}/B_{MSY}	1.18	1.03	1.36	1.48	1.02	1.25
$B_{F_{current}}/B_{MSY}$	1.25	1.10	1.30	1.32	1.16	1.35
$B_{current}/B_{current_{F=0}}$	0.53	0.48	0.54	0.56	0.50	0.56
$B_{latest}/B_{latest_{F=0}}$	0.52	0.45	0.52	0.57	0.47	0.56
$SB_{current}/SB_0$	0.42	0.40	0.53	0.49	0.41	0.47
SB_{latest}/SB_0	0.36	0.31	0.43	0.43	0.31	0.41
$SB_{F_{current}}/SB_0$	0.39	0.34	0.42	0.40	0.36	0.45
$SB_{current}/SB_{MSY}$	1.47	1.34	1.77	1.83	1.37	1.55
SB_{latest}/SB_{MSY}	1.25	1.02	1.43	1.62	1.02	1.34
$SB_{F_{current}}/SB_{MSY}$	1.35	1.13	1.40	1.48	1.21	1.48
$SB_{curr}/SB_{curr_{F=0}}$	0.44	0.40	0.48	0.45	0.43	0.49
$SB_{latest}/SB_{latest_{F=0}}$	0.41	0.35	0.44	0.43	0.37	0.47
Steepness (h)	0.80	0.80	0.80	0.80	0.80	0.80

Table 16. Estimates of management quantities for the reference model and key sensitivity models. For the purpose of this assessment, 'current' is the average over the period 2006-2009 and 'latest' is 2010.

	LLcpueOP_TWcpueR6_PTTP	LLcpueOP_PTTP_TWcpueR6_dwtSize50	LLcpueOP_PTTP_TWcpueR6_JPSize	LLcpueOP_PTTP_TWcpueR6_h65	LLcpueOP_PTTP_TWcpueR6_h95	LLcpueOP_PTTP_TWcpueR6_hEST
$C_{current}$	551,120	551,416	550,923	551,300	551,283	551,330
C_{latest}	507,100	507,392	507,175	507,443	507,358	507,534
$Y_{F_{current}}$	520,400	542,000	517,600	495,200	565,200	396,240
$Y_{F_{MSY}}$ or MSY	538,800	563,600	534,000	498,000	644,800	411,600
$Y_{F_{current}}/MSY$	0.97	0.96	0.97	0.99	0.88	0.96
$C_{current}/MSY$	1.02	0.98	1.03	1.11	0.85	1.34
C_{latest}/MSY	0.94	0.90	0.95	1.02	0.79	1.23
F_{MSY}	0.09	0.10	0.09	0.07	0.12	0.05
F_{mult}	1.31	1.32	1.29	1.10	1.84	0.81
$F_{current}/F_{MSY}$	0.77	0.76	0.78	0.91	0.54	1.23
B_0	3,740,000	3,847,000	3,745,000	4,184,000	3,951,000	4,389,000
B_{MSY}	1,419,000	1,458,000	1,414,000	1,705,000	1,337,000	1,902,000
B_{MSY}/B_0	0.38	0.38	0.38	0.41	0.34	0.43
$B_{current}$	1,881,625	1,874,290	1,874,733	2,077,099	2,062,825	2,094,382
B_{latest}	1,677,832	1,639,518	1,662,548	1,829,130	1,830,430	1,831,252
$B_{F_{current}}$	1,770,000	1,843,000	1,748,000	1,857,000	2,106,000	1,498,000
$B_{current_{F=0}}$	3,563,564	3,478,201	3,587,771	3,761,366	3,748,738	3,776,534
$B_{latest_{F=0}}$	3,211,918	3,090,650	3,233,411	3,369,741	3,372,376	3,370,230
SB_0	2,001,000	1,842,000	2,037,000	2,272,000	2,145,000	2,382,000
SB_{MSY}	576,000	505,000	589,000	766,000	504,900	906,200
SB_{MSY}/SB_0	0.29	0.27	0.29	0.34	0.24	0.38
$SB_{current}$	844,604	729,431	858,453	977,039	968,780	987,047
SB_{latest}	720,650	602,560	737,611	831,030	825,333	838,017
$SB_{F_{current}}$	775,500	698,000	782,200	851,800	964,400	688,200
$SB_{current_{F=0}}$	1,935,073	1,686,447	1,980,839	2,075,899	2,068,838	2,084,380
$SB_{latest_{F=0}}$	1,760,226	1,528,839	1,807,832	1,876,259	1,871,138	1,882,293
$B_{current}/B_0$	0.50	0.49	0.50	0.50	0.52	0.48
B_{latest}/B_0	0.45	0.43	0.44	0.44	0.46	0.42
$B_{F_{current}}/B_0$	0.47	0.48	0.47	0.44	0.53	0.34
$B_{current}/B_{MSY}$	1.33	1.29	1.33	1.22	1.54	1.10
B_{latest}/B_{MSY}	1.18	1.12	1.18	1.07	1.37	0.96
$B_{F_{current}}/B_{MSY}$	1.25	1.26	1.24	1.09	1.58	0.79
$B_{current}/B_{current_{F=0}}$	0.53	0.54	0.52	0.55	0.55	0.55
$B_{latest}/B_{latest_{F=0}}$	0.52	0.53	0.51	0.54	0.54	0.54
$SB_{current}/SB_0$	0.42	0.40	0.42	0.43	0.45	0.41
SB_{latest}/SB_0	0.36	0.33	0.36	0.37	0.38	0.35
$SB_{F_{current}}/SB_0$	0.39	0.38	0.38	0.37	0.45	0.29
$SB_{current}/SB_{MSY}$	1.47	1.44	1.46	1.28	1.92	1.09
SB_{latest}/SB_{MSY}	1.25	1.19	1.25	1.08	1.63	0.92
$SB_{F_{current}}/SB_{MSY}$	1.35	1.38	1.33	1.11	1.91	0.76
$SB_{curr}/SB_{curr_{F=0}}$	0.44	0.43	0.43	0.47	0.47	0.47
$SB_{latest}/SB_{latest_{F=0}}$	0.41	0.39	0.41	0.44	0.44	0.45
Steepness (h)	0.80	0.80	0.80	0.65	0.95	0.51

Table 17. Estimates of management quantities for the reference model and key sensitivity models. For the purpose of this assessment, 'current' is the average over the period 2006-2009 and 'latest' is 2010.

	LLcpueOP_TWcpueR6_PTTP	LLcpueOP_PTTP_TWcpueR6_PSold	LLcpueOP_TWcpueR6_PTTP_JPPS_JPtags	LLcpueOP_PTTP_TWcpueR6_splitSelectR3	Region3
$C_{current}$	551,120	445,784	551,222	553,251	459,511
C_{latest}	507,100	452,287	507,146	509,845	413,321
$Y_{F_{current}}$	520,400	467,200	534,000	572,800	409,200
$Y_{F_{MSY}}$ or MSY	538,800	498,400	563,200	661,600	422,000
$Y_{F_{current}}/MSY$	0.97	0.94	0.95	0.87	0.97
$C_{current}/MSY$	1.02	0.89	0.98	0.84	1.09
C_{latest}/MSY	0.94	0.91	0.90	0.77	0.98
F_{MSY}	0.09	0.09	0.09	0.09	0.10
F_{mult}	1.31	1.46	1.40	1.79	1.28
$F_{current}/F_{MSY}$	0.77	0.69	0.72	0.56	0.78
B_0	3,740,000	3,439,000	3,959,000	4,834,000	2,925,000
B_{MSY}	1,419,000	1,321,000	1,495,000	1,821,000	1,104,000
B_{MSY}/B_0	0.38	0.38	0.38	0.38	0.38
$B_{current}$	1,881,625	1,688,719	2,033,239	2,673,636	1,486,950
B_{latest}	1,677,832	1,522,074	1,864,364	2,579,253	1,449,200
$B_{F_{current}}$	1,770,000	1,766,000	1,959,000	2,775,000	1,365,000
$B_{current_{F=0}}$	3,563,564	2,963,116	3,705,696	4,299,105	2,874,231
$B_{latest_{F=0}}$	3,211,918	2,798,561	3,402,365	4,100,117	2,690,200
SB_0	2,001,000	1,868,000	2,132,000	2,624,000	1,437,000
SB_{MSY}	576,000	553,900	615,200	775,900	399,100
SB_{MSY}/SB_0	0.29	0.30	0.29	0.30	0.28
$SB_{current}$	844,604	797,779	939,140	1,326,091	590,578
SB_{latest}	720,650	659,374	800,426	1,104,670	568,390
$SB_{F_{current}}$	775,500	814,300	882,800	1,338,000	533,400
$SB_{current_{F=0}}$	1,935,073	1,630,174	2,025,137	2,372,002	1,423,044
$SB_{latest_{F=0}}$	1,760,226	1,508,966	1,840,602	2,132,597	1,380,600
$B_{current}/B_0$	0.50	0.49	0.51	0.55	0.51
B_{latest}/B_0	0.45	0.44	0.47	0.53	0.50
$B_{F_{current}}/B_0$	0.47	0.51	0.49	0.57	0.47
$B_{current}/B_{MSY}$	1.33	1.28	1.36	1.47	1.35
B_{latest}/B_{MSY}	1.18	1.15	1.25	1.42	1.31
$B_{F_{current}}/B_{MSY}$	1.25	1.34	1.31	1.52	1.24
$B_{current}/B_{current_{F=0}}$	0.53	0.57	0.55	0.62	0.52
$B_{latest}/B_{latest_{F=0}}$	0.52	0.54	0.55	0.63	0.54
$SB_{current}/SB_0$	0.42	0.43	0.44	0.51	0.41
SB_{latest}/SB_0	0.36	0.35	0.38	0.42	0.40
$SB_{F_{current}}/SB_0$	0.39	0.44	0.41	0.51	0.37
$SB_{current}/SB_{MSY}$	1.47	1.44	1.53	1.71	1.48
SB_{latest}/SB_{MSY}	1.25	1.19	1.30	1.42	1.42
$SB_{F_{current}}/SB_{MSY}$	1.35	1.47	1.43	1.72	1.34
$SB_{curr}/SB_{curr_{F=0}}$	0.44	0.49	0.46	0.56	0.42
$SB_{latest}/SB_{latest_{F=0}}$	0.41	0.44	0.43	0.52	0.41
Steepness (h)	0.80	0.80	0.80	0.80	0.80

Table 18: Comparison of historical estimates of $\boldsymbol{F_{current}/F_{MSY}}$ for each year from 2001-2009 and the average for the period 2006-09 for the model runs described in Table 10.

	$F_{current}/F_{MSY}$									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2006-09
LLcpueAG_PTTP	0.70	0.76	0.74	0.70	0.77	0.70	0.69	0.79	0.67	0.71
LLcpueAG_RTTP	0.65	0.73	0.75	0.66	0.80	0.68	0.68	0.85	0.71	0.73
LLcpueOP_PTTP	0.65	0.72	0.72	0.65	0.77	0.64	0.64	0.78	0.64	0.67
LLcpueOP_PTTP_ TWcpueR6_dwtSize50	0.61	0.66	0.64	0.63	0.68	0.64	0.63	0.74	0.65	0.66
LLcpueOP_PTTP_ TWcpueR6_h65	0.86	0.97	0.95	0.88	1.01	0.87	0.86	1.03	0.88	0.91
LLcpueOP_PTTP_ TWcpueR6_h95	0.51	0.58	0.56	0.53	0.60	0.52	0.52	0.62	0.52	0.54
LLcpueOP_PTTP_ TWcpueR6_hEST	1.15	1.31	1.28	1.18	1.36	1.17	1.17	1.39	1.19	1.23
LLcpueOP_PTTP_ TWcpueR6_JPSize	0.75	0.85	0.82	0.77	0.88	0.74	0.75	0.88	0.75	0.78
LLcpueOP_PTTP_ TWcpueR6_PSold	0.72	0.68	0.67	0.66	0.74	0.63	0.66	0.79	0.67	0.69
LLcpueOP_PTTP_ TWcpueR6_splitSelectR3	0.52	0.58	0.51	0.50	0.61	0.52	0.53	0.65	0.54	0.56
LLcpueOP_RTTP	0.72	0.81	0.85	0.74	0.90	0.77	0.79	0.98	0.84	0.85
LLcpueOP_TWcpueR6 _PTTP	0.74	0.83	0.81	0.76	0.86	0.73	0.73	0.87	0.74	0.77
LLcpueOP_TWcpueR6 _PTTP_JPPS_JPtags	0.68	0.76	0.74	0.69	0.80	0.68	0.68	0.81	0.69	0.72
LLcpueOP_TWcpueR6 _RTTP	0.79	0.90	0.93	0.81	0.98	0.82	0.84	1.05	0.89	0.90
Region3	0.65	0.66	0.80	0.69	0.78	0.76	0.77	0.87	0.73	0.78

Table 19: Comparison of the historical estimates of $\boldsymbol{SB_{current}/SB_{MSY}}$ for each year from 2001-2009 for the model runs described in Table 10.

	$SB_{current}/SB_{MSY}$									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2006-09
LLcpueAG_PTTP	1.50	1.35	1.54	1.62	1.63	1.76	1.82	1.85	1.91	1.83
LLcpueAG_RTTP	1.47	1.48	1.51	1.65	1.62	1.76	1.76	1.81	1.74	1.77
LLcpueOP_PTTP	1.19	1.21	1.24	1.35	1.35	1.52	1.52	1.59	1.57	1.55
LLcpueOP_PTTP_TWcpueR6_dwtSize50	1.37	1.21	1.32	1.37	1.36	1.50	1.55	1.54	1.57	1.54
LLcpueOP_PTTP_TWcpueR6_h65	1.00	0.97	1.04	1.11	1.10	1.25	1.25	1.31	1.30	1.28
LLcpueOP_PTTP_TWcpueR6_h95	1.47	1.45	1.56	1.65	1.65	1.88	1.87	1.95	1.99	1.92
LLcpueOP_PTTP_TWcpueR6_hEST	0.86	0.83	0.89	0.95	0.94	1.07	1.07	1.12	1.11	1.09
LLcpueOP_PTTP_TWcpueR6_JPSize	1.08	1.08	1.17	1.25	1.24	1.40	1.40	1.51	1.51	1.46
LLcpueOP_PTTP_TWcpueR6_PSold	1.18	1.10	1.18	1.28	1.26	1.41	1.40	1.47	1.48	1.44
LLcpueOP_PTTP_TWcpueR6_splitSelectR3	1.27	1.27	1.39	1.48	1.48	1.69	1.68	1.72	1.75	1.71
LLcpueOP_RTTP	1.22	1.19	1.19	1.27	1.27	1.40	1.38	1.39	1.29	1.37
LLcpueOP_TWcpueR6_PTTP	1.13	1.09	1.18	1.24	1.24	1.42	1.43	1.51	1.51	1.47
LLcpueOP_TWcpueR6_PTTP_JPPS_JPtags	1.16	1.14	1.26	1.34	1.30	1.49	1.49	1.56	1.57	1.53
LLcpueOP_TWcpueR6_RTTP	1.15	1.13	1.14	1.21	1.22	1.35	1.34	1.38	1.29	1.34
Region3	1.04	1.20	1.52	1.52	1.34	1.56	1.48	1.43	1.45	1.48

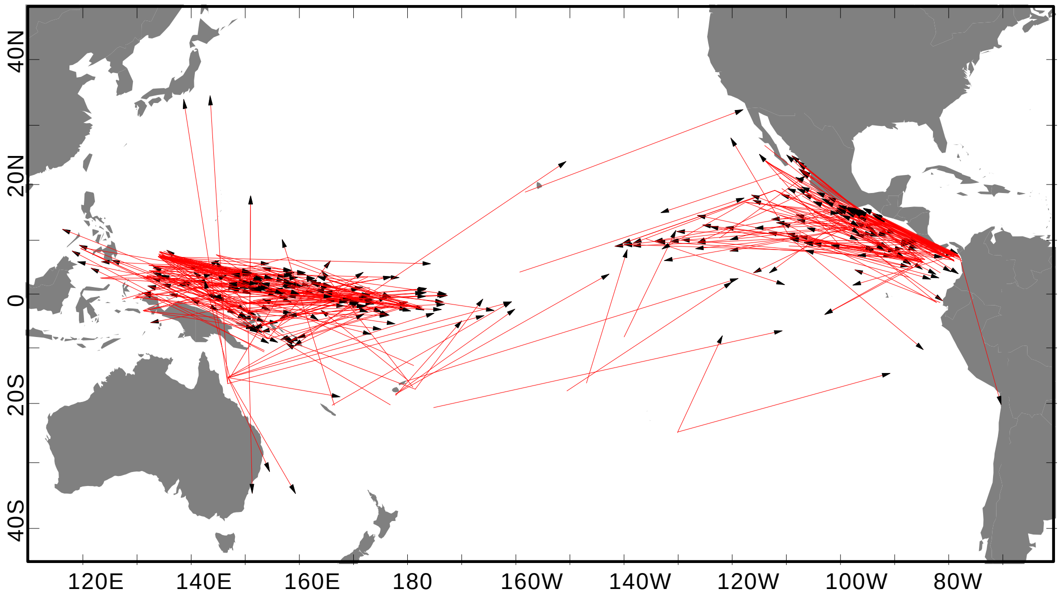


Figure 1. Long-distance (greater than 1,000 nmi) movements of tagged yellowfin tuna. The figure does not include PTTP or Japanese releases/recoveries.

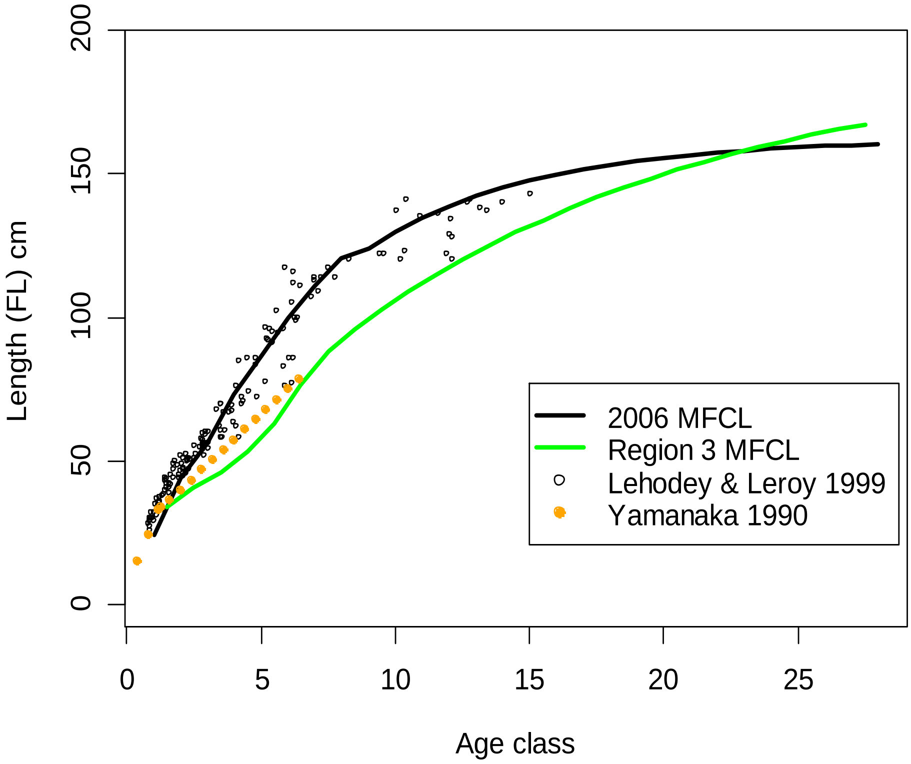


Figure 2. A comparison of yellowfin growth estimated from WCPO and 2007 region 3 MFCL models and the results from ageing studies using otolith daily increments.

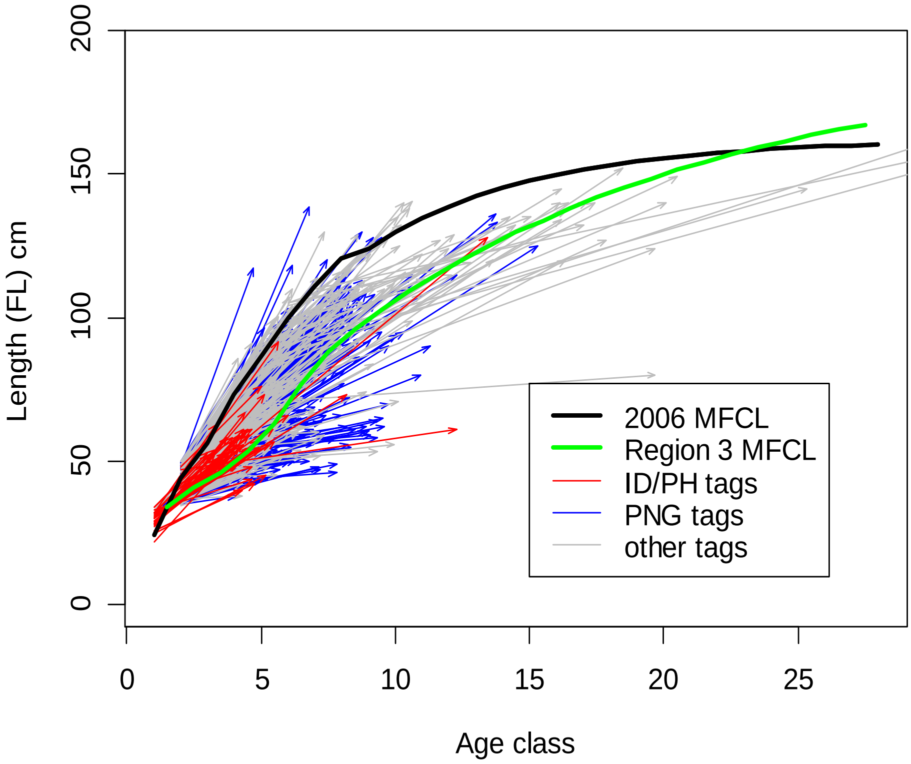


Figure 3. A comparison of yellowfin growth estimated from WCPO and region 3 (2007) MFCL models with growth increments from tagged fish released in Indonesian/Philippines waters, PNG waters, and other areas.

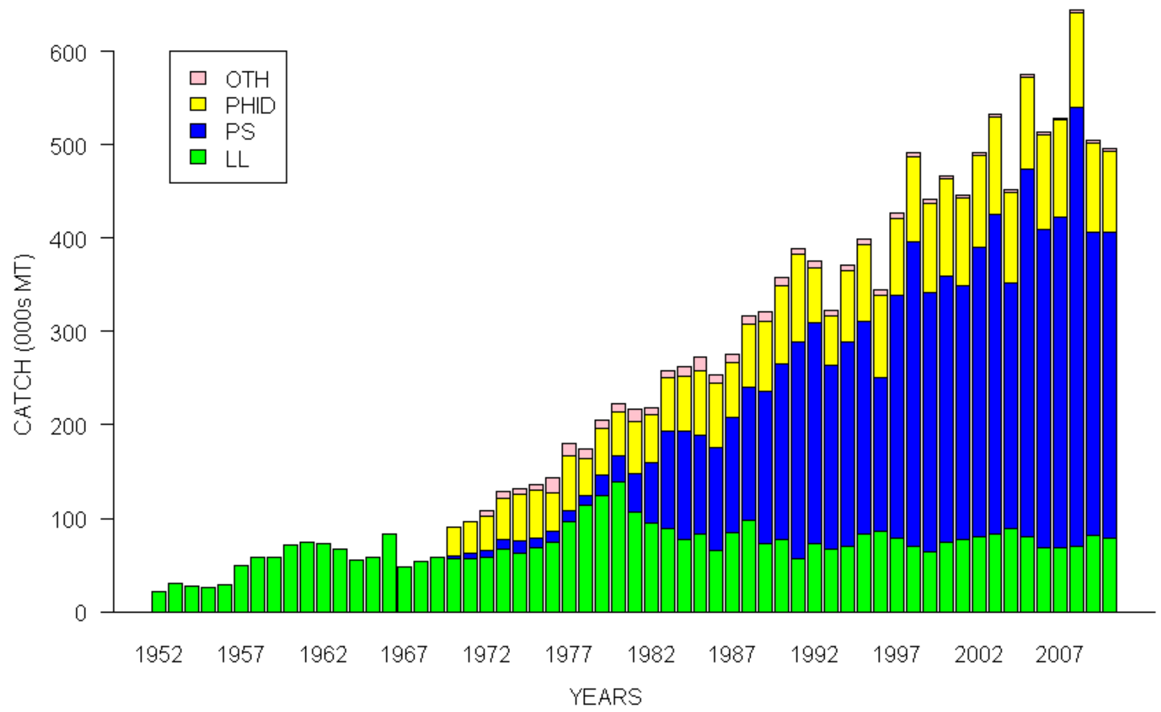


Figure 4. Total annual catches (1000s mt) of yellowfin from the WCPO included within the assessment model by fishing method from 1952 to 2010. The purse seine (PS) catches are the best available catch estimates (corrected for sampling bias). The annual catches from 2010 are incomplete.

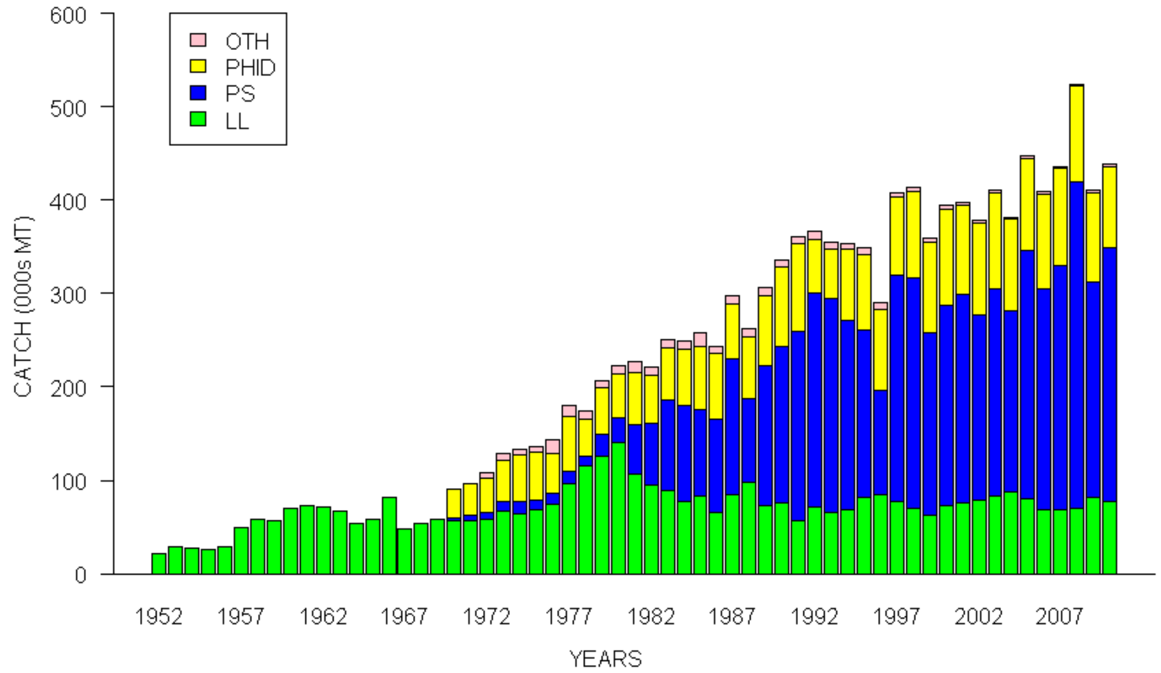


Figure 5. Total annual catches (1000s mt) of yellowfin from the WCPO included within the alternative PS catch history assessment model by fishing method from 1952 to 2010. The purse seine (PS) catches are <u>not</u> corrected for sampling bias. The annual catches from 2010 are incomplete.

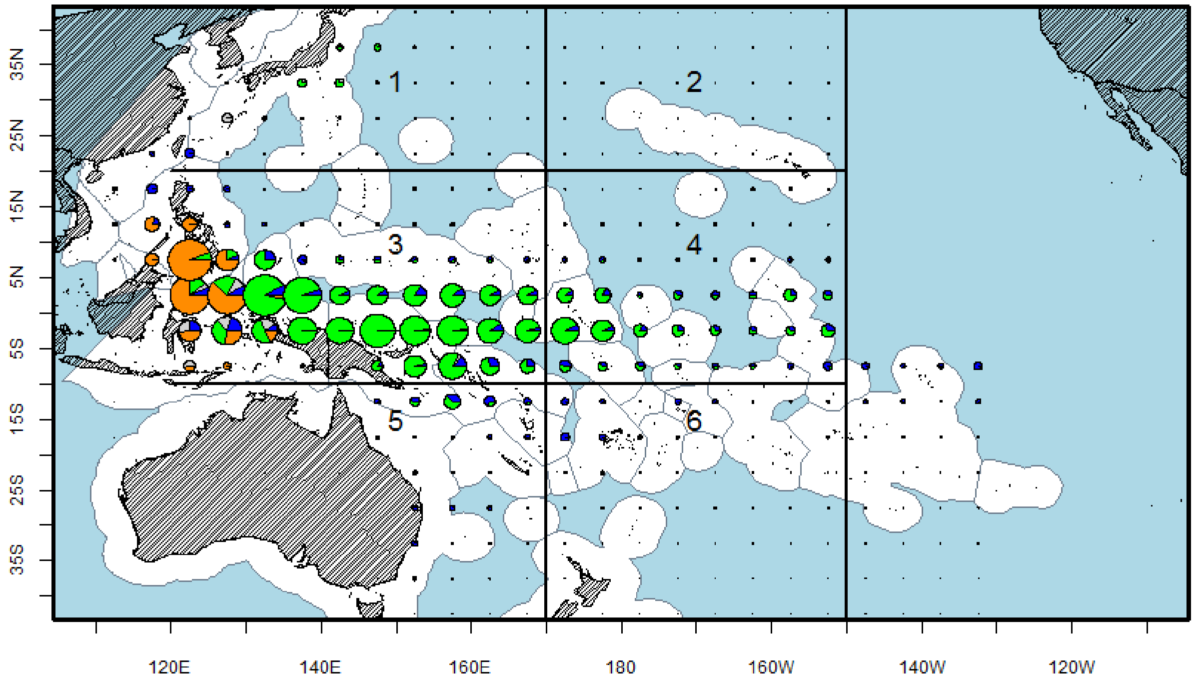


Figure 6. Distribution of cumulative WCPFC yellowfin tuna catch from 2000–2009 by 5 degree squares of latitude and longitude and fishing gear; longline (blue), purse-seine (green), pole-and-line (grey) and other (principally Indonesia and Philippines, dark orange). The grey lines indicate the spatial stratification of the assessment models.

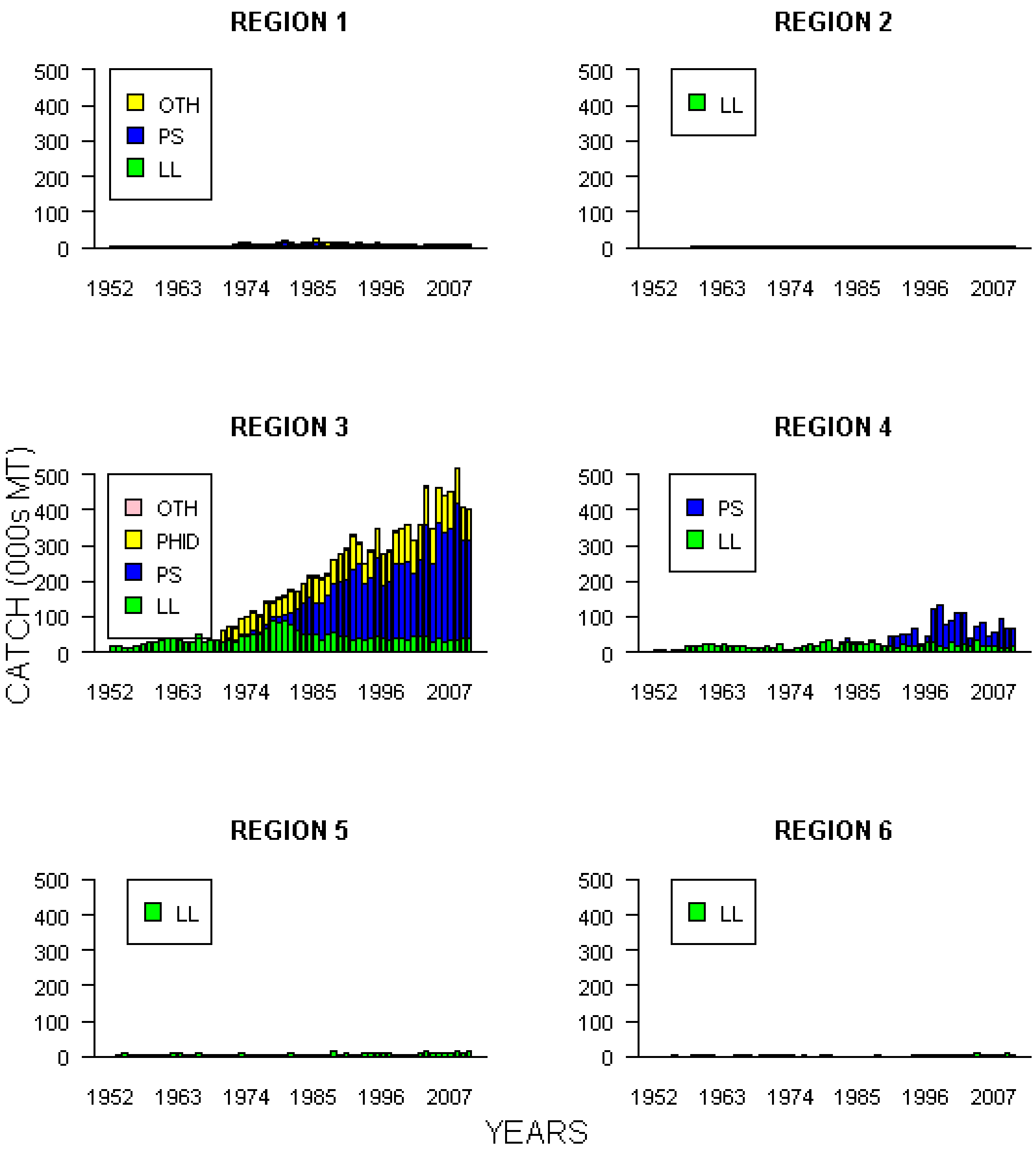


Figure 7. Total annual catch (1000s mt) of yellowfin by fishing method and MFCL region from 1952 to 2010. Data from 2010 are incomplete.

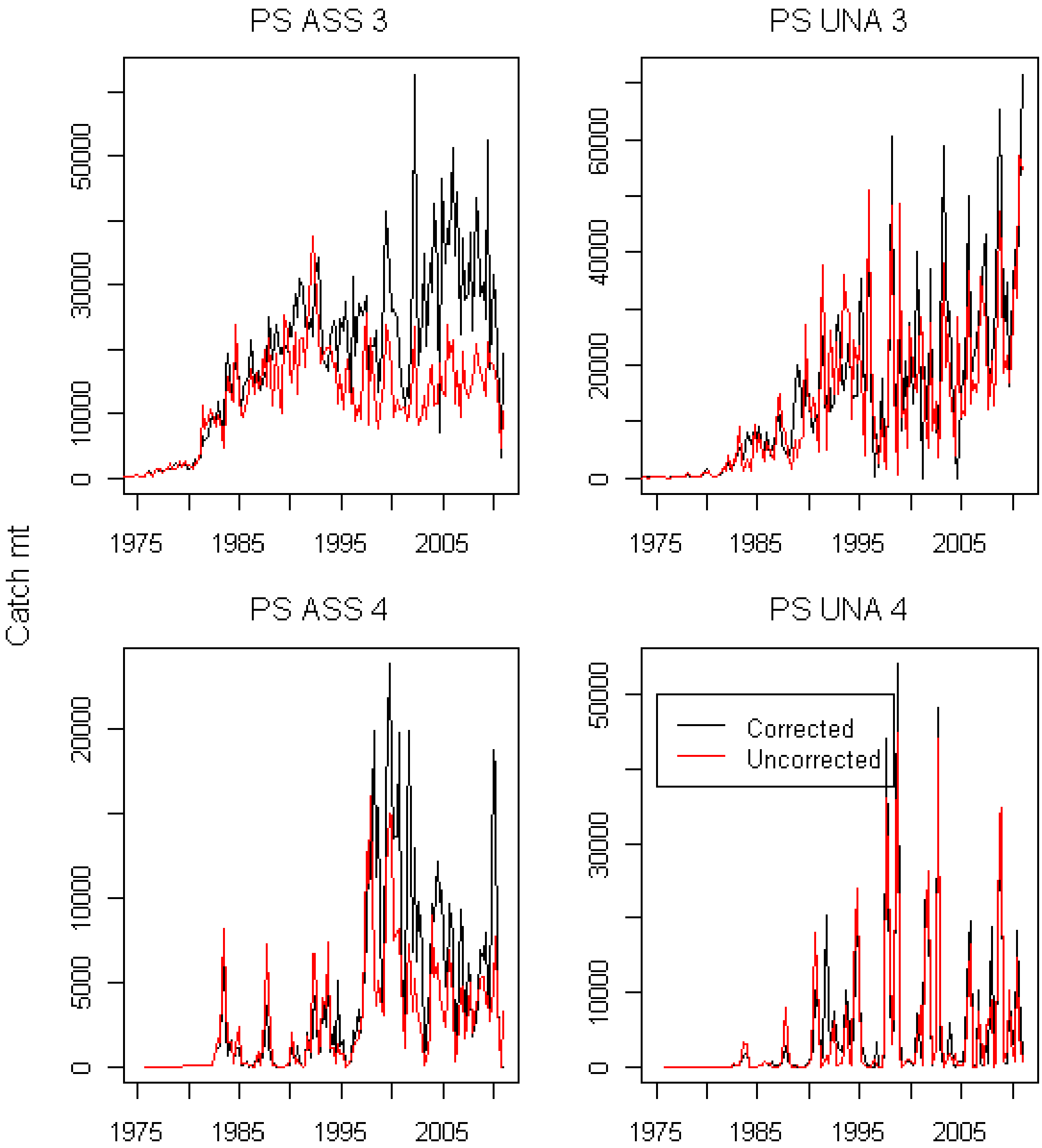


Figure 8. A comparison of the corrected (spill sample) and uncorrected quarterly purse-seine catch histories by fishery.

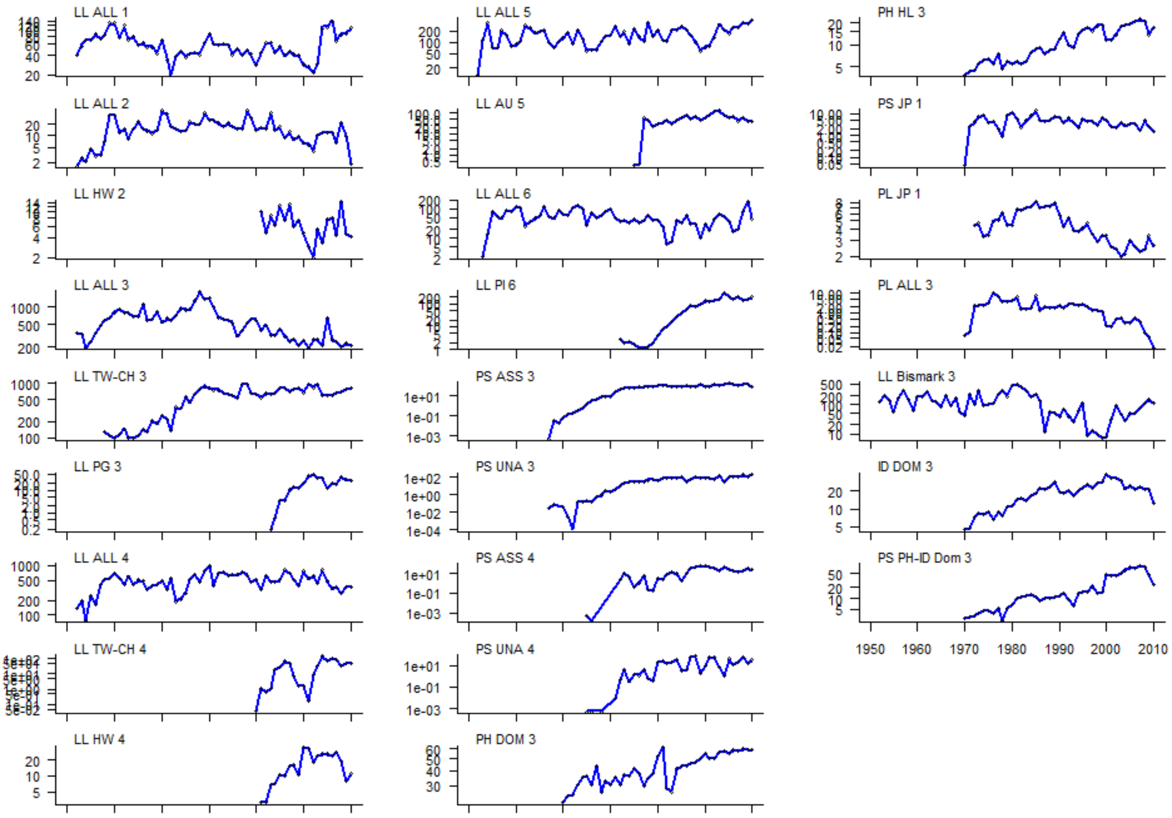


Figure 9. Annual catches, by fishery. Circles are observed and the lines are model predictions. Units are catch number in thousands for the longline fisheries and thousand metric tonnes for all other fisheries.

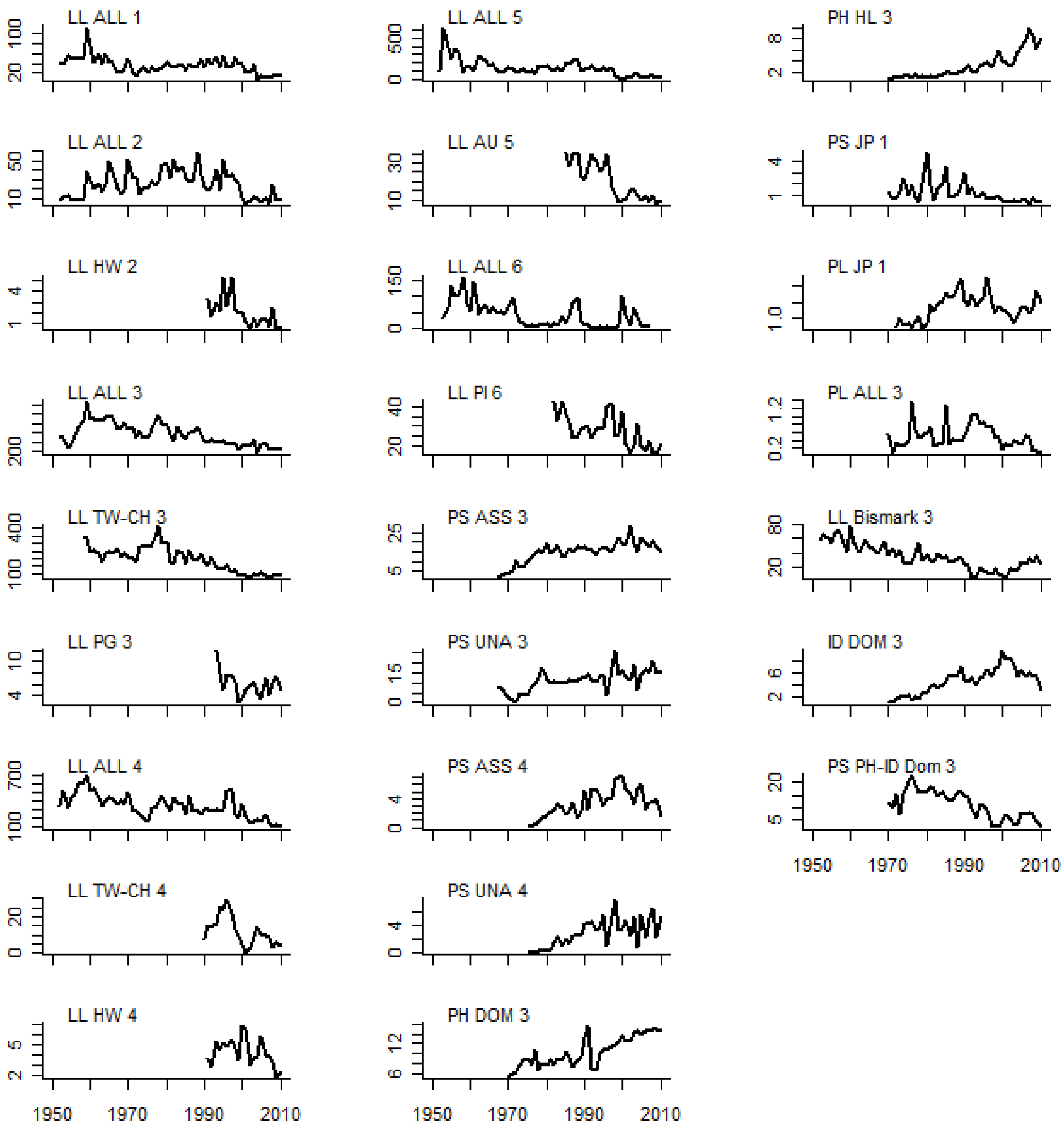


Figure 10. Catch-per-unit-effort (CPUE) by fishery. Units are catch number per GLM-standardised effort (with increasing catchability) (fisheries LL ALL 1–LL ALL 6), catch number per 100 nominal hooks (LL HW, CH/TW LL, LL PI, LL PG, LL BMK) and catch (mt) per day fished/searched (all PS and PL fisheries). Note that CPUE for PH and ID MISC 3 is arbitrary and not based on data (see discussion on catchability and effort deviation constraints for these fisheries).

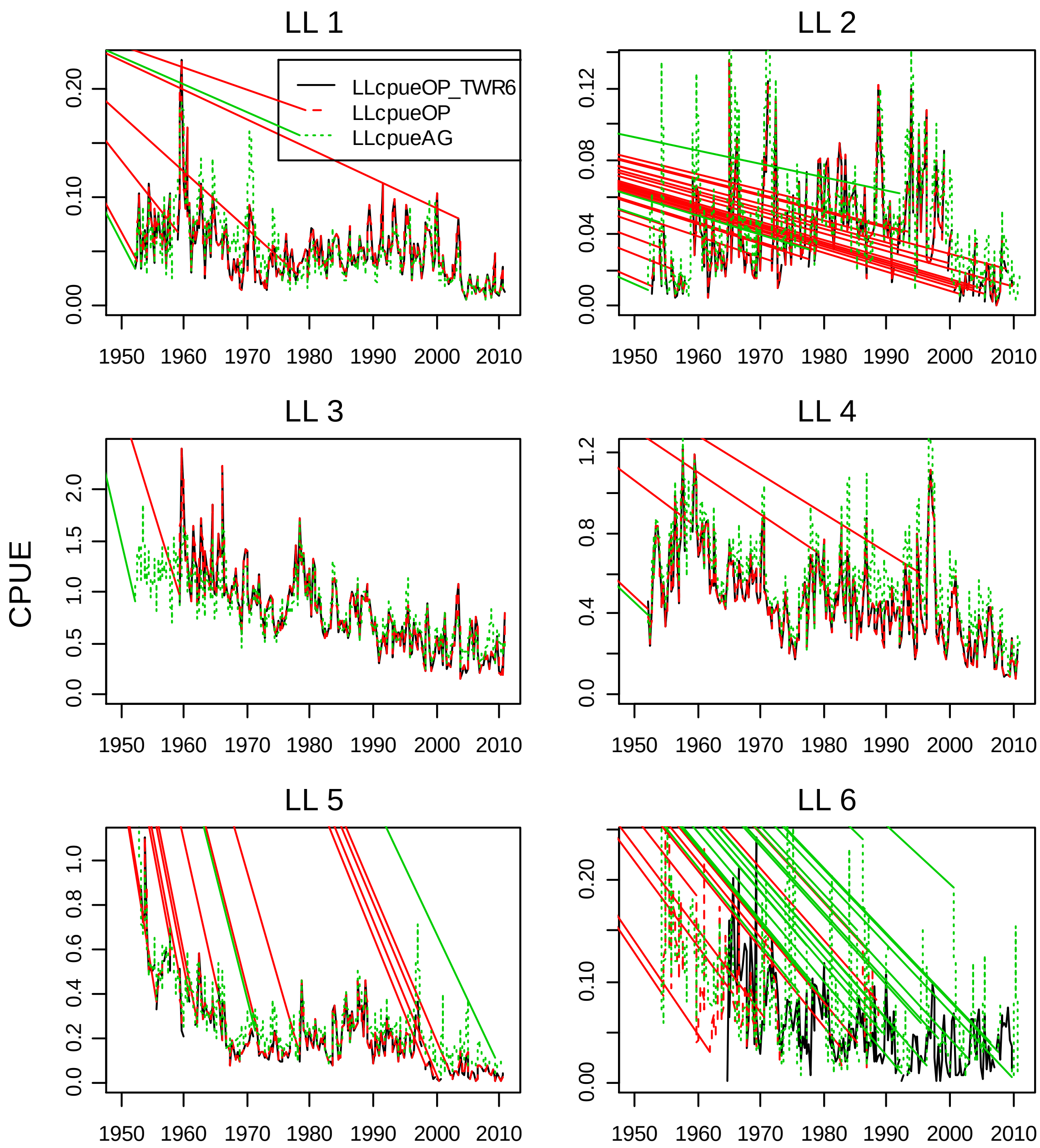


Figure 11. The three standardised catch-per-unit-effort (CPUE) options for the principal longline fisheries (LL ALL 1–6), scaled by the respective region scalars.

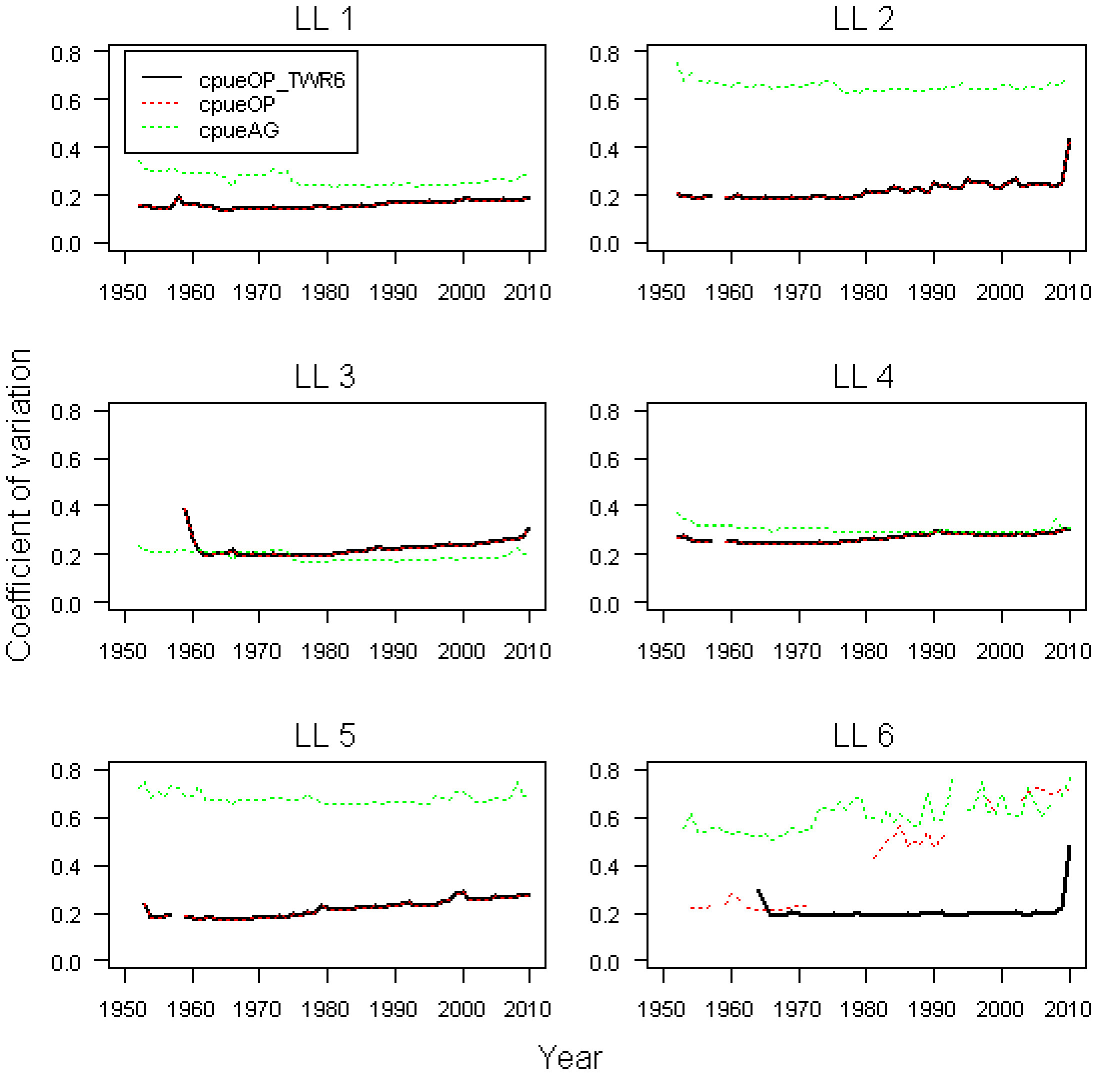


Figure 12. The coefficients of variation applied to the regional longline standardised CPUE indices by region for each the CPUE options.

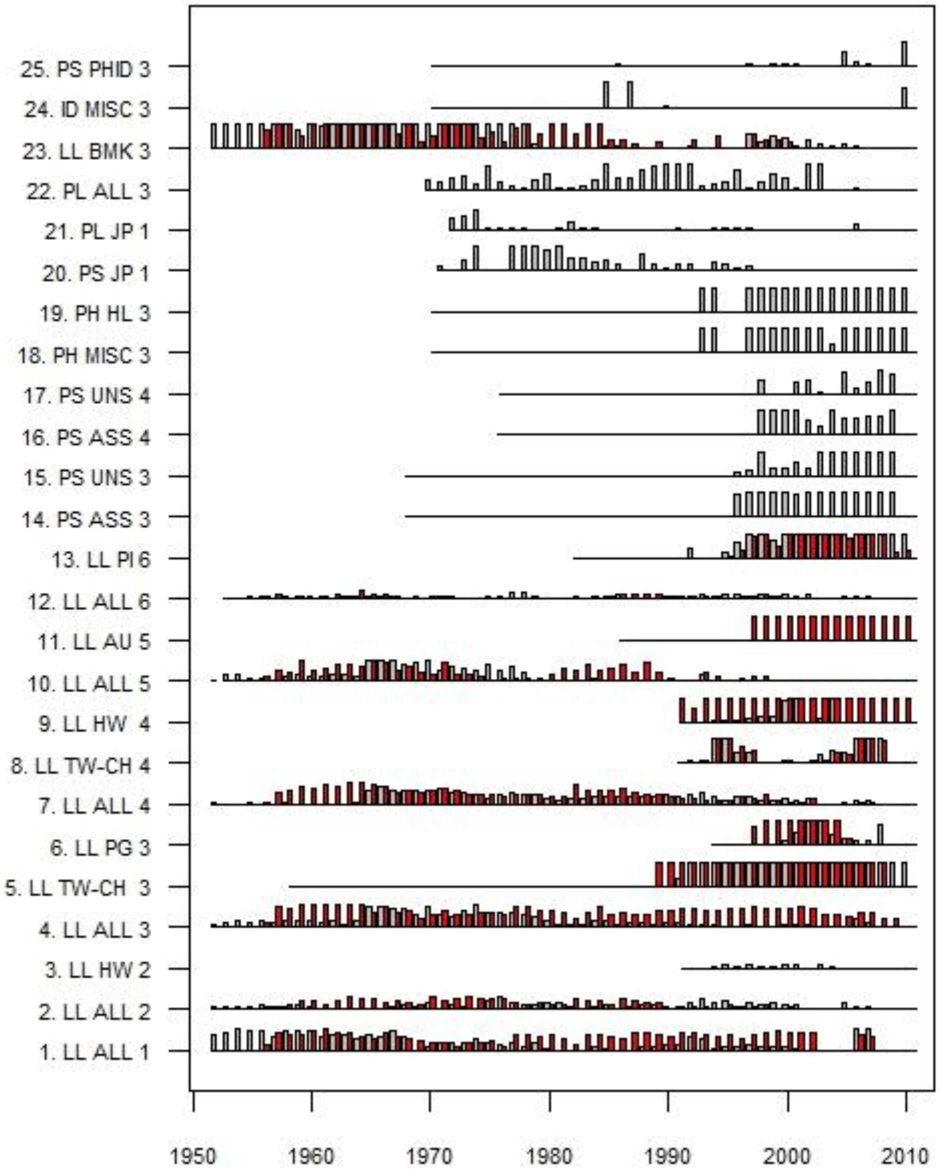


Figure 13. Number of fish size measurements by year for each fishery. The grey bars represent length measurements and the red bars represent weight measurements. The bar height is proportional to the number of fish measured up to a maximum of 4,000 which corresponds to the maximum effective sample size (1,000 fish per quarter). The extent of the horizontal lines indicates the period over which each fishery occurred.

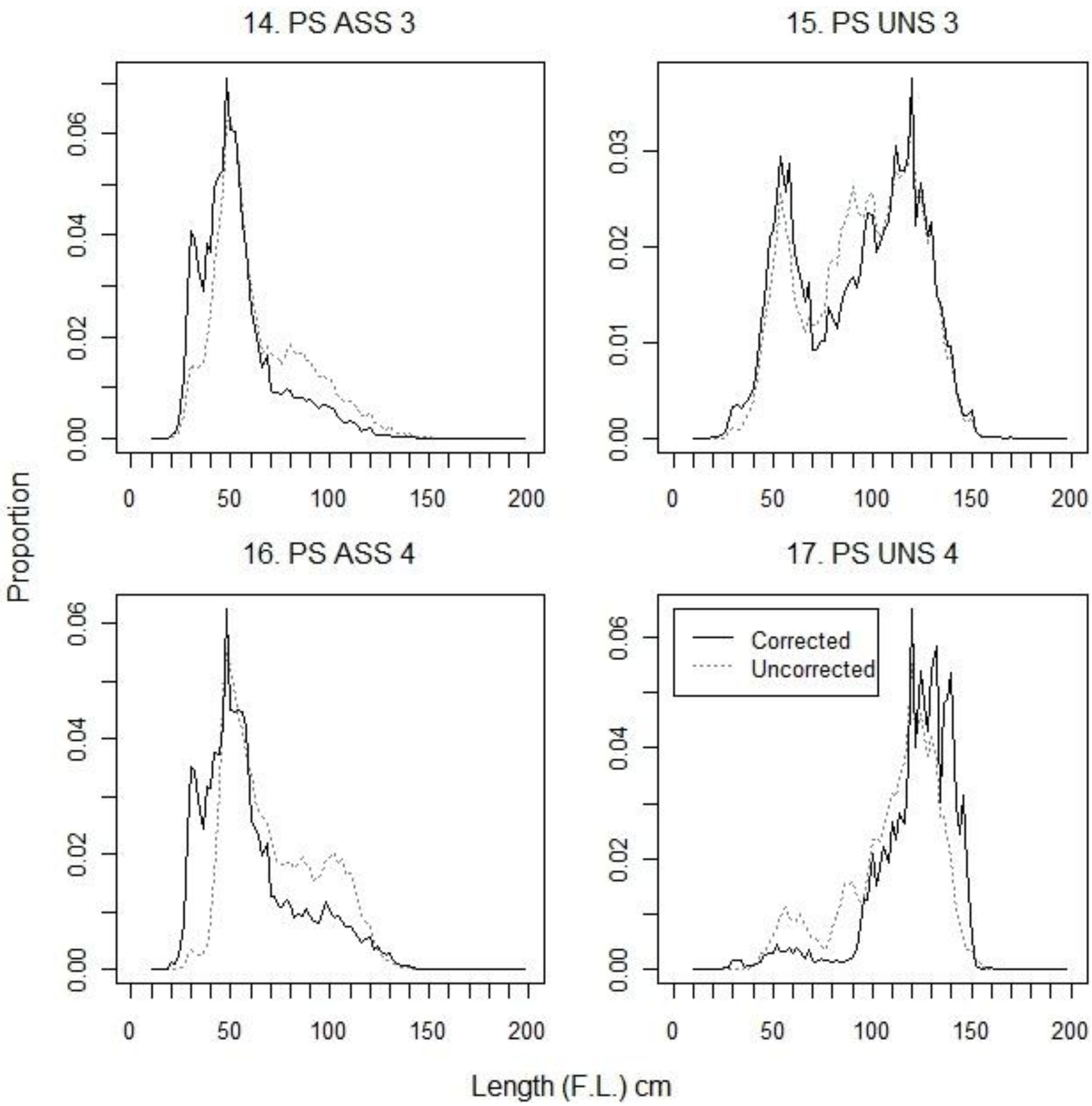


Figure 14. Comparison of the bias corrected length frequency data from the purse seine fisheries aggregated for the period 1996-2007.

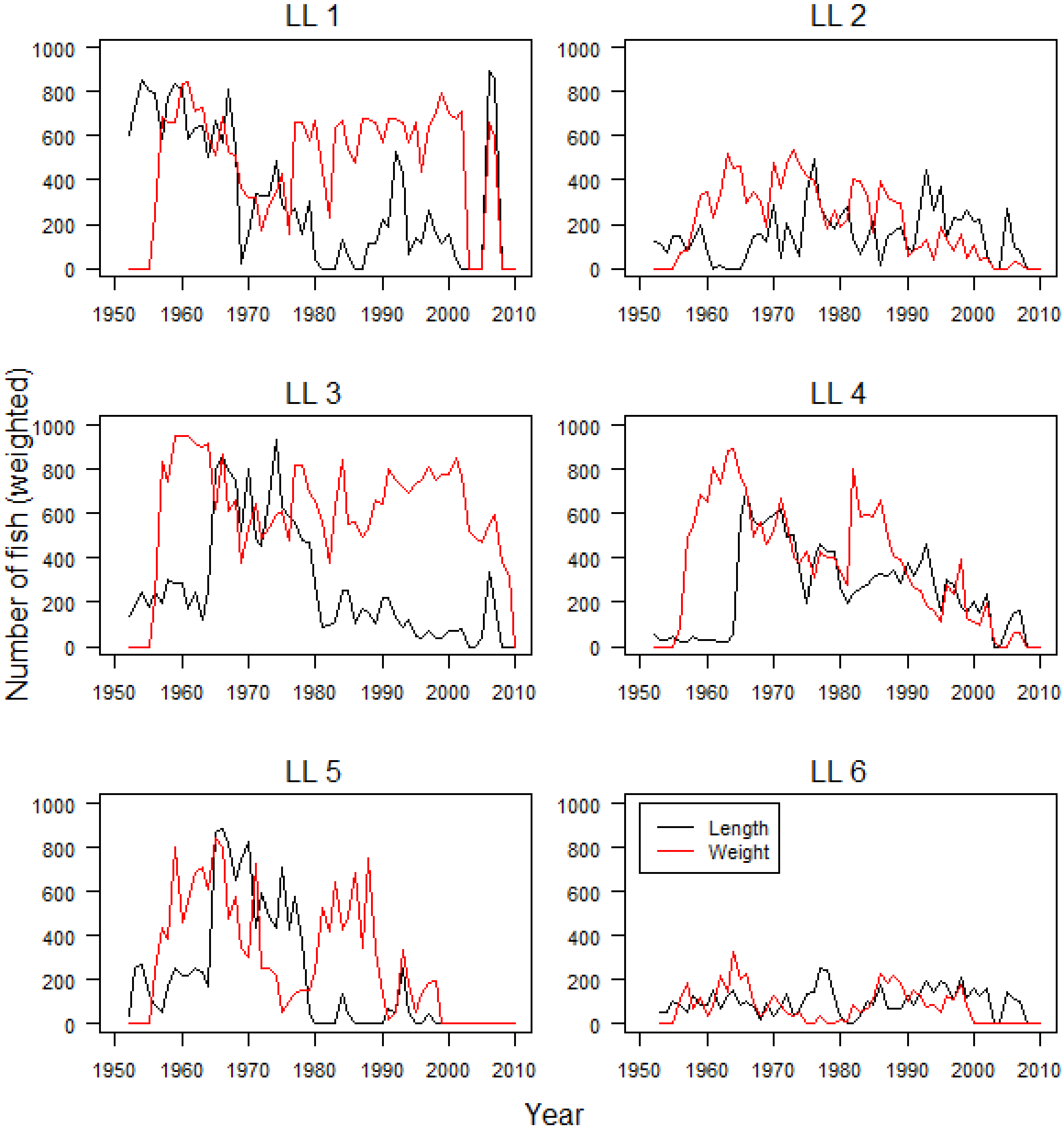


Figure 15. The sample size (number of fish) of the Japanese longline length and weight frequency data included in the assessment model by region (following spatial reweighting). For presentation purposes, sample sizes were averaged by year. For the principal model runs, the sample size was divided by 20 to determine the effective sample size used in the model.

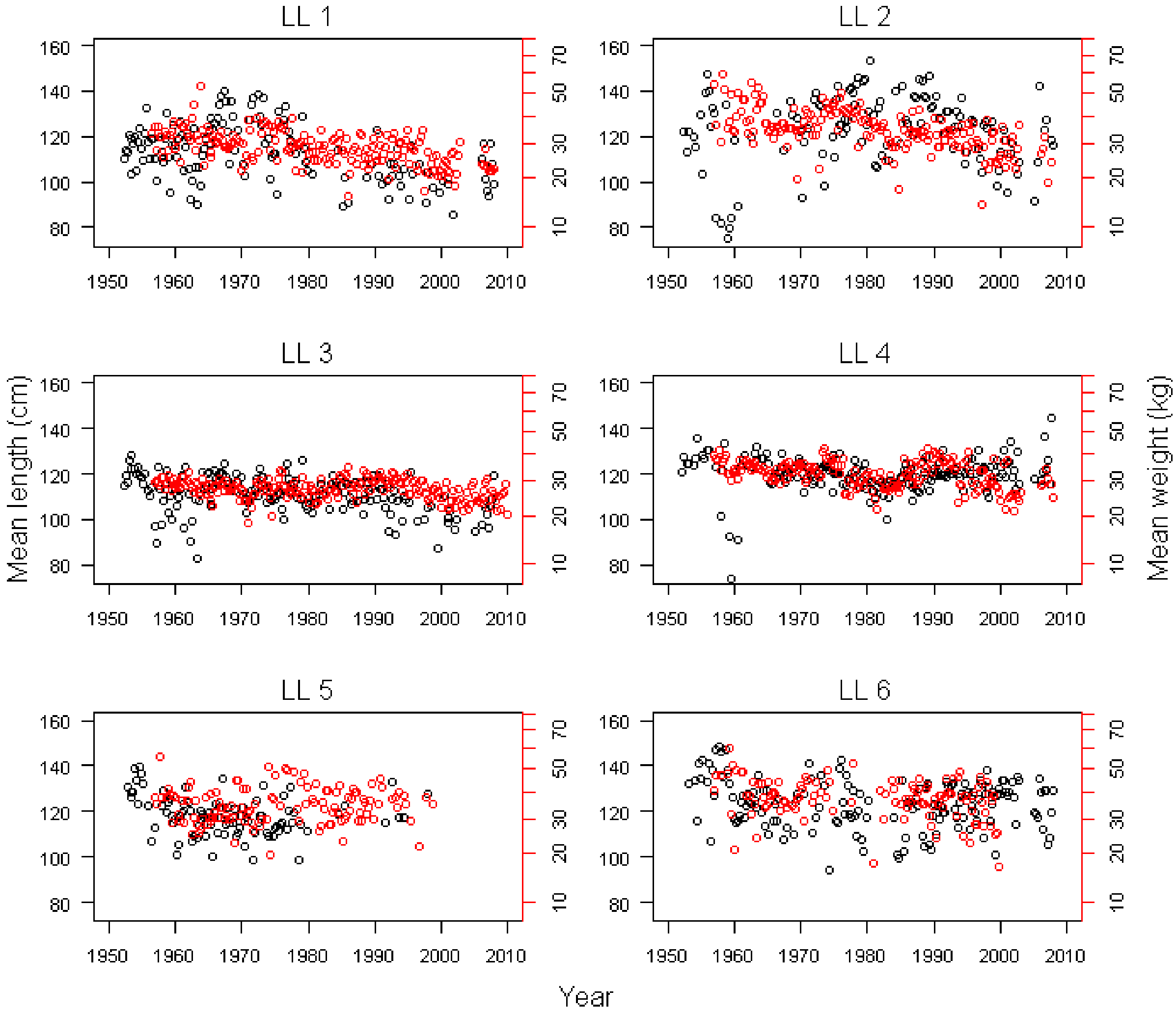


Figure 16. The mean fish length (F.L.) (black) and fish weight (red) from the individual quarterly size frequency samples from the region specific Japanese longline fisheries.

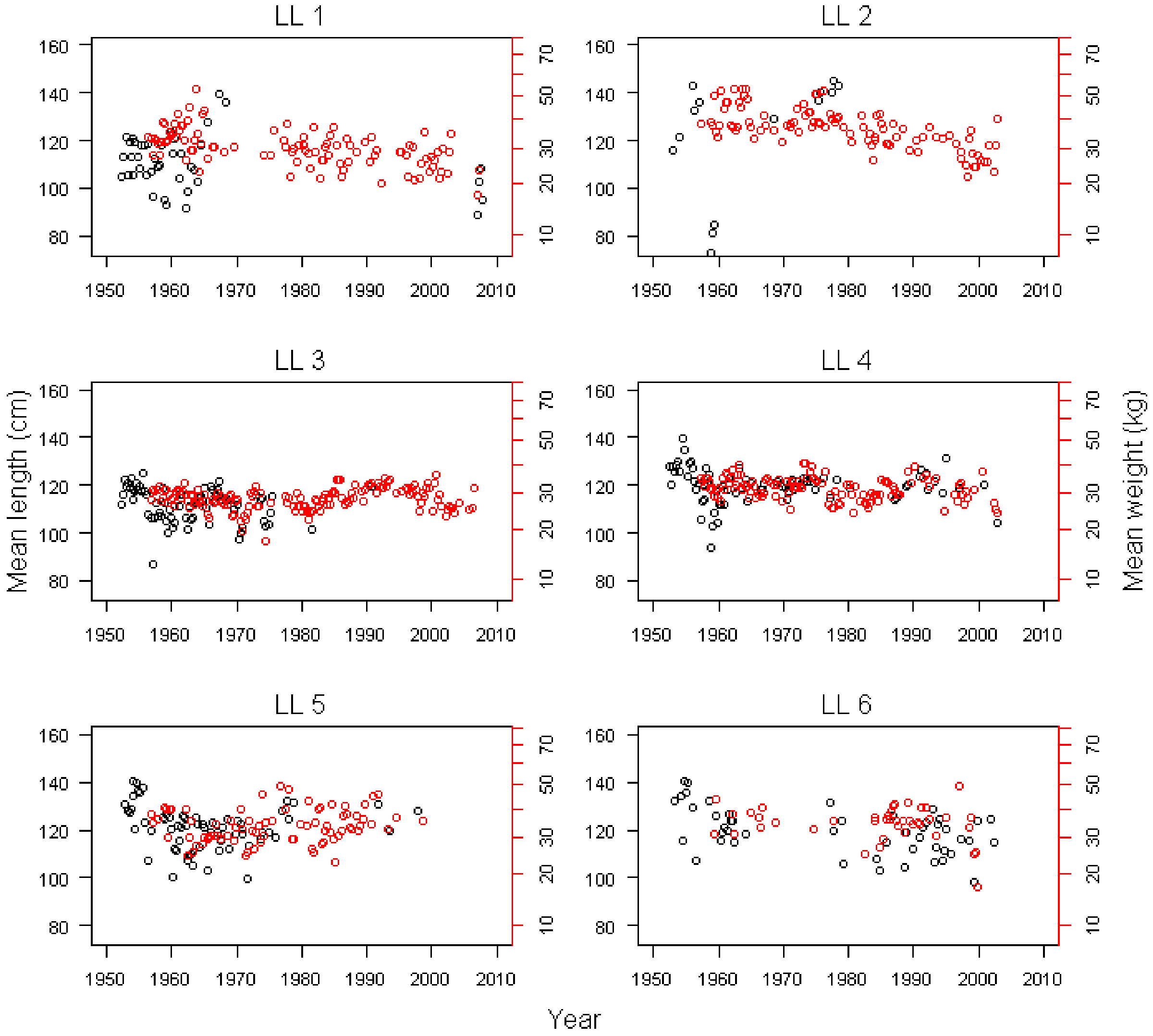


Figure 17. The mean fish length (F.L.) (black) and fish weight (red) from the individual quarterly size frequency samples from the region specific Japanese longline fisheries included in the 2009 yellowfin assessment.

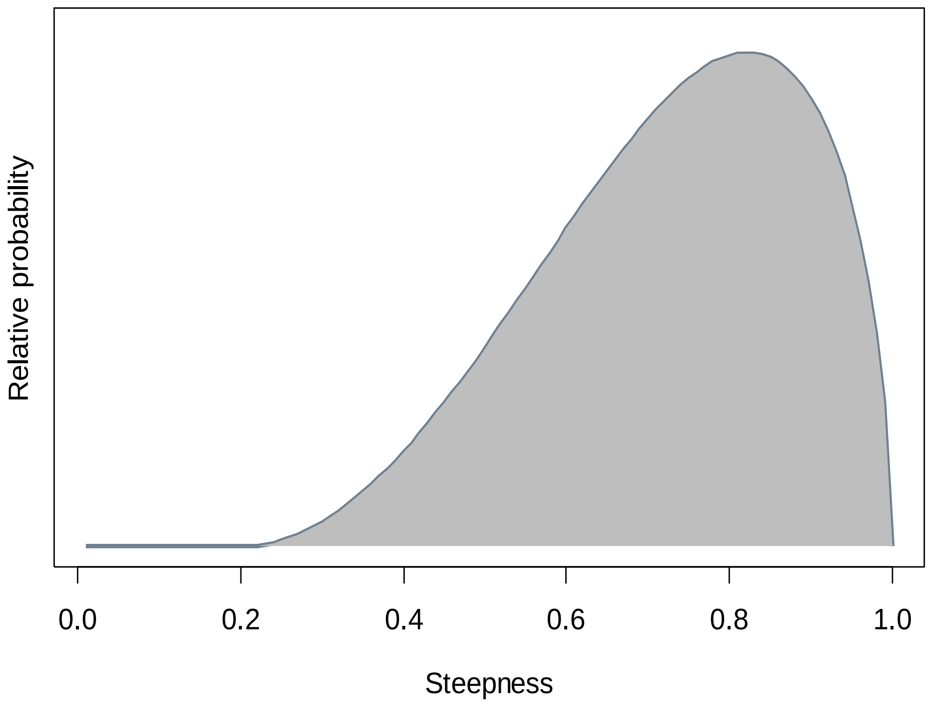


Figure 18. Prior for the steepness parameter of the relationship between spawning biomass and recruitment (SSR) (mode = 0.85, standard deviation = 0.16). The prior was used for the model option that estimated steepness.

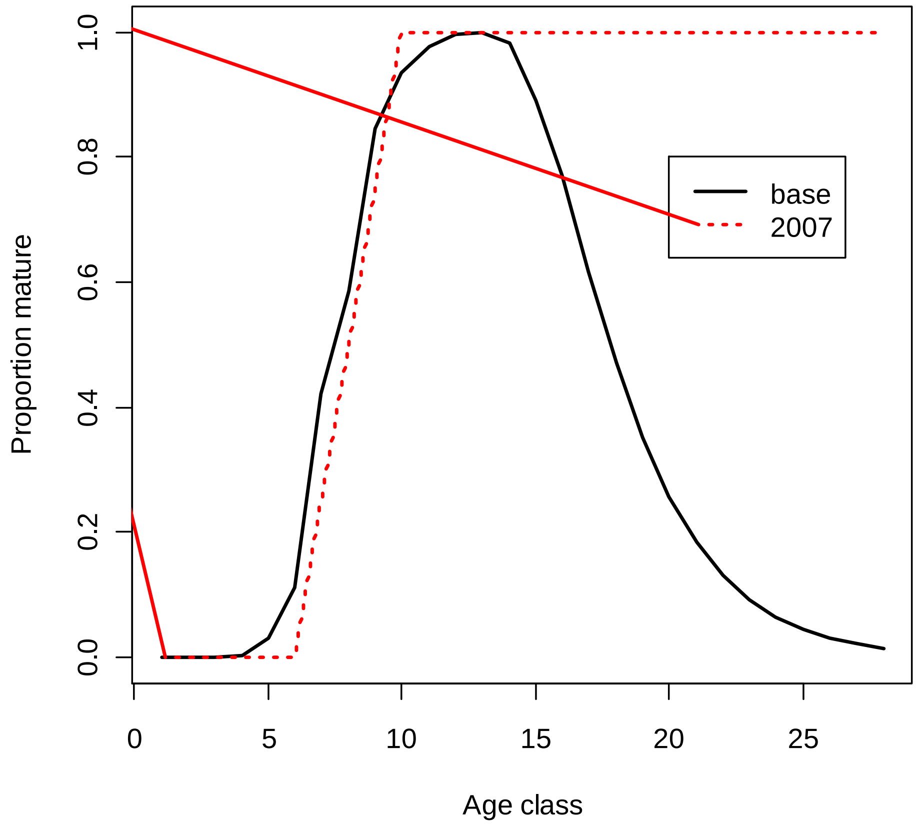


Figure 19. Proportion mature (reproductive potential) by age class for the current assessment (base) and the values assumed in the 2007 stock assessment.

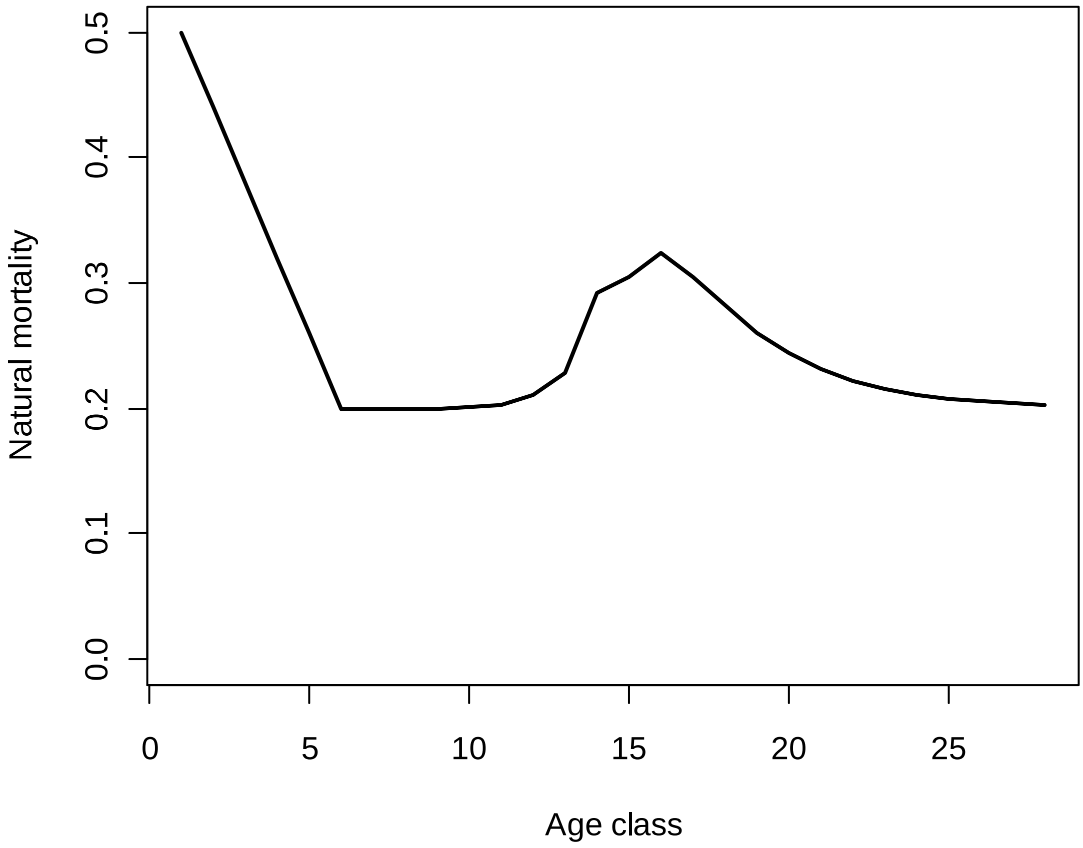


Figure 20. Age-specific natural mortality assumed for the assessment.

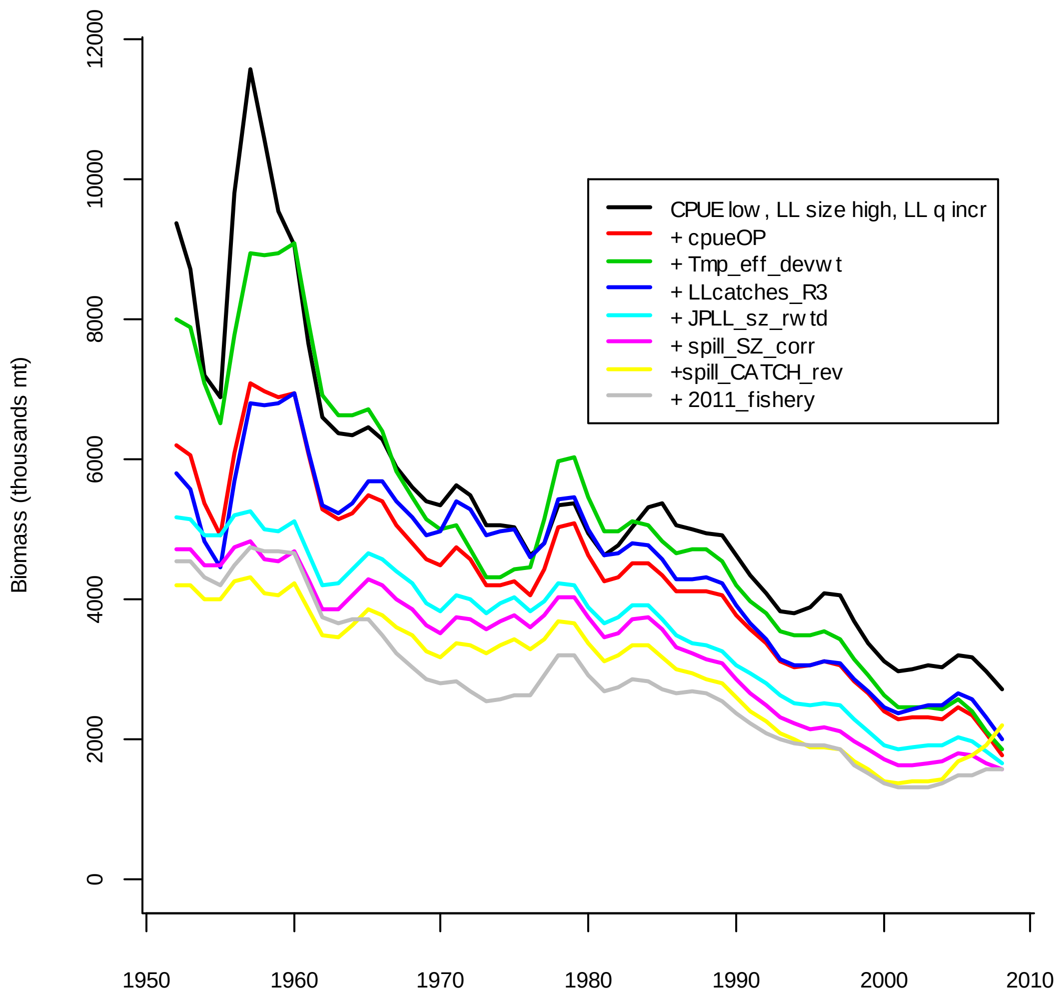


Figure 21. Total biomass (mt) from successive model runs with step-wise changes in key data sets and model assumptions from the "base 2009" model (CPUE low, LL sample high, LL q incr, black line) to replicate the 2011 reference model (grey line).

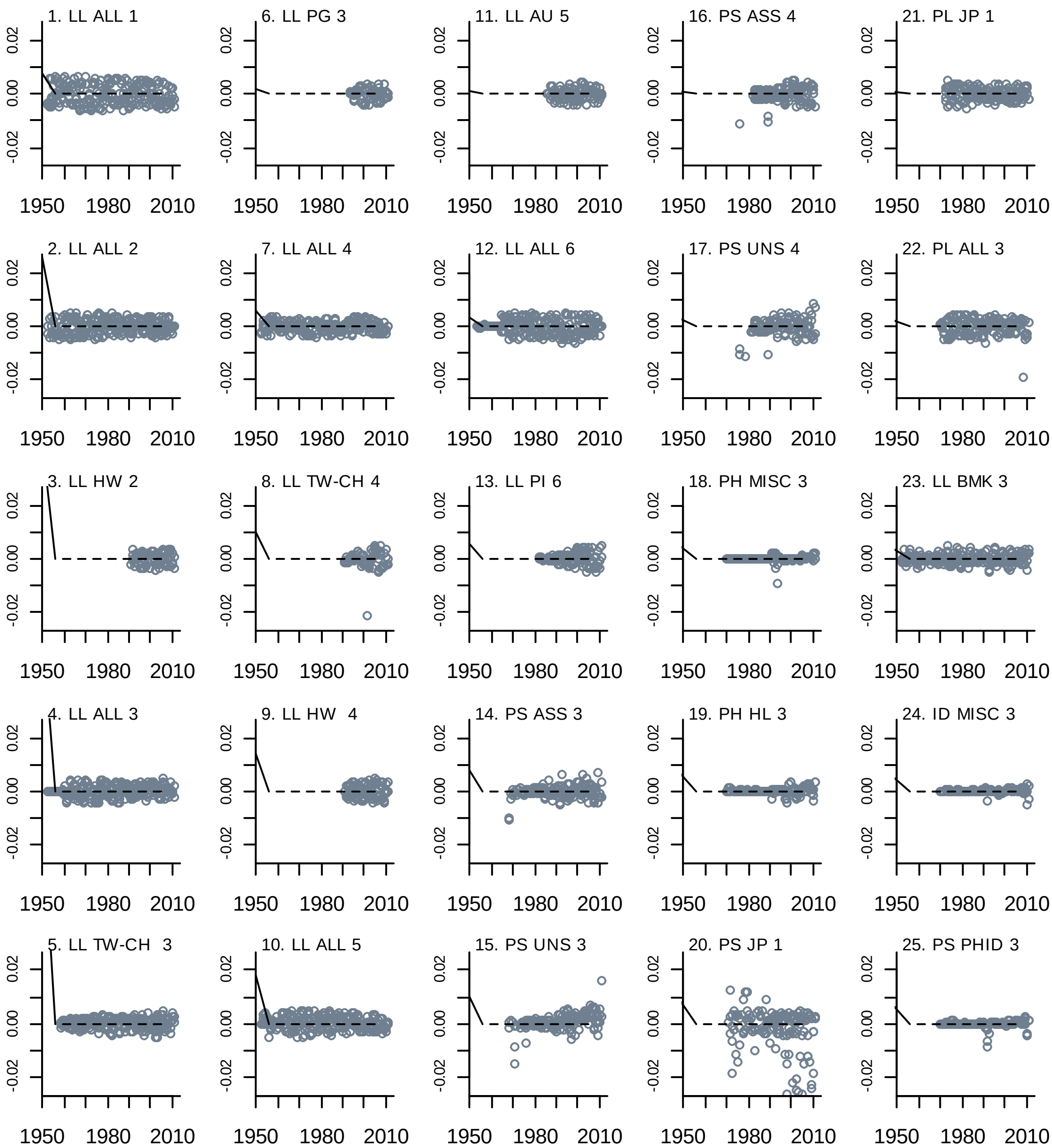


Figure 22. Residuals of ln (total catch) for each fishery.

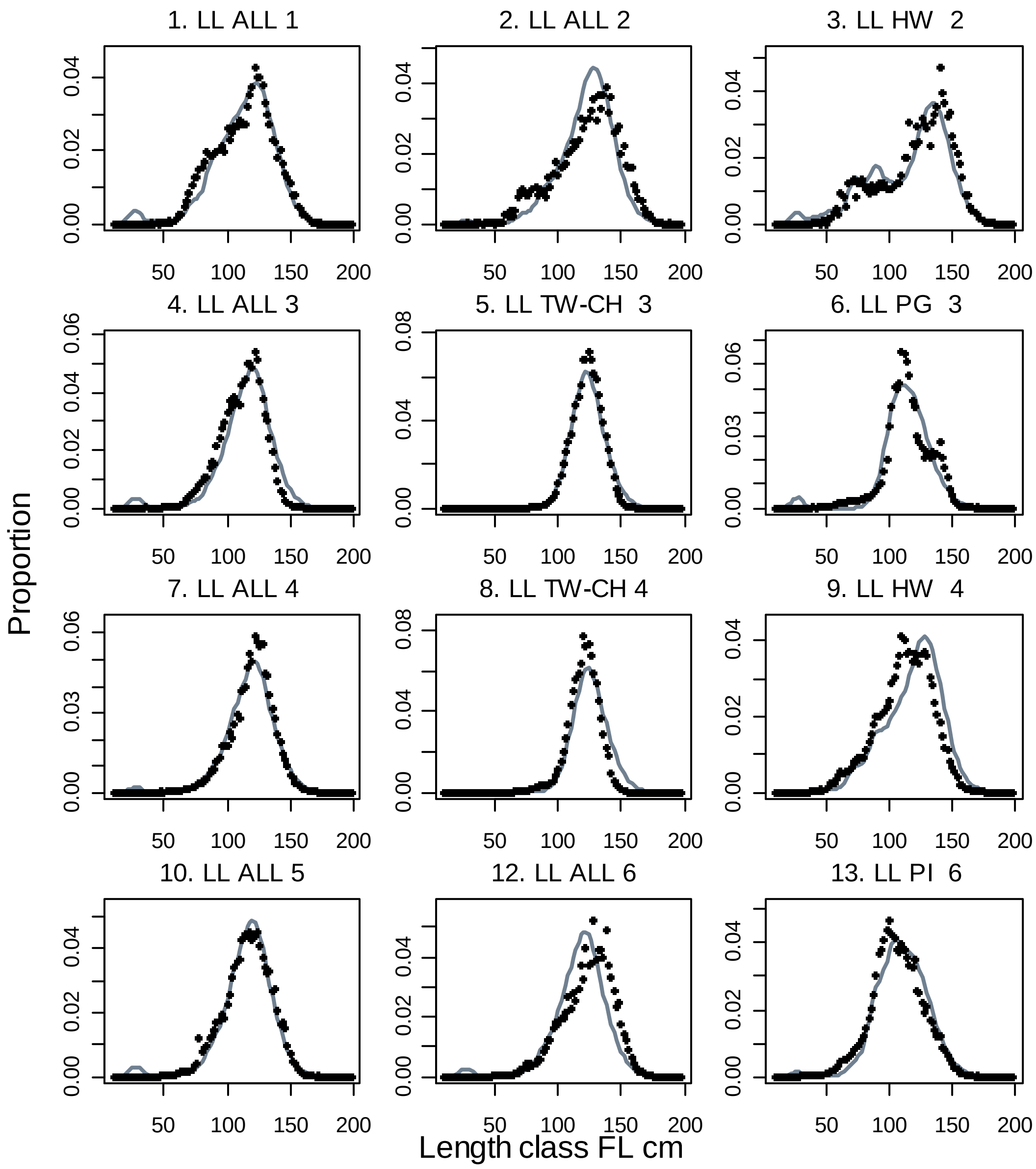


Figure 23. Observed (points) and predicted (line) length frequencies (in cm) for each fishery aggregated over time. No length data are included in the models for AU LL.

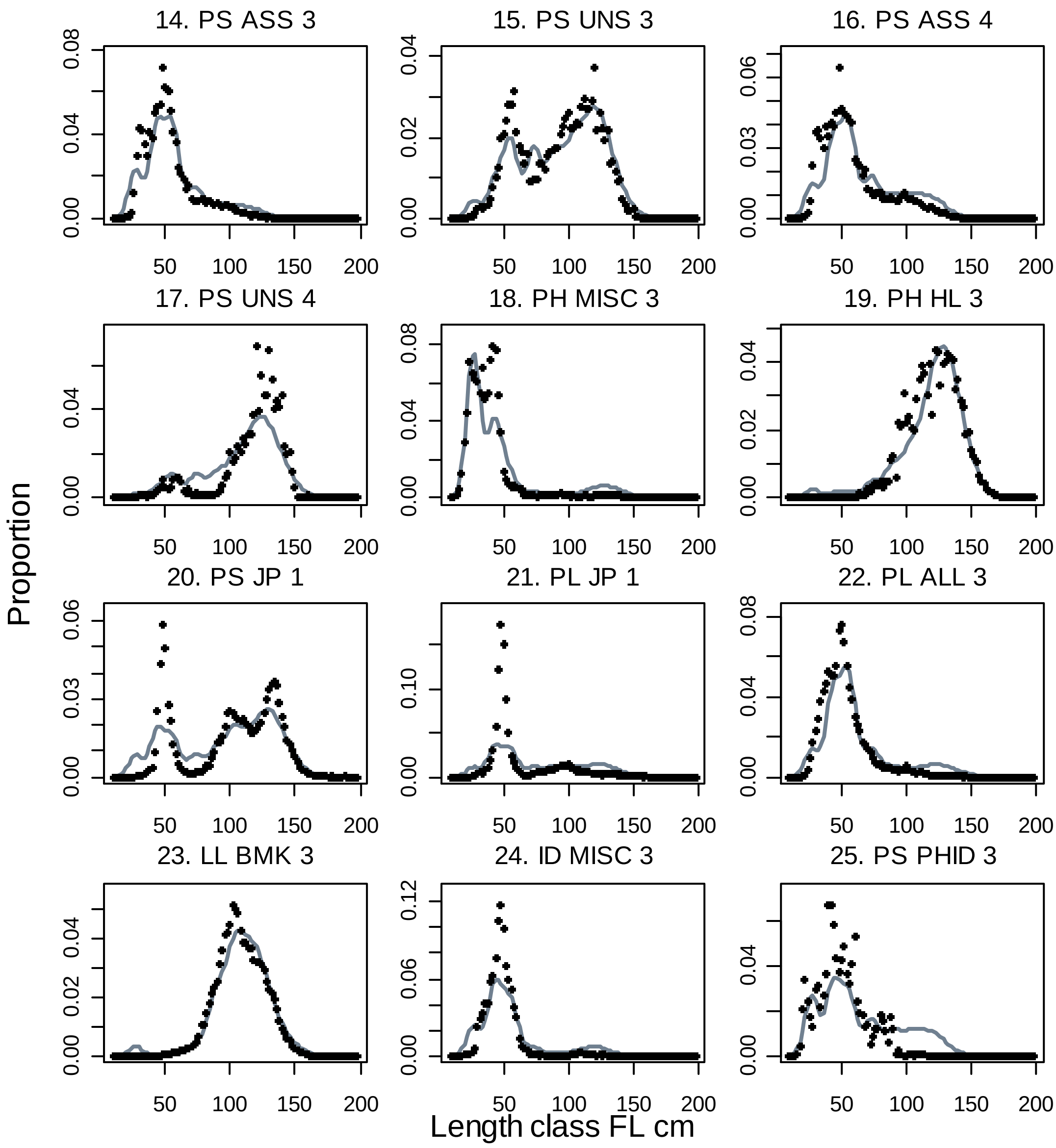


Figure 23 continued.

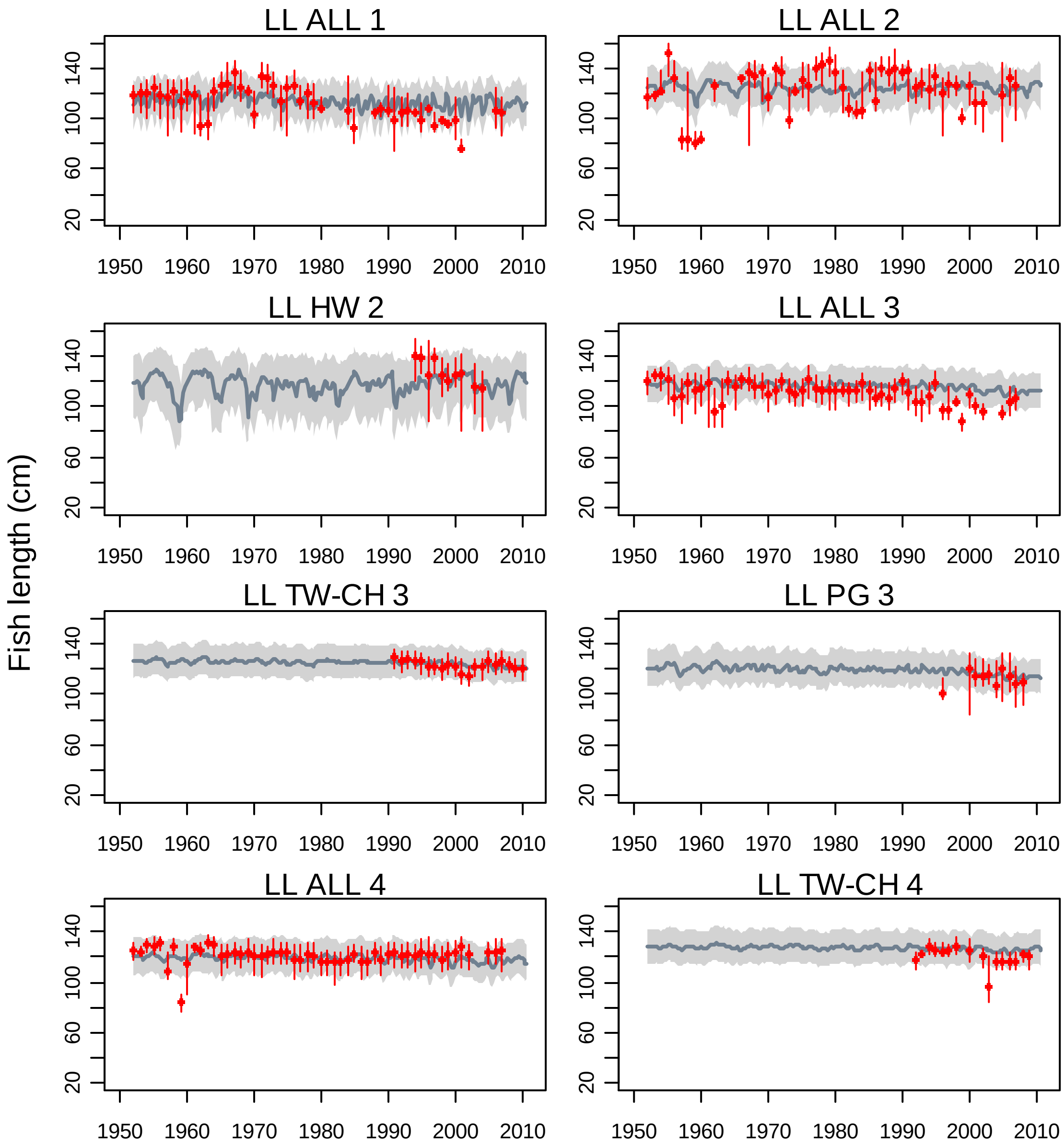


Figure 24. A comparison of the observed (red points) and predicted (grey line) median fish length (FL, cm) of yellowfin tuna by fishery for the main fisheries with length data. The confidence intervals represent the values encompassed by the 25% and 75% quantiles. Sampling data are aggregated by year and only length samples with a minimum of 30 fish per year are plotted.

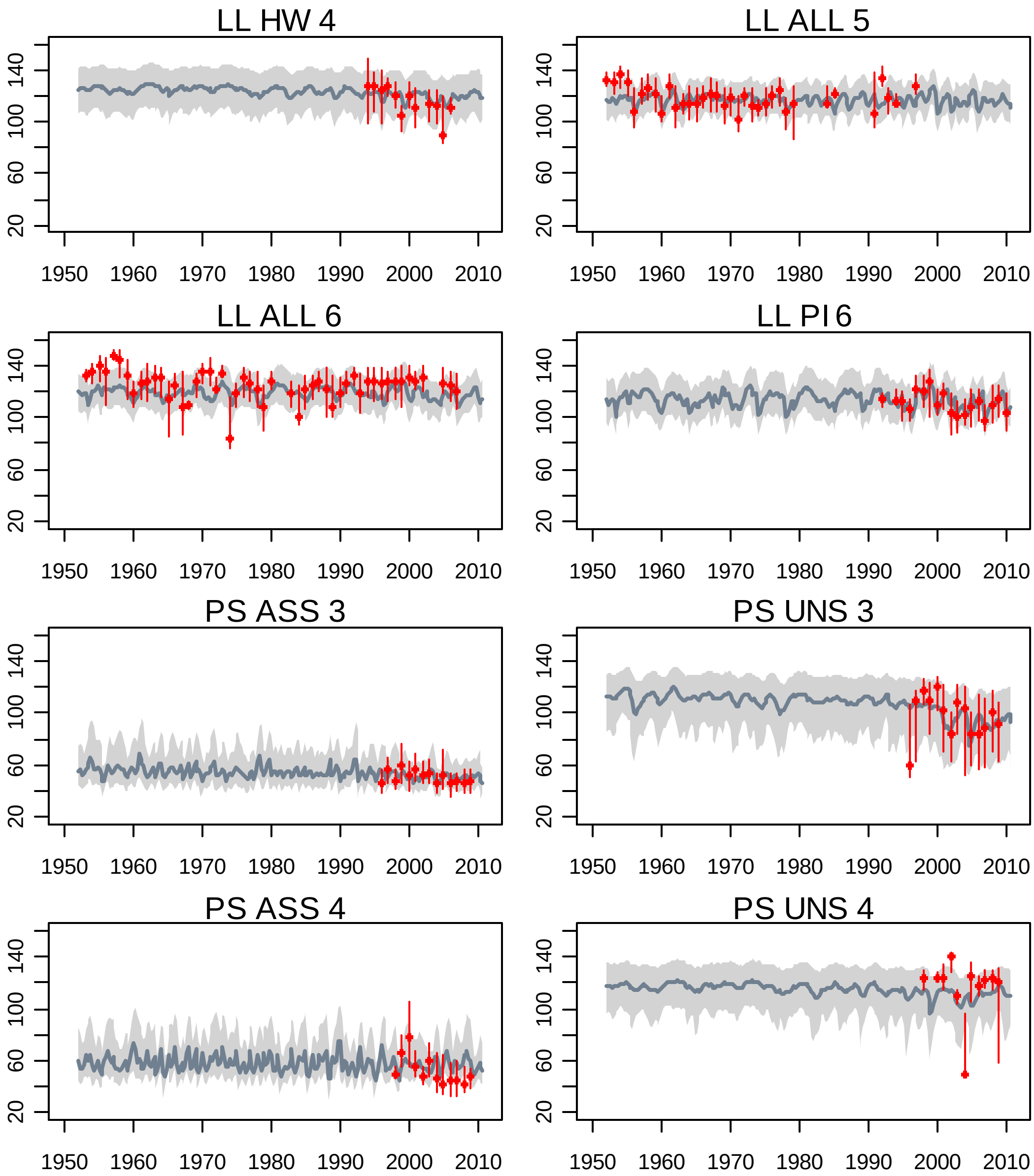


Figure 24 (continued).

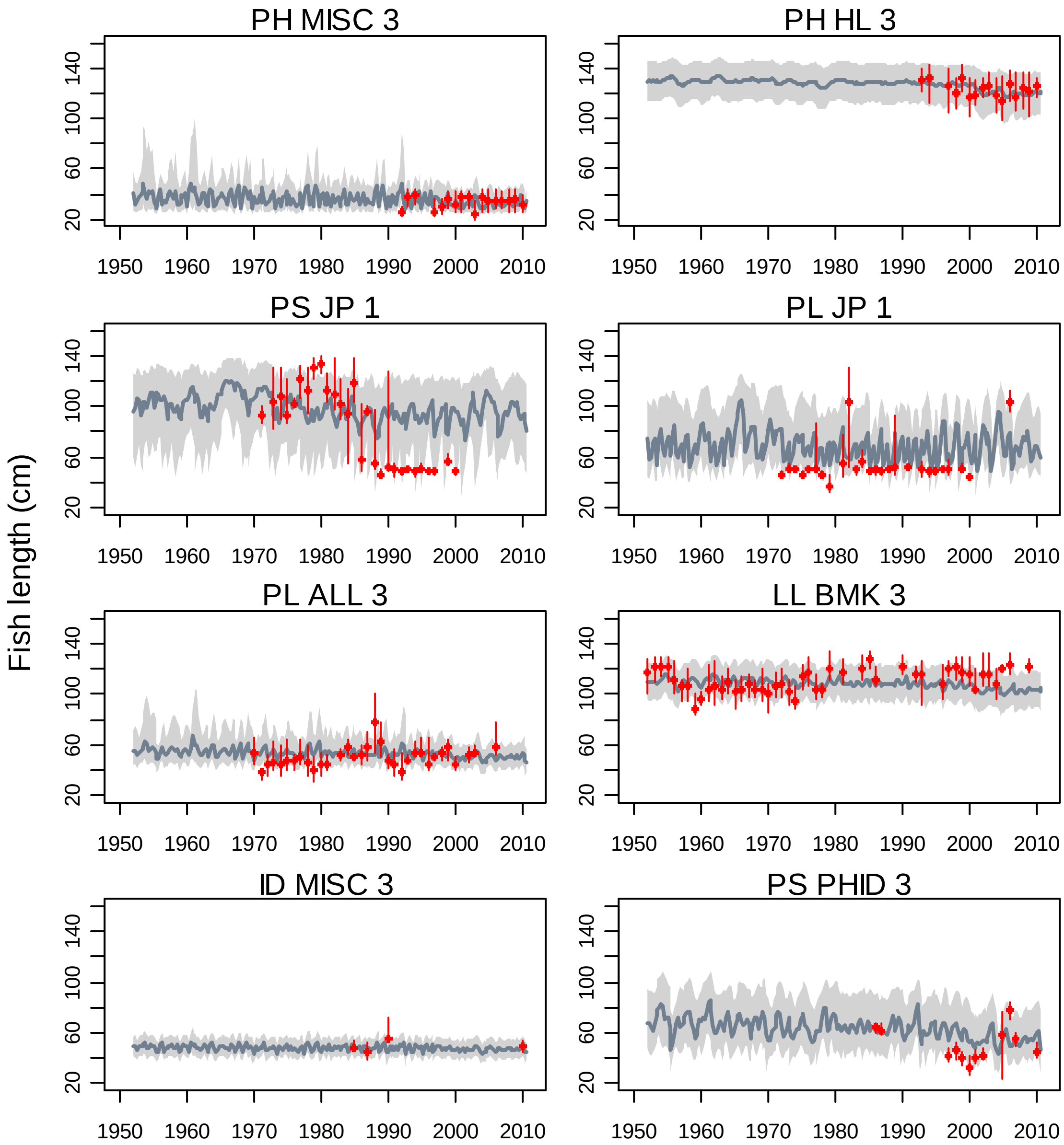


Figure 24 (continued).

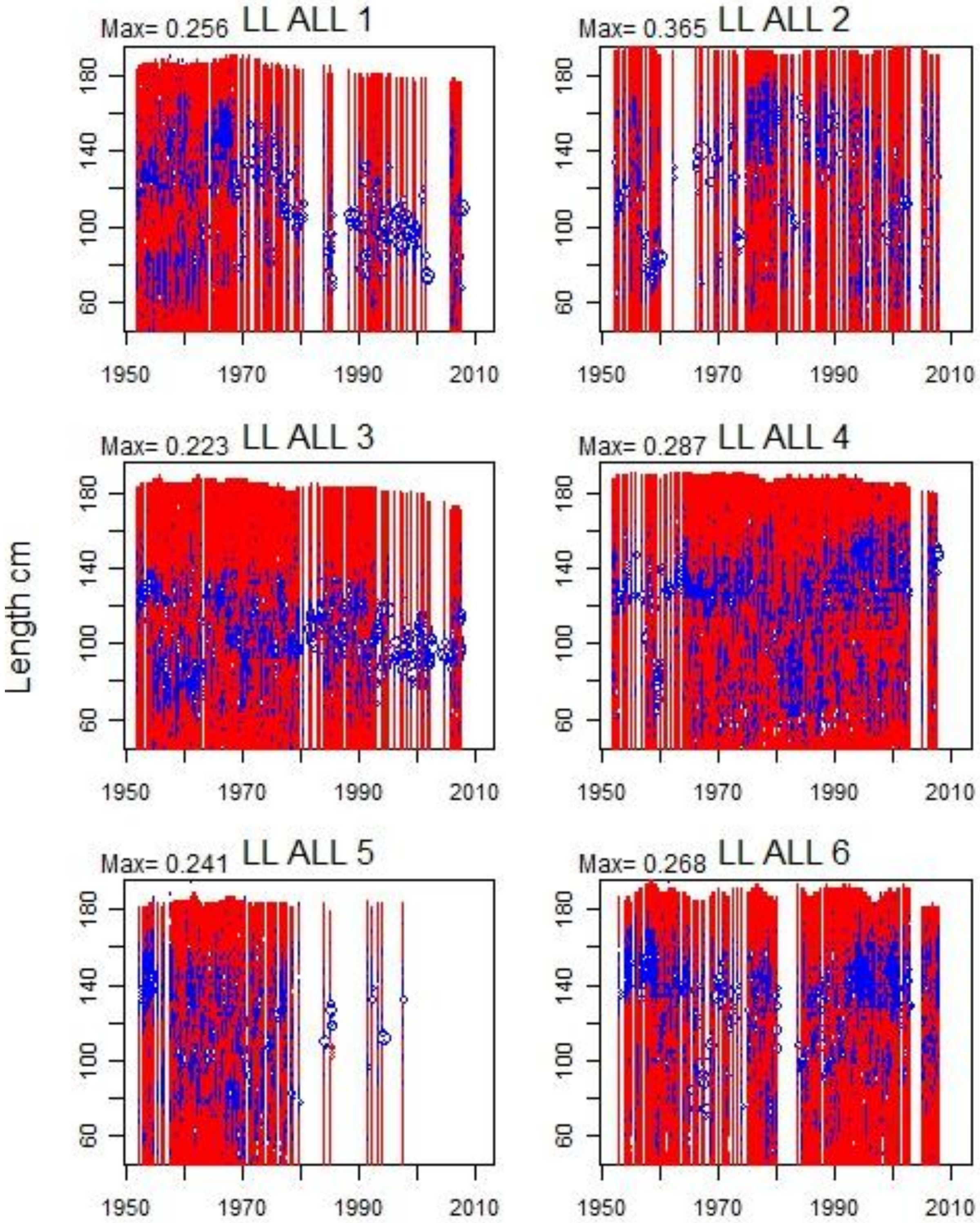


Figure 25. Residuals (observed – predicted proportions) of the fit to the length frequency data from each of the principal longline fisheries. The size of the circle is proportional to the residual; blue circles are positive residuals, red circles negative residuals. The maximum residual is given for each fishery.

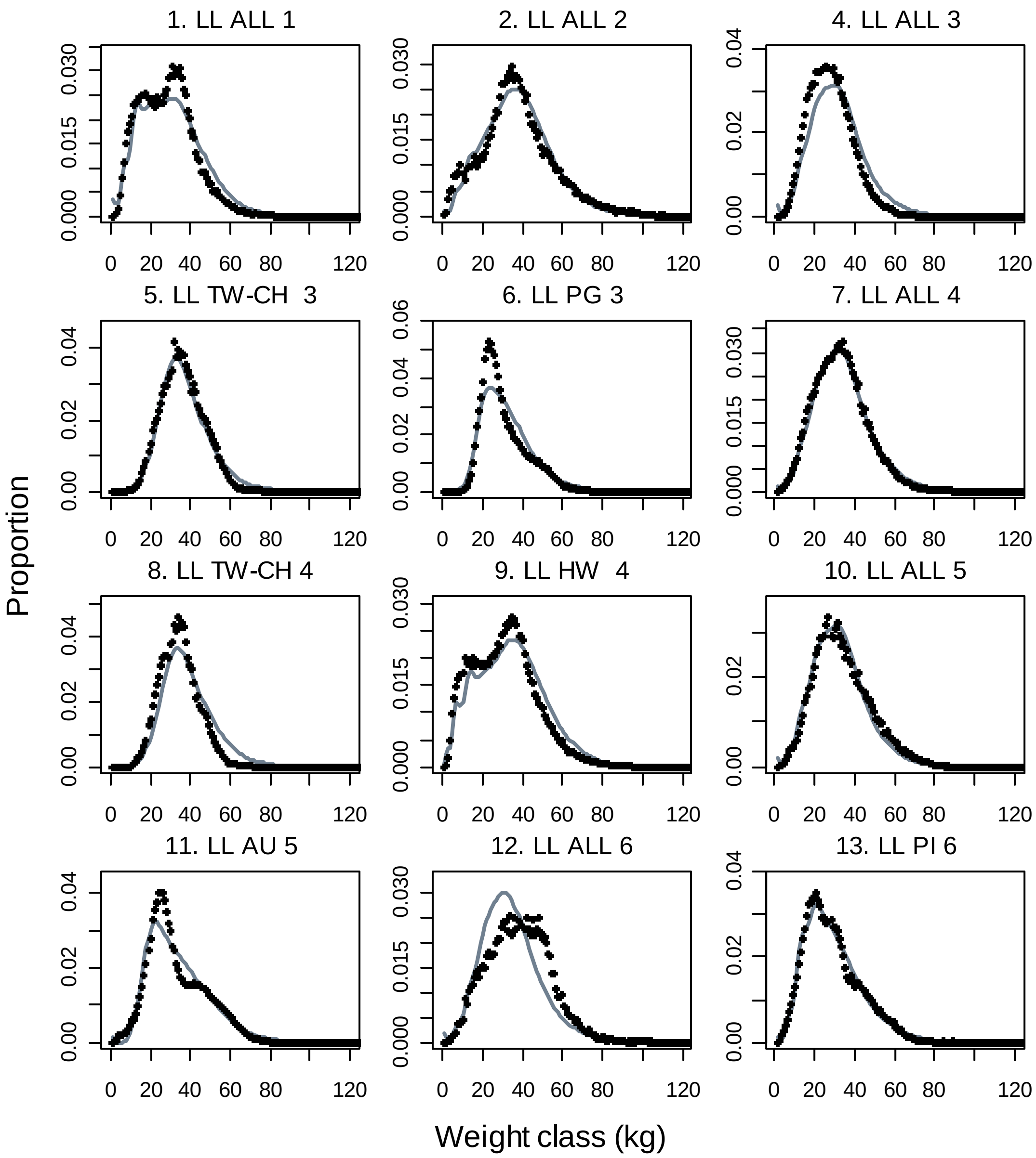


Figure 26. Observed (points) and predicted (line) weight frequencies (in kg) for each fishery aggregated over time.

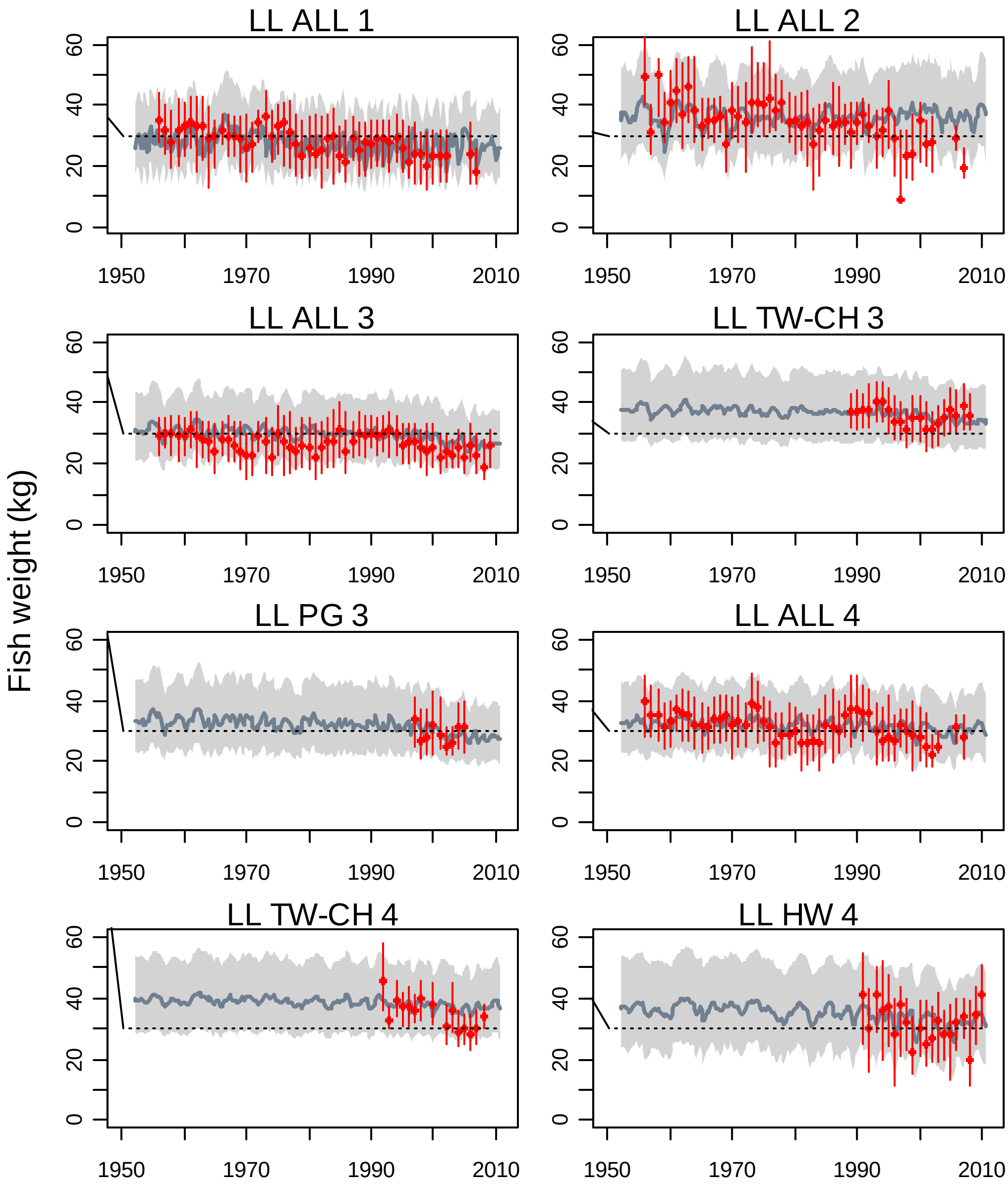


Figure 27. A comparison of the observed (red points) and predicted (grey line) median fish weight (whole weight, kg) of yellowfin tuna by fishery for the main fisheries with weight data. The confidence intervals represent the values encompassed by the 25% and 75% quantiles. Sampling data are aggregated by year and only weight samples with a minimum of 30 fish per year are plotted. The dashed line at 30 kg is for reference only.

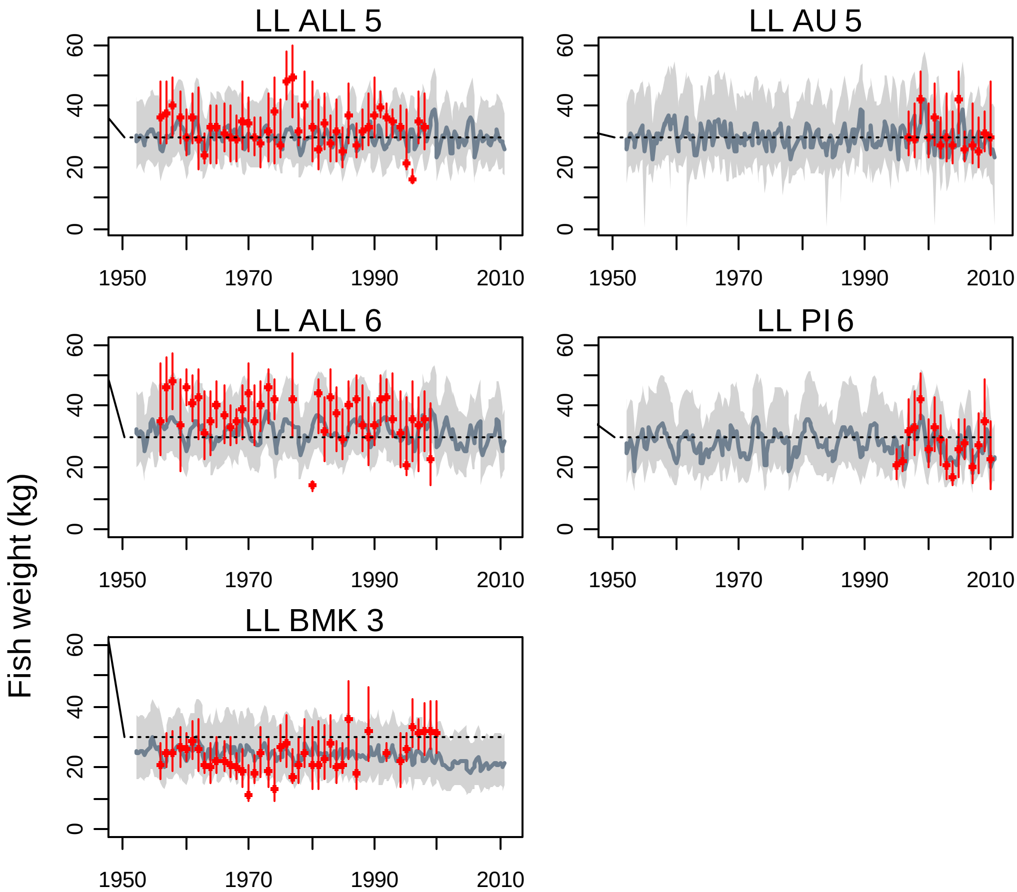


Figure 27 (continued).

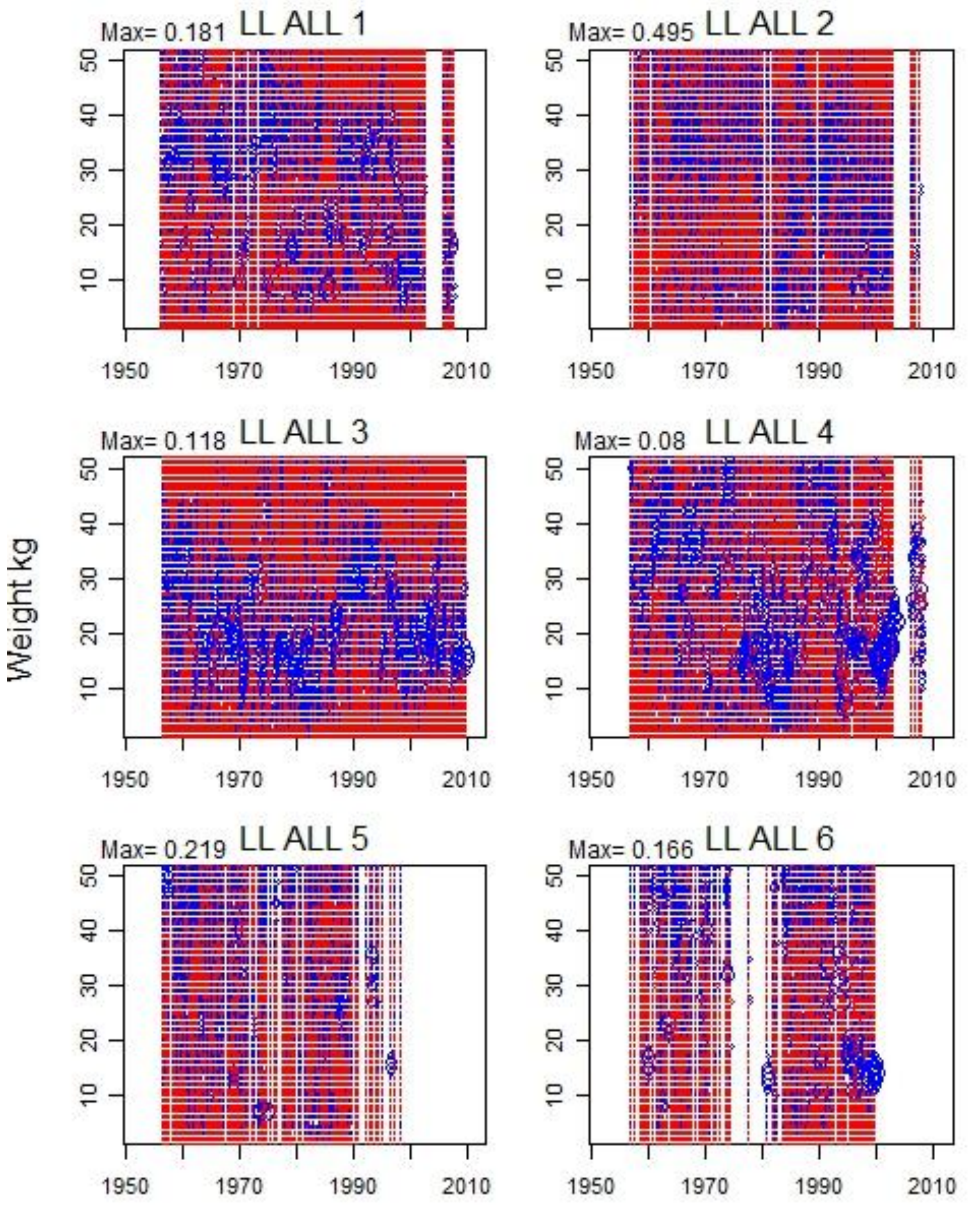


Figure 28. Residuals (observed – predicted proportions) of the fit to the weight frequency data for the principal longline fisheries. The size of the circle is proportional to the residual; blue circles are positive residuals, red circles negative residuals. The maximum residual is given for each fishery.

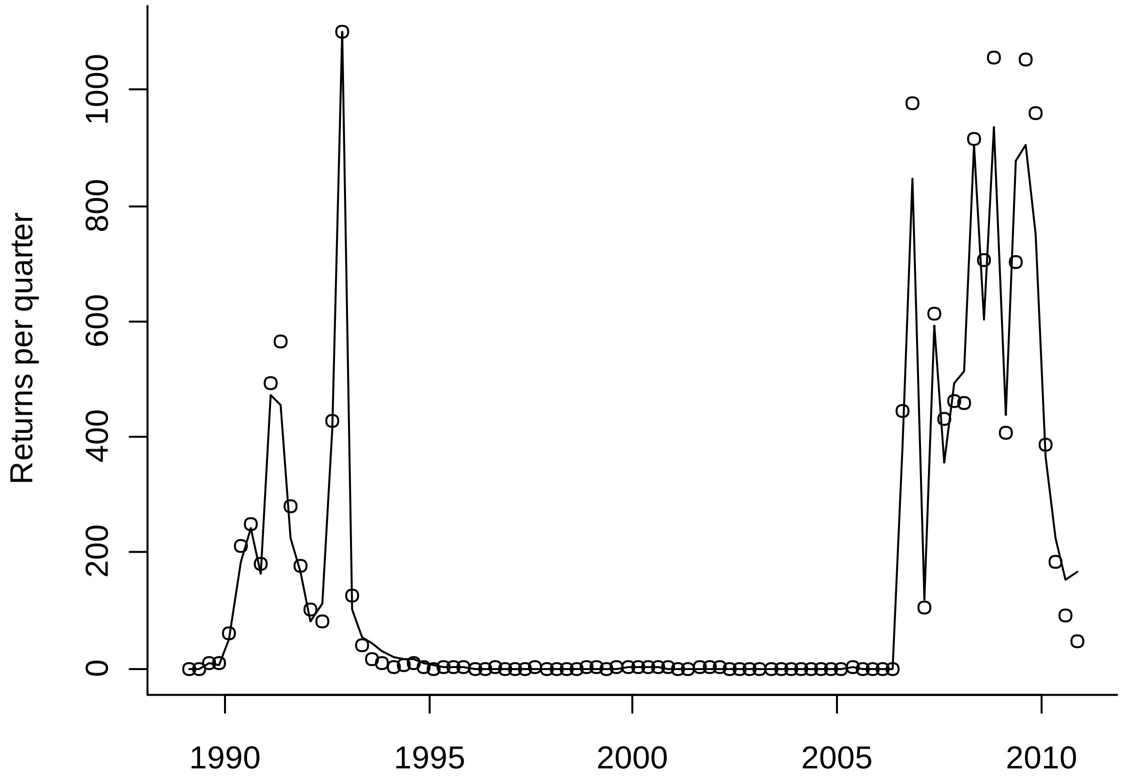
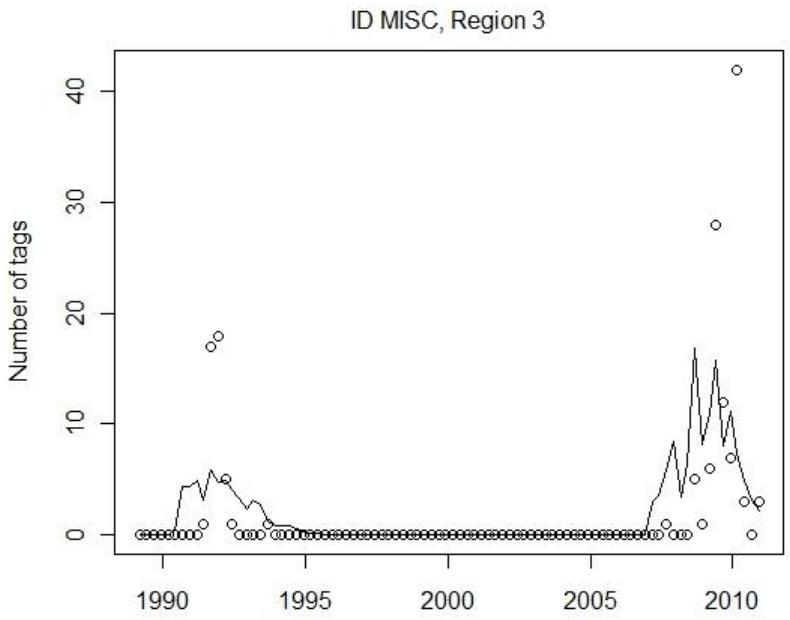


Figure 29. Number of observed (points) and predicted (line) tag returns by recapture period (quarter).



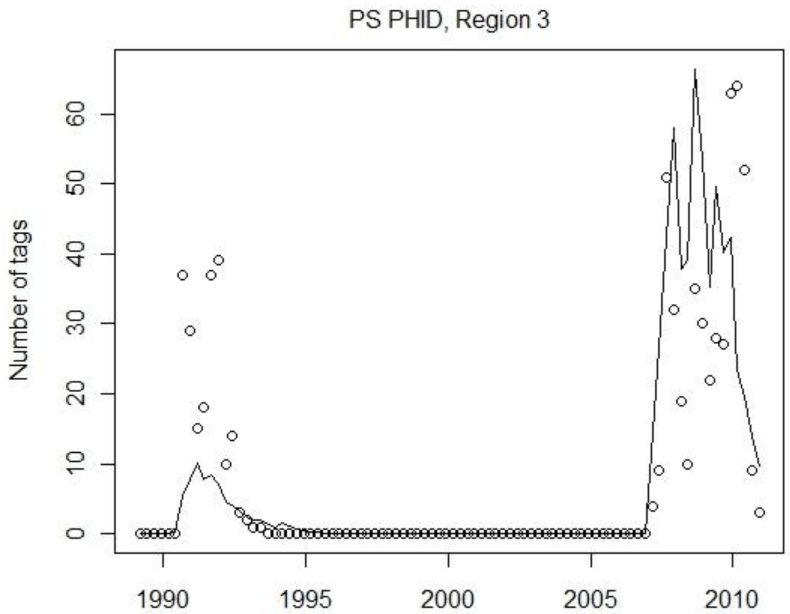


Figure 30a. Number of observed (points) and predicted (line) tag returns by recapture period (quarter) for the main fisheries (or groups of fisheries) recovering tags.

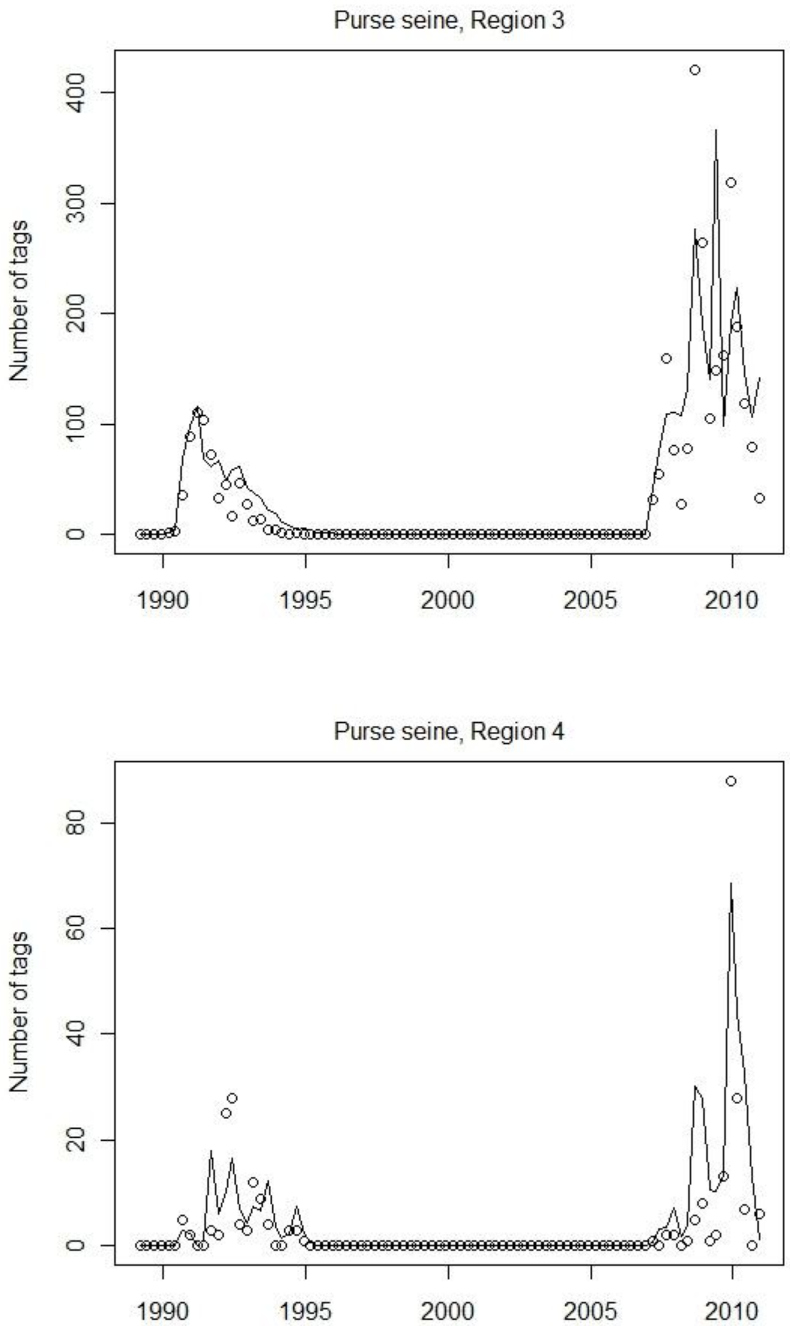


Figure 30b continued.

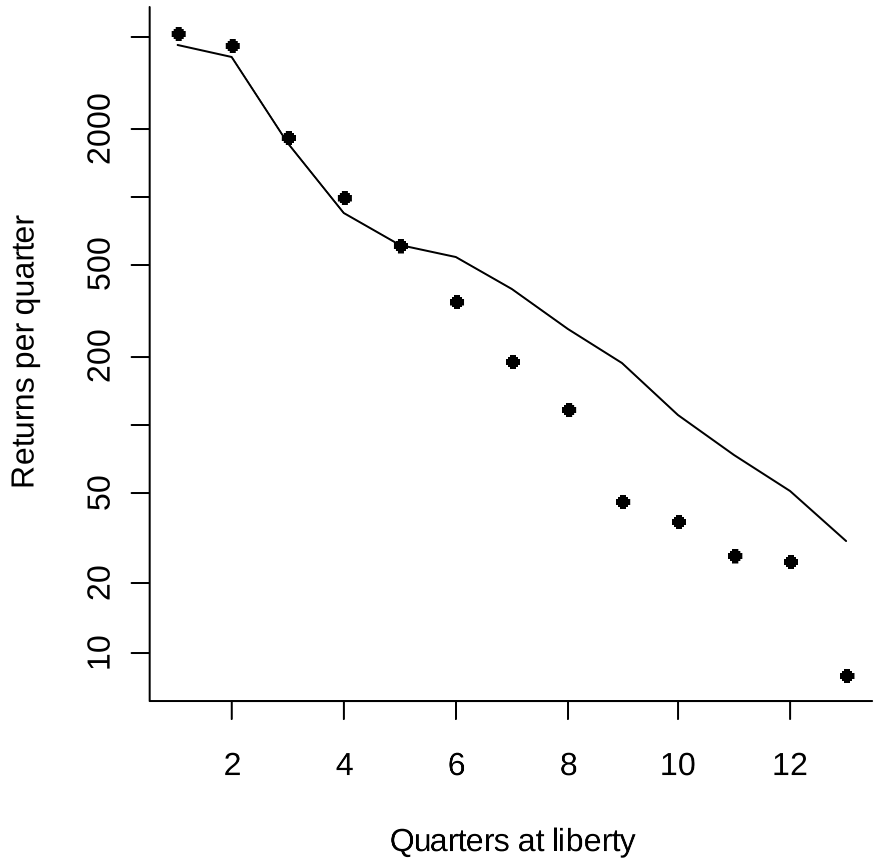


Figure 31. Number of observed (points) and predicted (line) tag returns by periods at liberty (quarters).

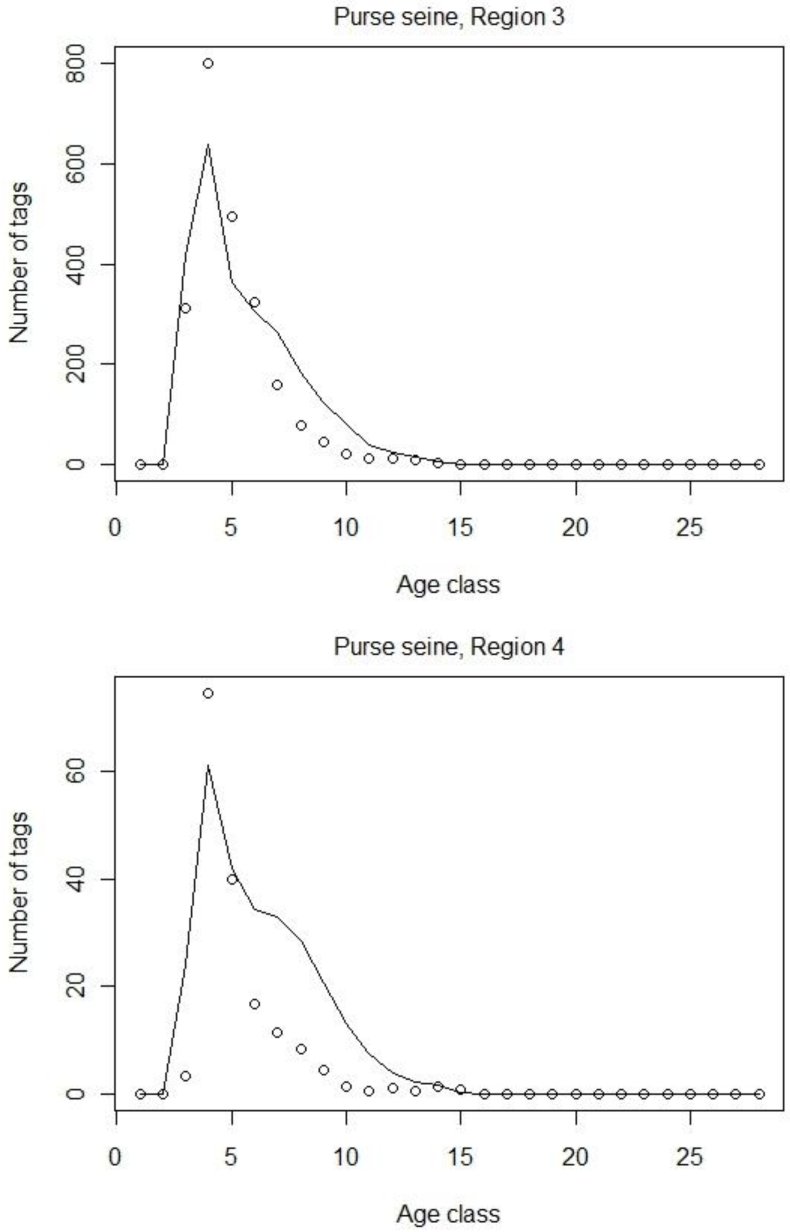
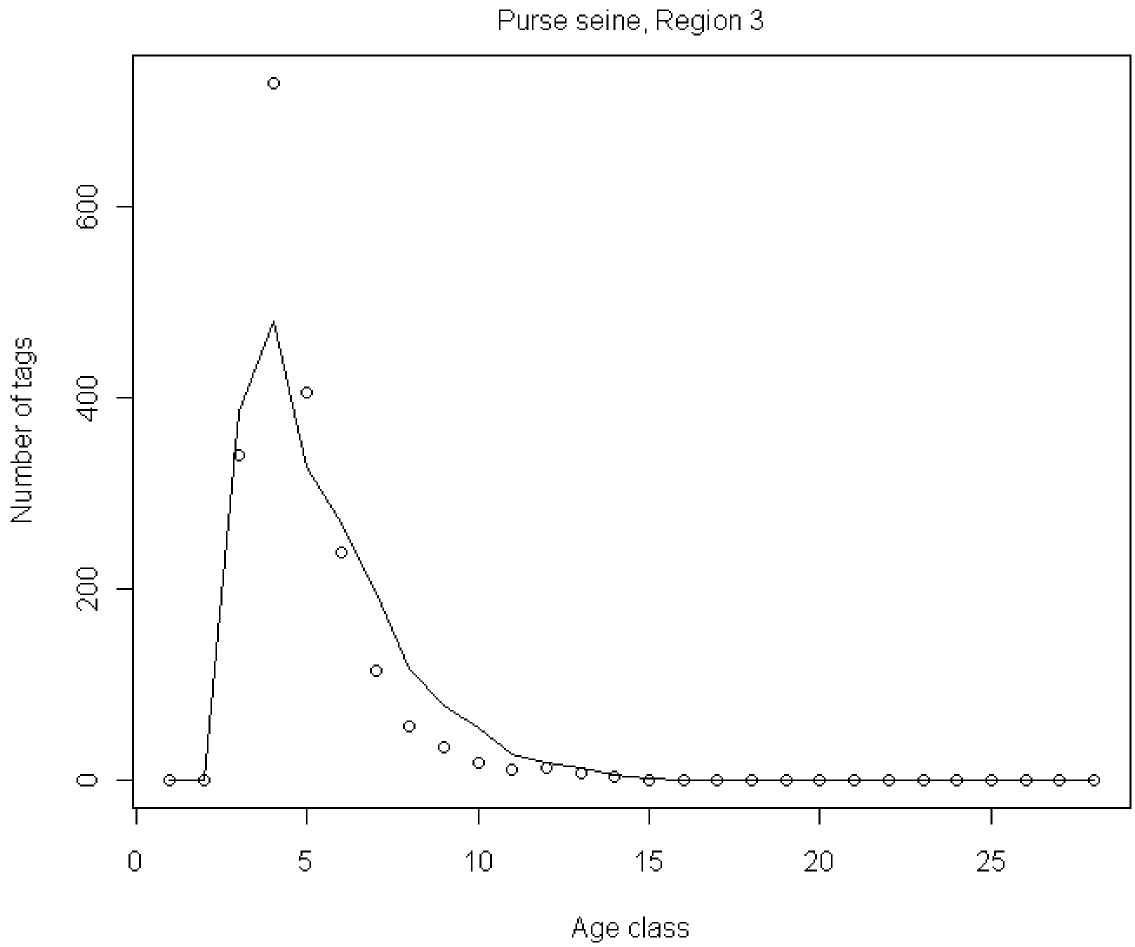


Figure 32. Observed (points) and predicted (line) number of PTTP tag recoveries by quarterly age class for the aggregate purse seine fisheries in region 3 (top) and region 4 (bottom) (note: the regional purse seine fisheries are grouped for the tag likelihood).



Region 3 model

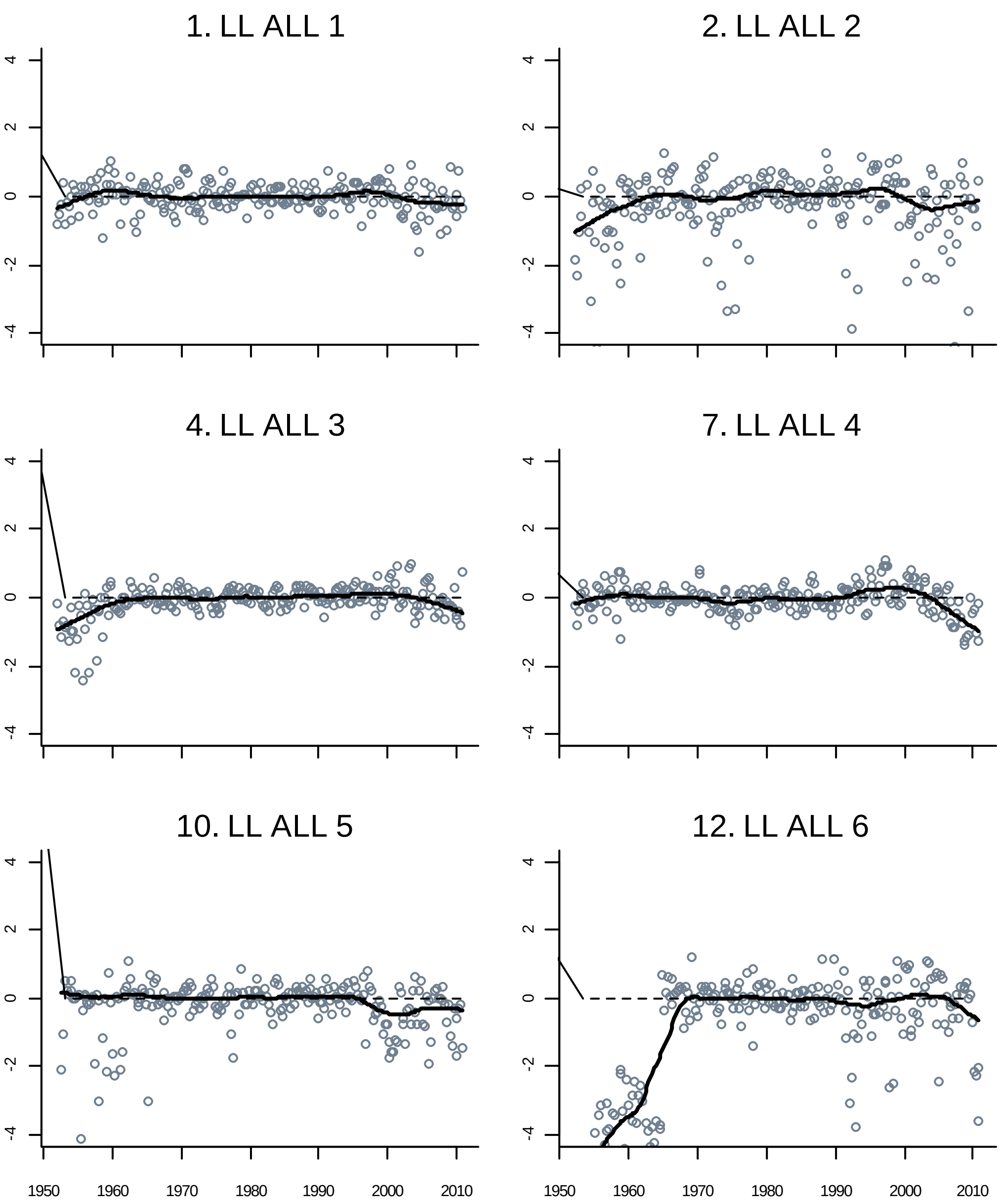


Figure 33. Effort deviations for the principal longline fisheries. The solid black line represents the lowess smoothed trend of the data.

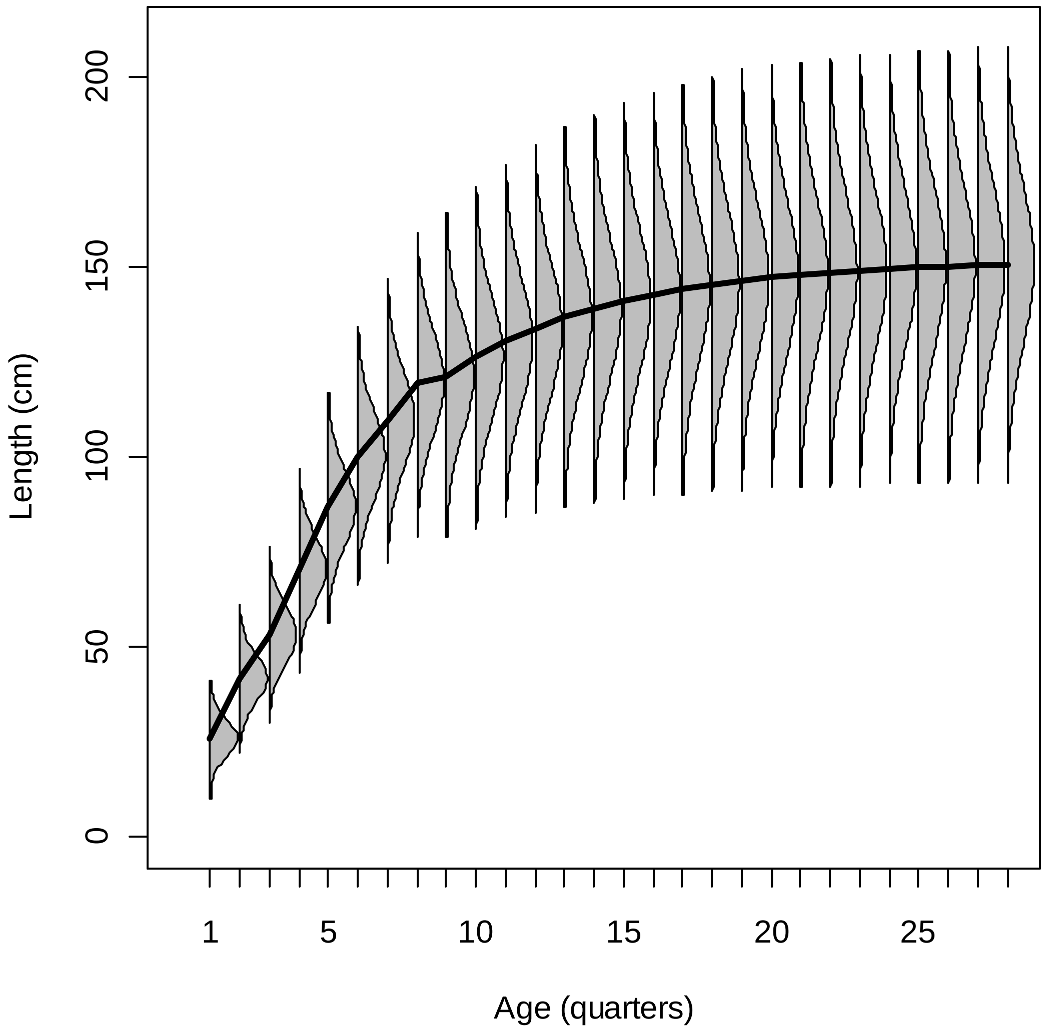


Figure 34. Estimated growth of yellowfin derived from the base-case assessment model. The black line represents the estimated mean length (FL, cm) at age and the grey area represents the estimated distribution of length at age.

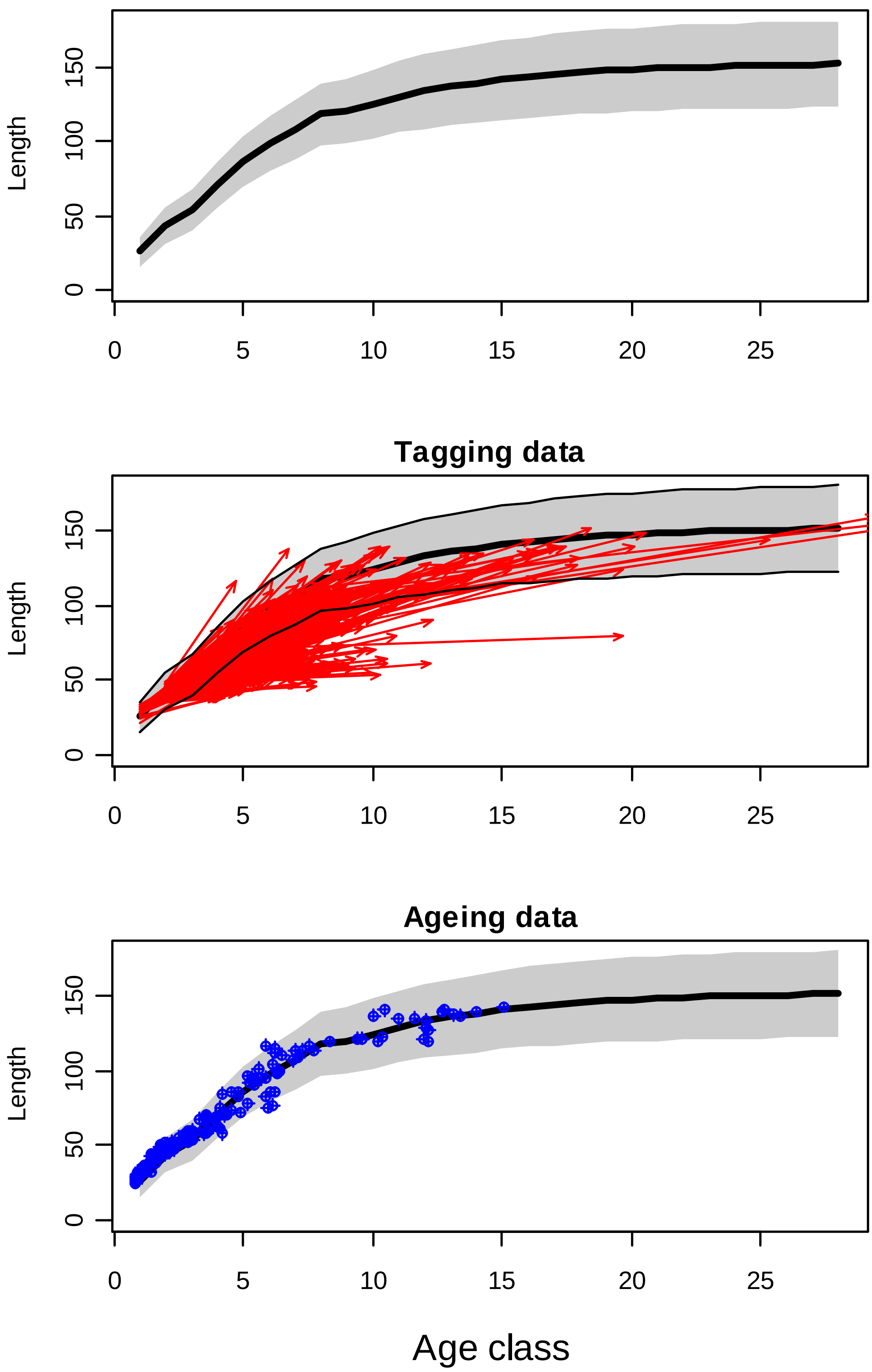


Figure 35. Estimated mean lengths-at-age (heavy line) and the variability of length-at-age (shaded area represents ± 2 SD). Age is in quarters and length is in cm (top figure). For comparison, length at age estimates are presented from tag release and recapture data (middle figure) and empirical age determination from otolith readings (bottom figure). The tagging data is presented as a linear growth vector (depicted as an arrow) from length at release to length at recovery. Only fish at liberty for at least 150 days are included (813 records). Age at release is assumed from the estimated growth function.

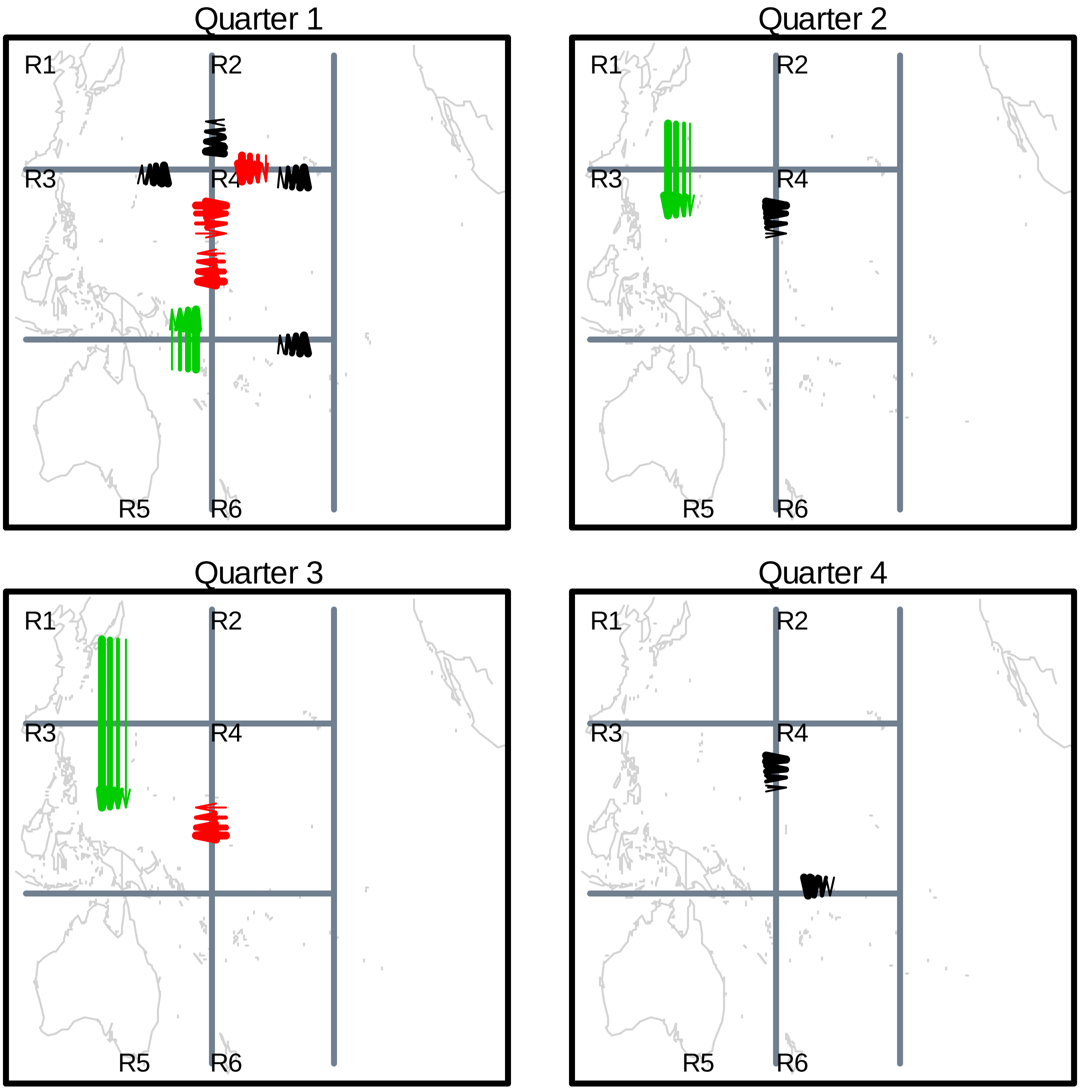


Figure 36. Estimated quarterly movement coefficients at age (1, 7, 15, 25 quarters) from the base-case model. The movement coefficient is proportional to the length of the arrow and increased weight of the arrow represents increasing age. The maximum movement (quarter 3, region 1 to region 3) represents movement of 40% of the fish at the start of the quarter. Movement rates are colour coded: black, 0.5–5%; red 5–10%; green >10%.

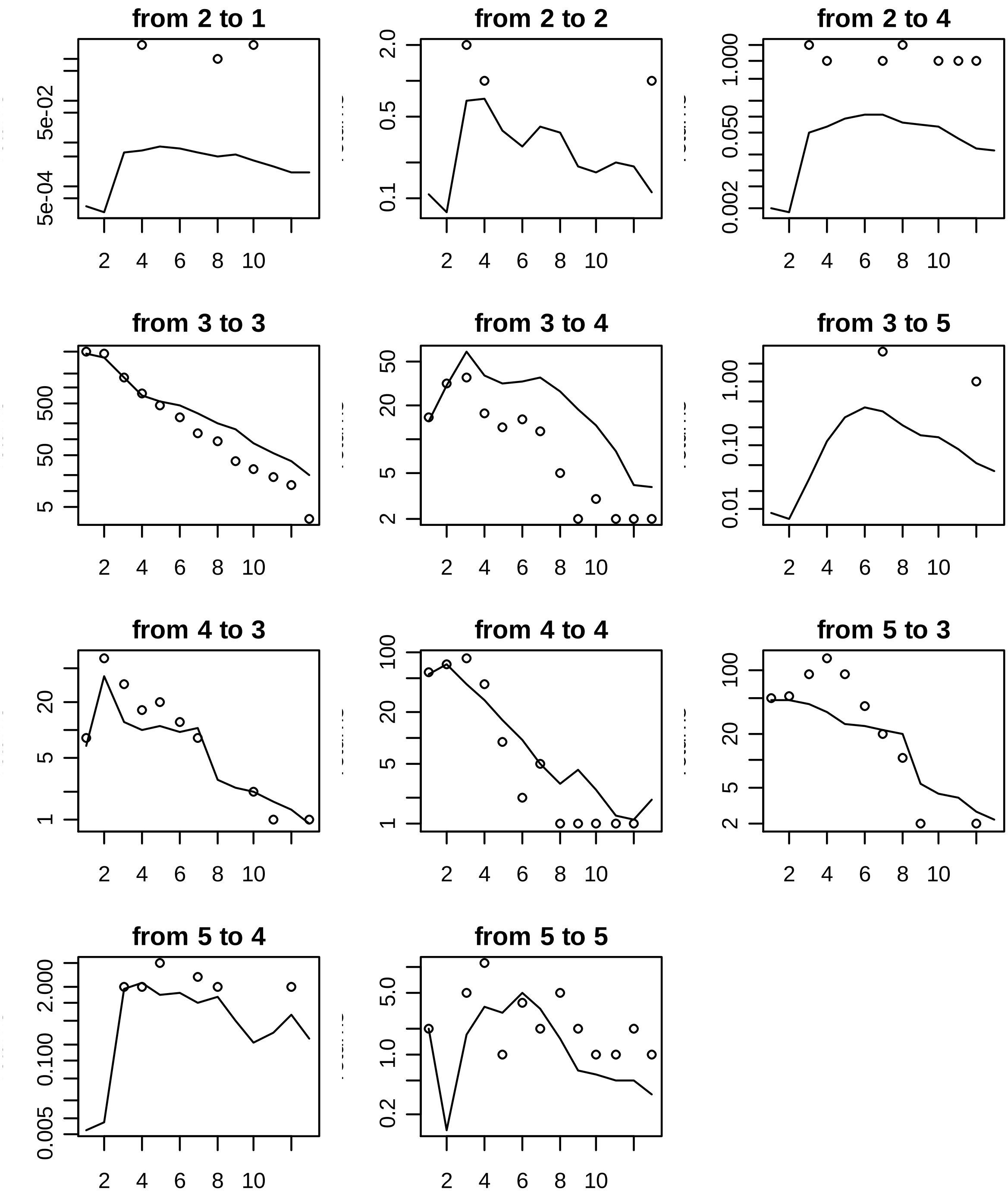


Figure 37. Observed (points) and predicted (line) number of tags recovered from releases in a specific region (from *regionx*) and recoveries in a specific region (to *regiony*) by quarter at liberty. Only release/recovery combinations with a least three recovered tags are presented.

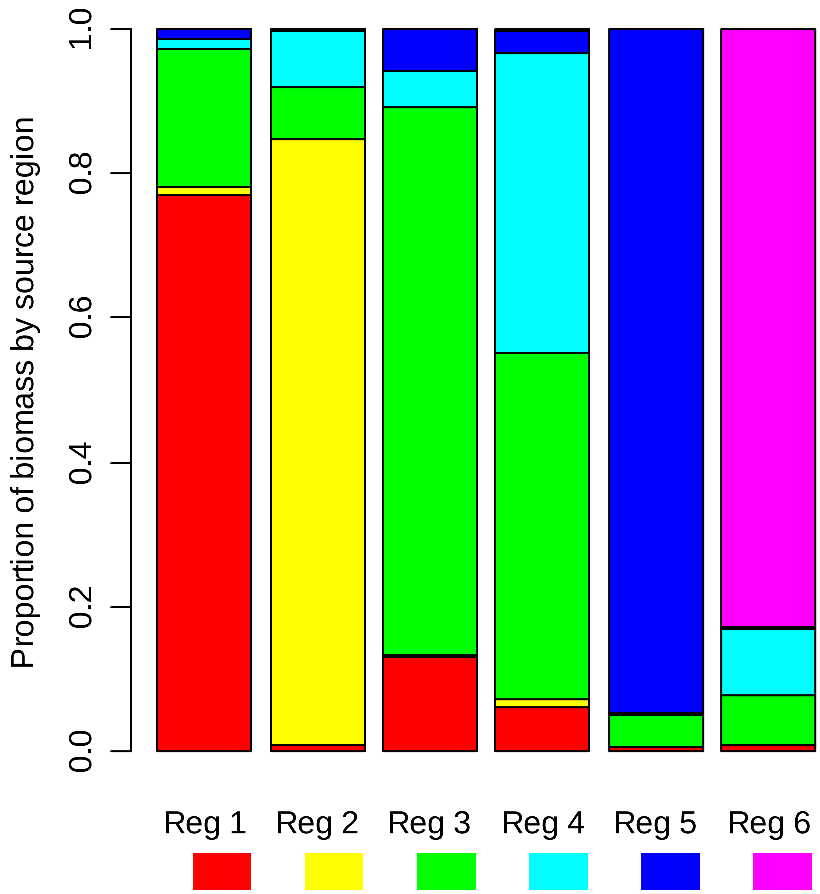


Figure 38. Proportional distribution of total biomass (by weight) in each region (Reg 1–6) apportioned by the source region of the fish. The colour of the home region is presented below the corresponding label on the x-axis. The biomass distributions are calculated based on the long-term average distribution of recruitment among regions, estimated movement parameters, and natural mortality. Fishing mortality is not taken into account.

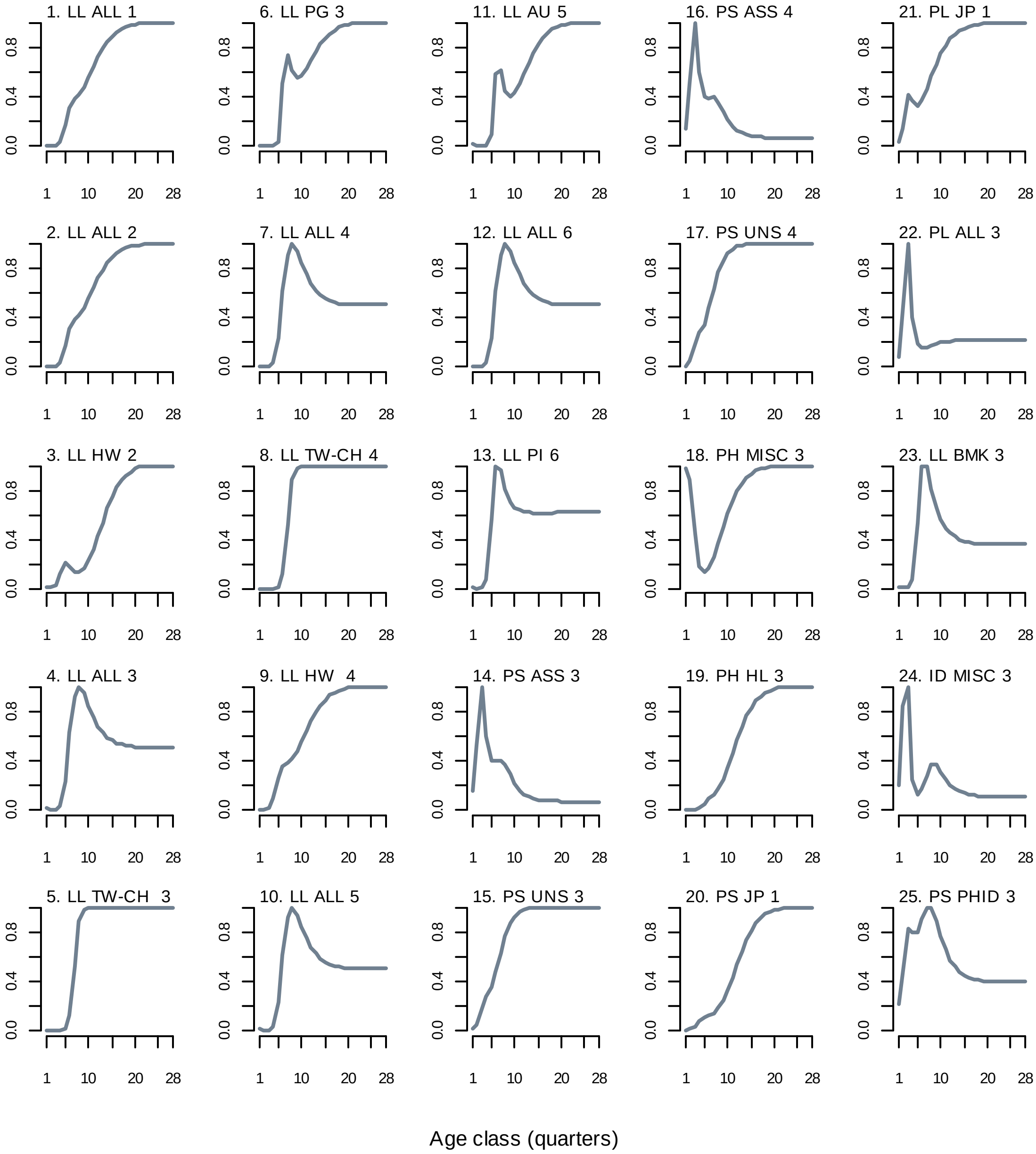


Figure 39. Selectivity coefficients, by fishery.

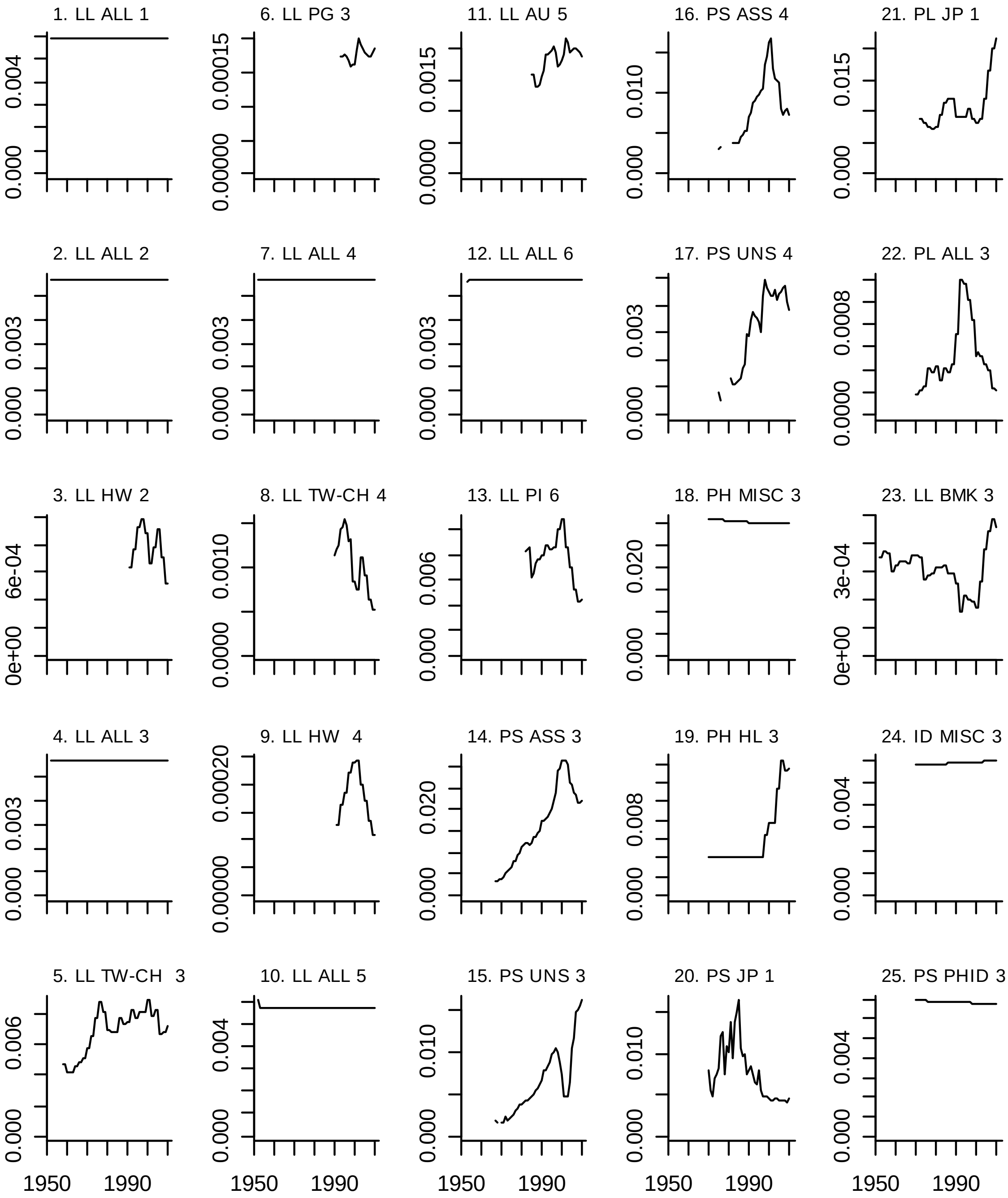


Figure 40. Average annual catchability time series, by fishery.

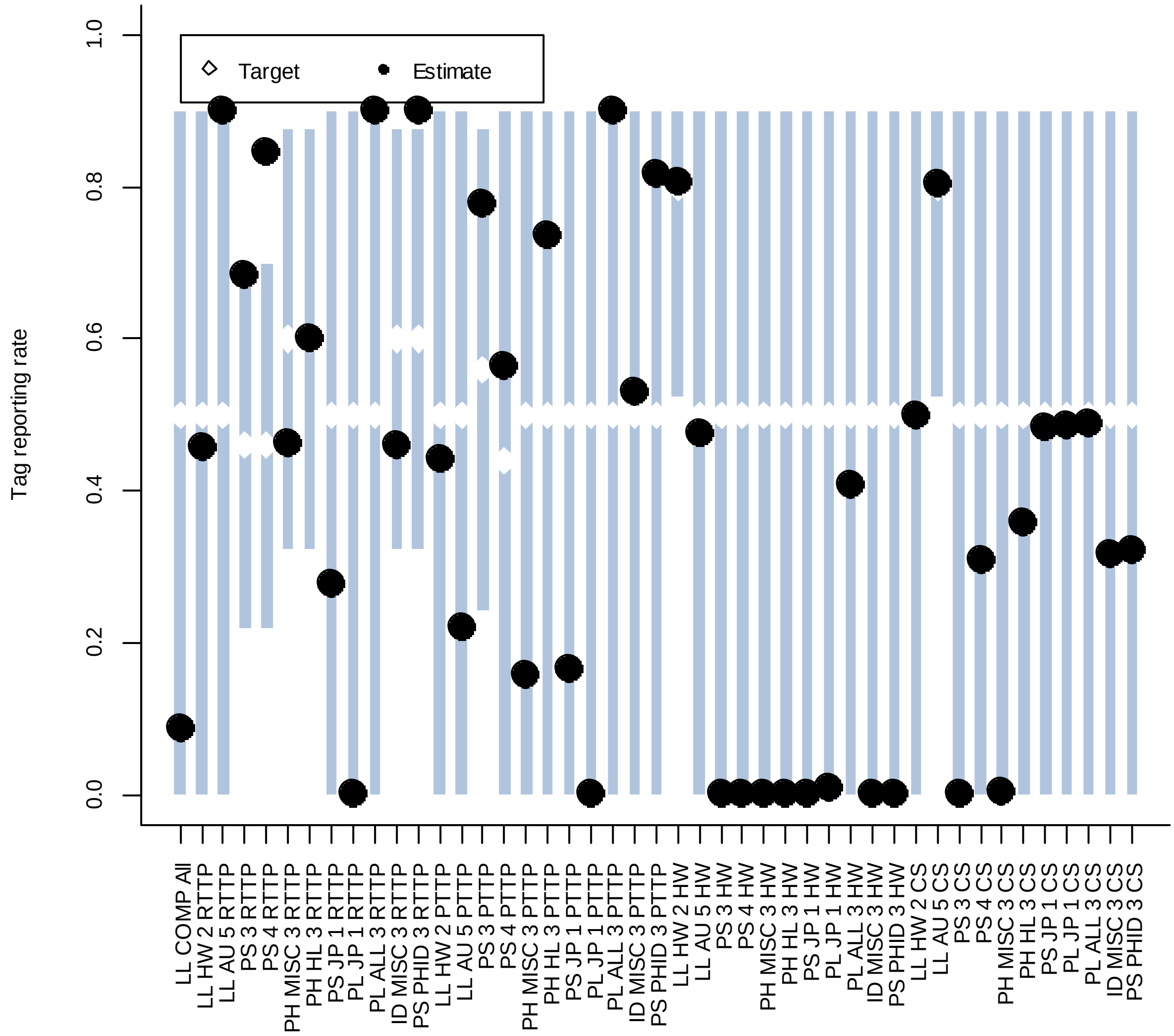


Figure 41. Estimated tag-reporting rates by fishery and tag release programme (black circles). The white diamonds indicate the modes of the priors for each reporting rate and the grey bars indicate a range of ±1 SD. Tag programmes are RTTP, PTTP, Hawai'i (HW) and Coral Sea (CS).

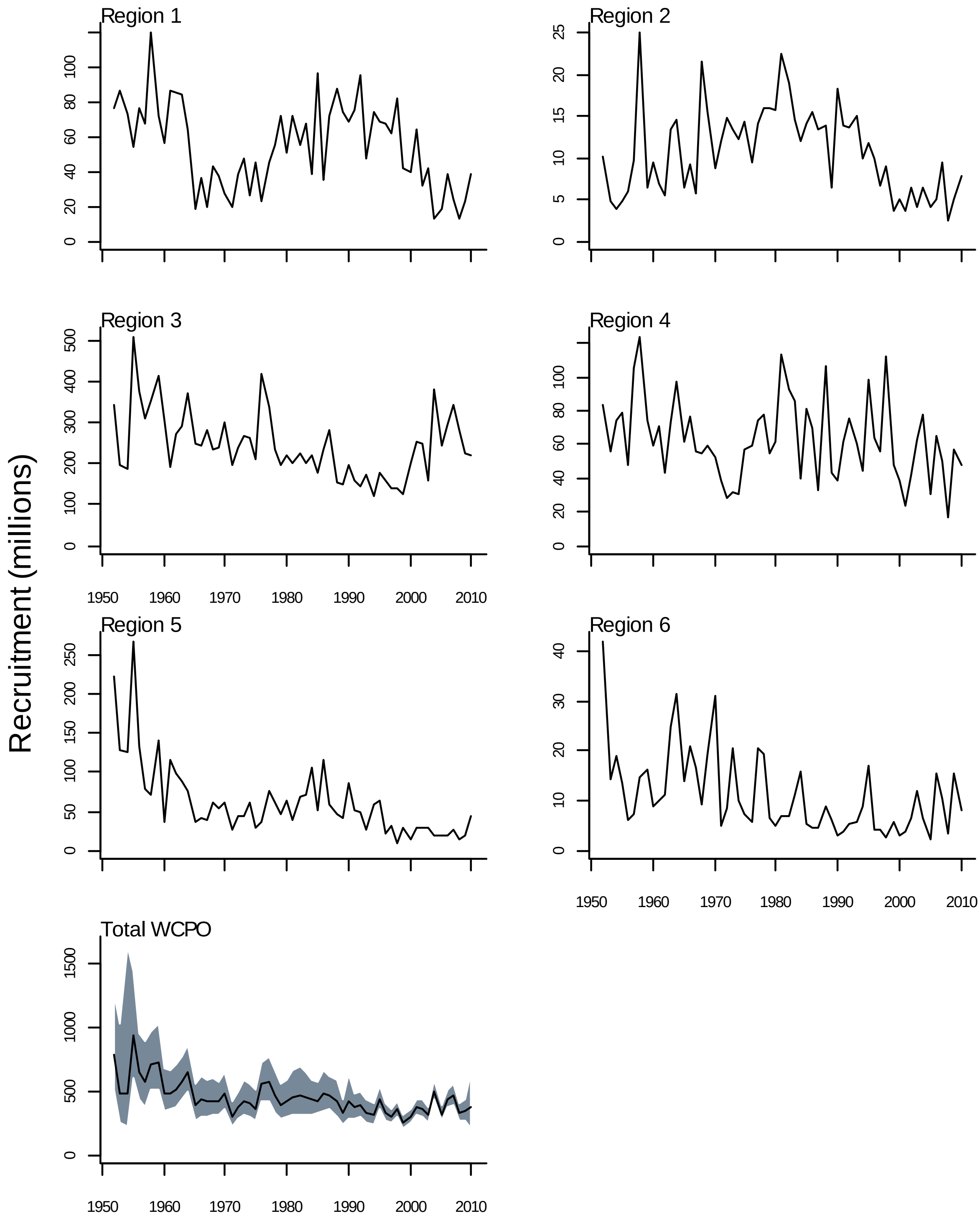


Figure 42. Estimated annual recruitment (millions of fish) by region and for the WCPO.

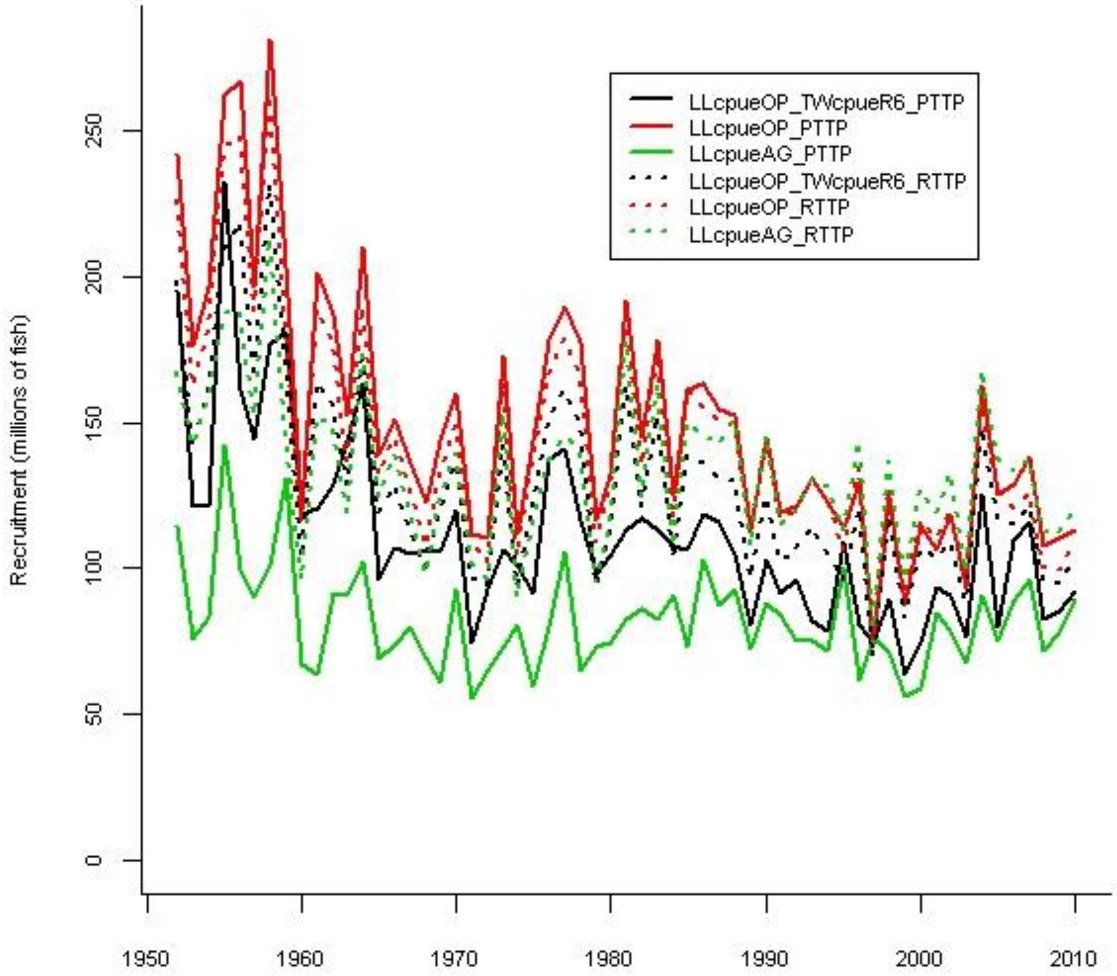


Figure 43. Estimated annual recruitment (millions of fish) for the WCPO obtained from the different model options.

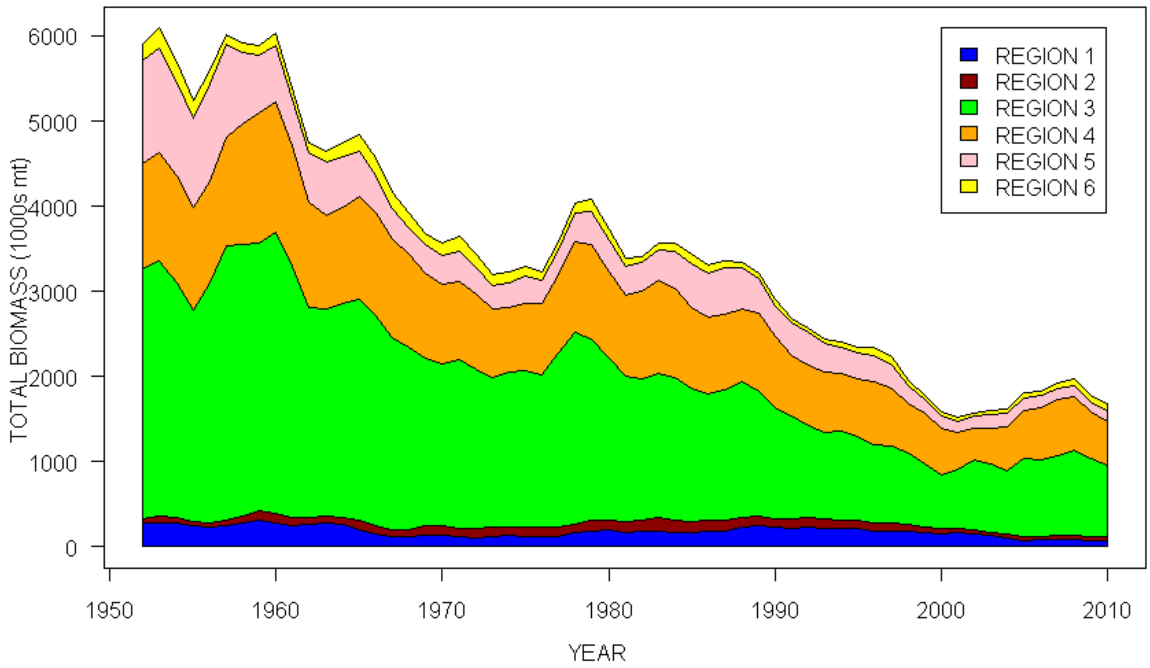


Figure 44. Estimated average annual total biomass (thousand mt) by model region and for the reference model.

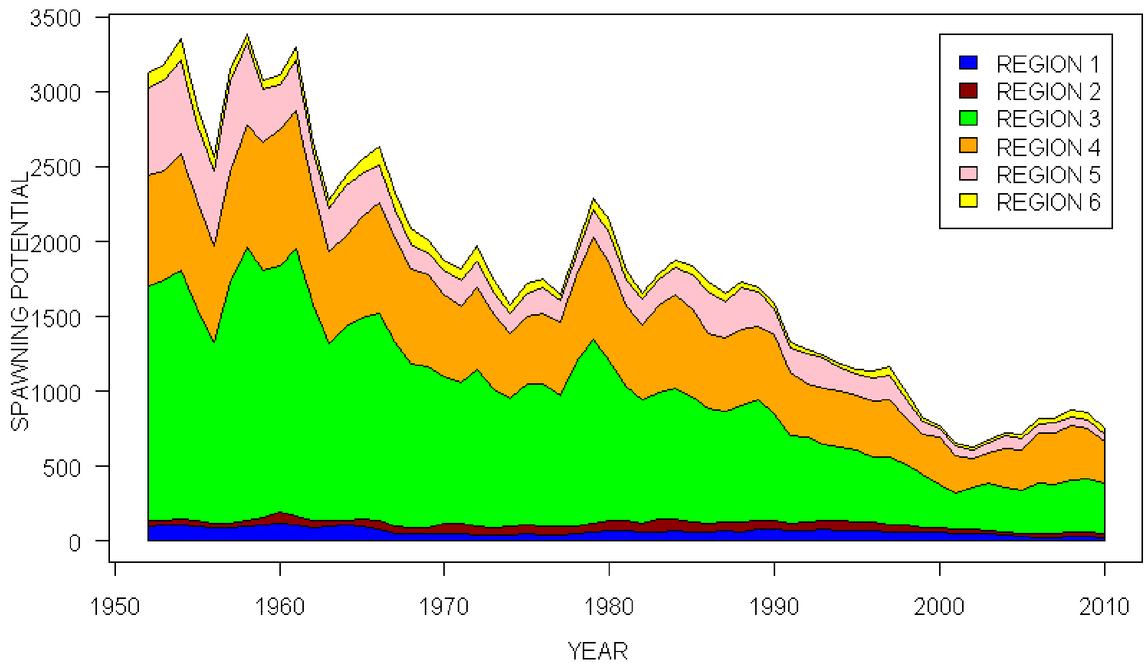


Figure 45. Estimated average annual spawning biomass (thousand mt) by model region and for the reference model.

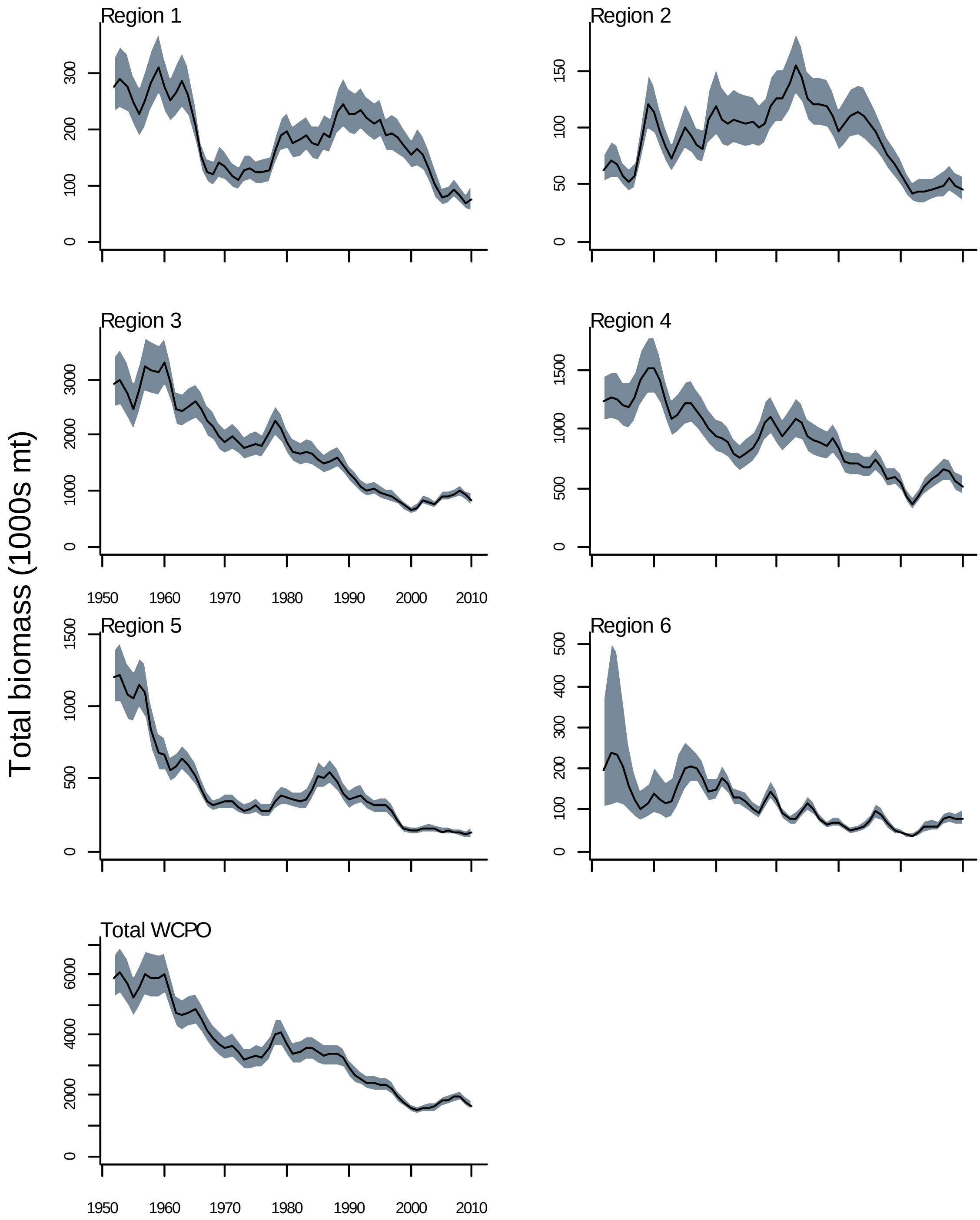


Figure 46. Estimated annual average total biomass by region and for the WCPO. The shaded areas indicate the approximate 95% confidence intervals.

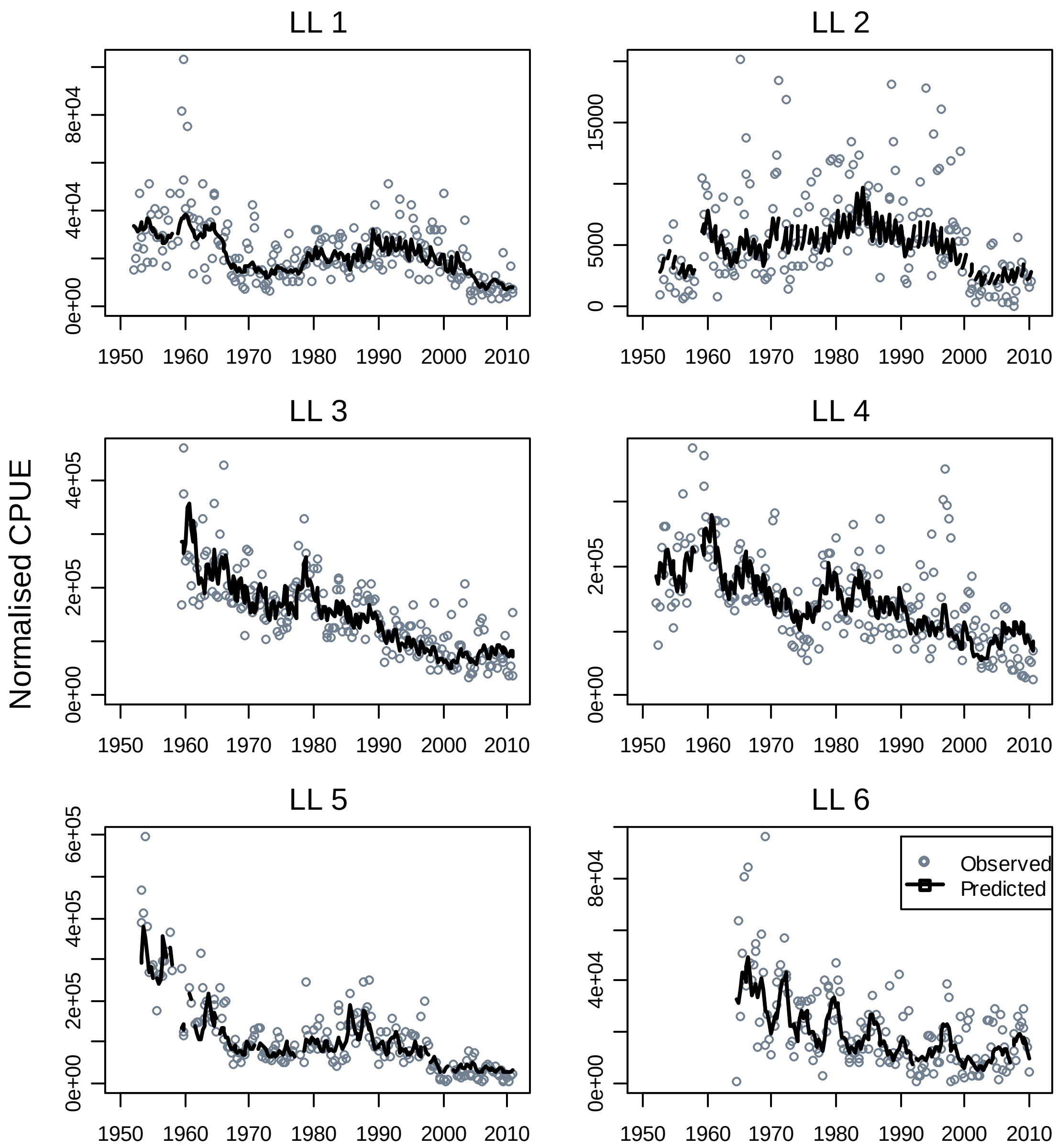
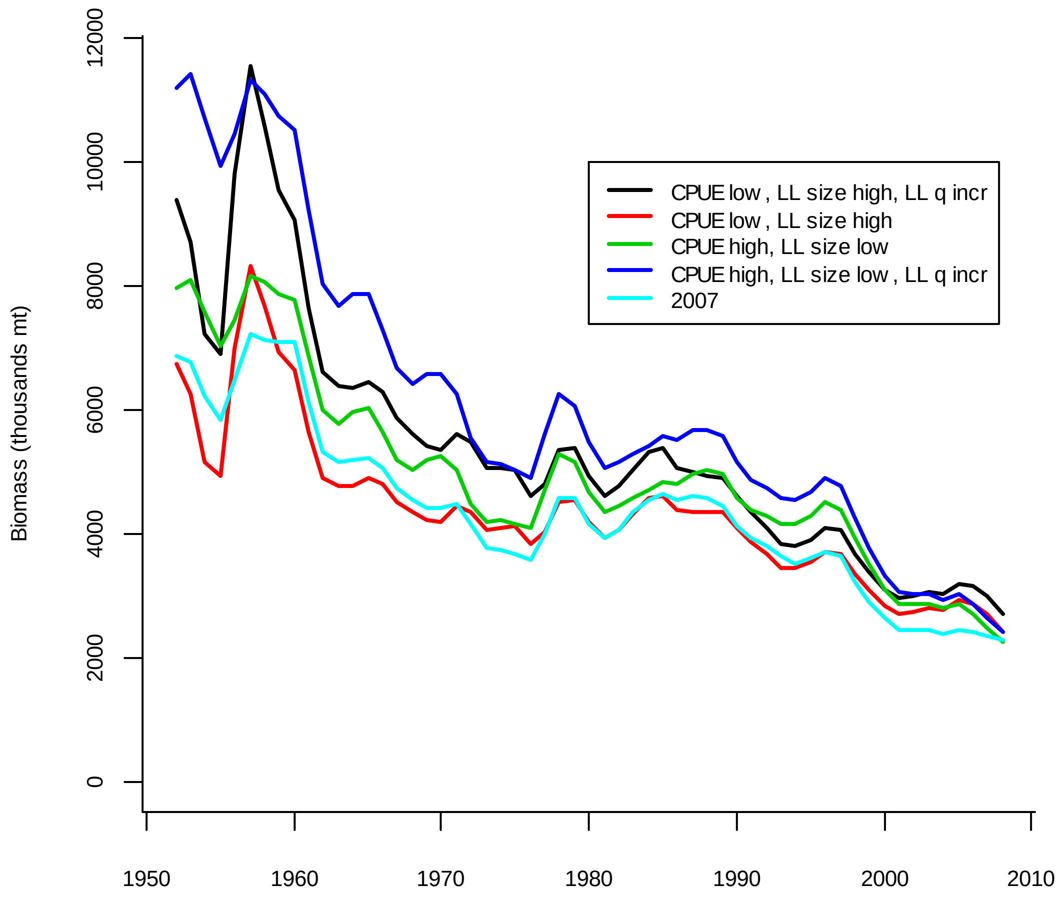


Figure 47. A comparison of the observed (points) and predicted (line) longline CPUE by quarter and region.



Biomass (thousands mt)
0
2000
4000
6000
8000
10000
12000
1950
1960
1970
1980
1990
2000
2010
CPUE low , LL size high, LL q incr
CPUE low , LL size high
CPUE high, LL size low
CPUE high, LL size low , LL q incr
2007

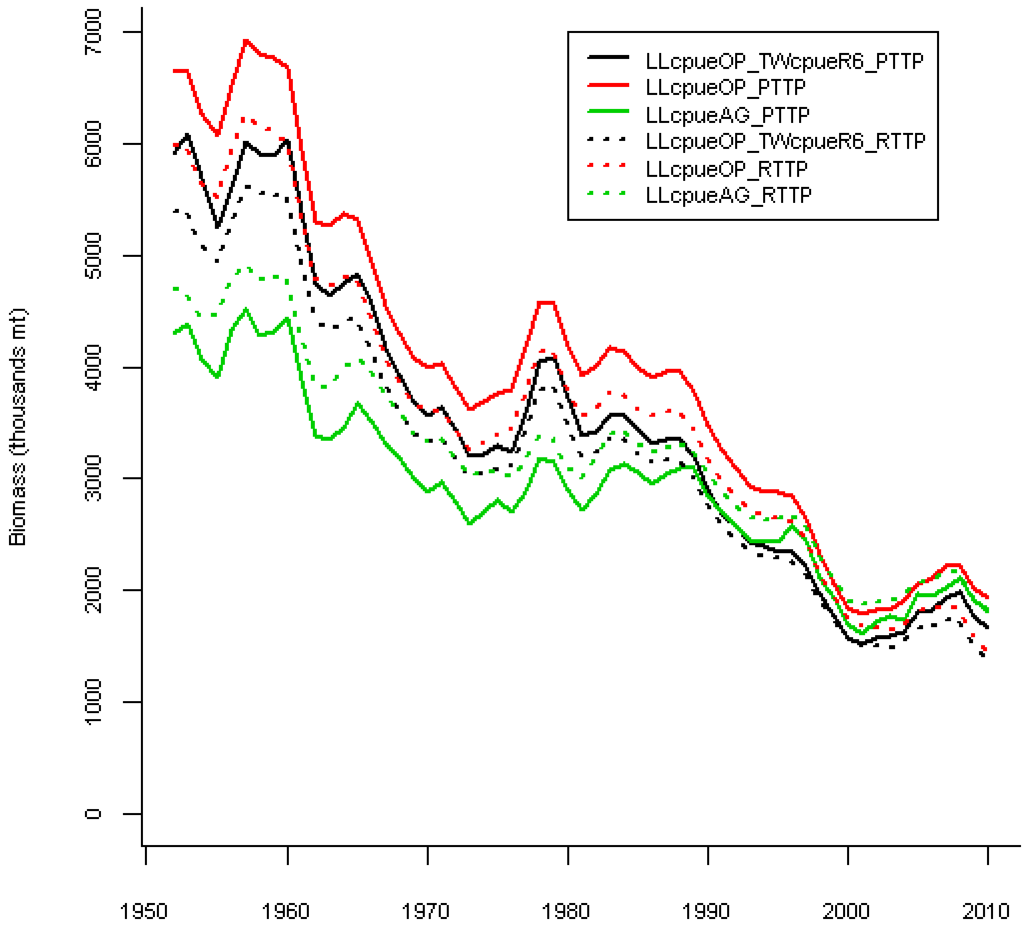


Figure 48a. Estimated average annual total biomass (thousands mt) for the WCPO obtained from a range of different model options.

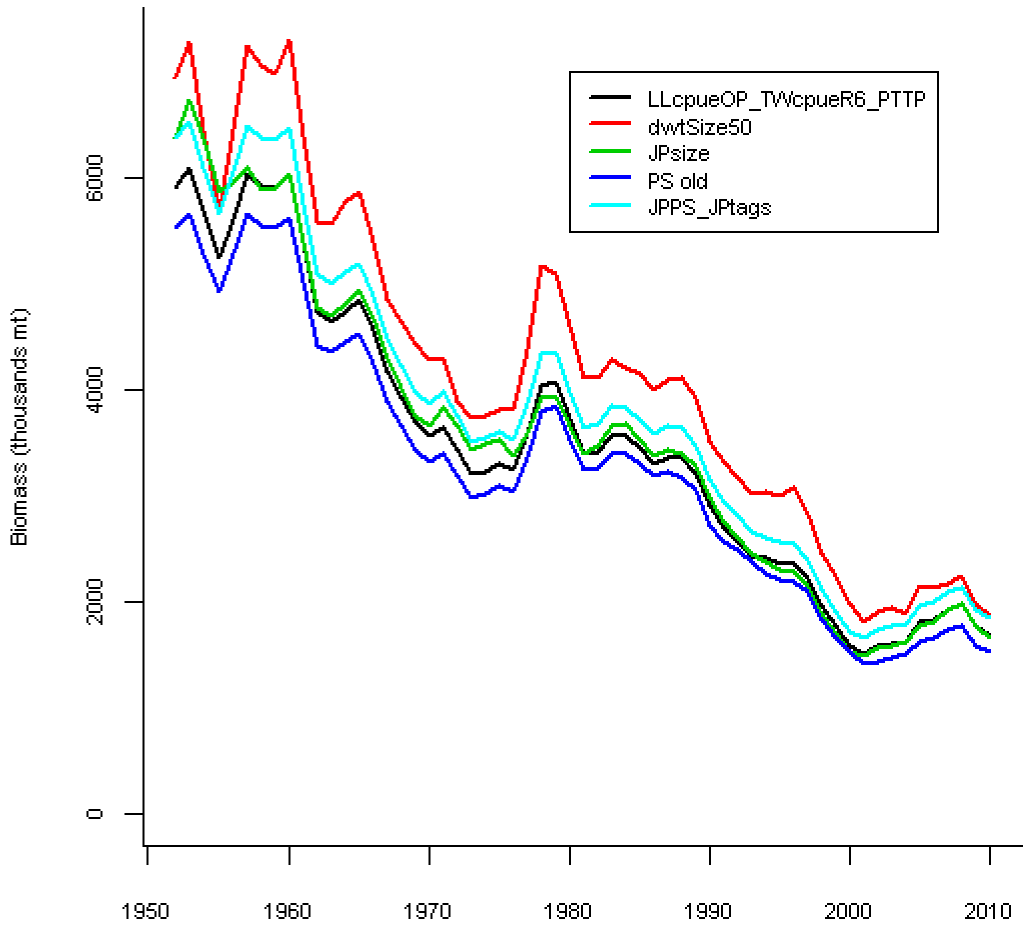


Figure 48b. Estimated average annual total biomass (thousands mt) for the WCPO obtained from a range of different model options.

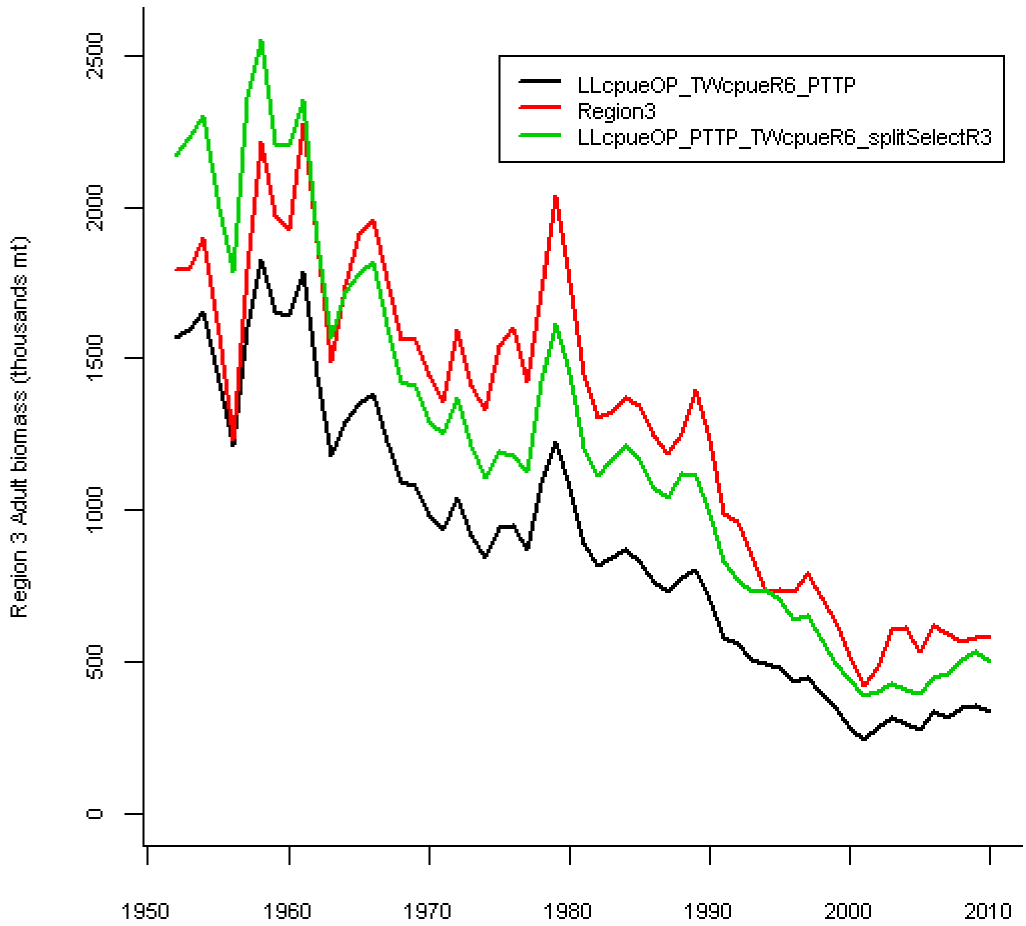


Figure 49. Estimated average annual spawning biomass (thousands mt) for the region 3 model compared to region 3 biomass estimates from two WCPO model options.

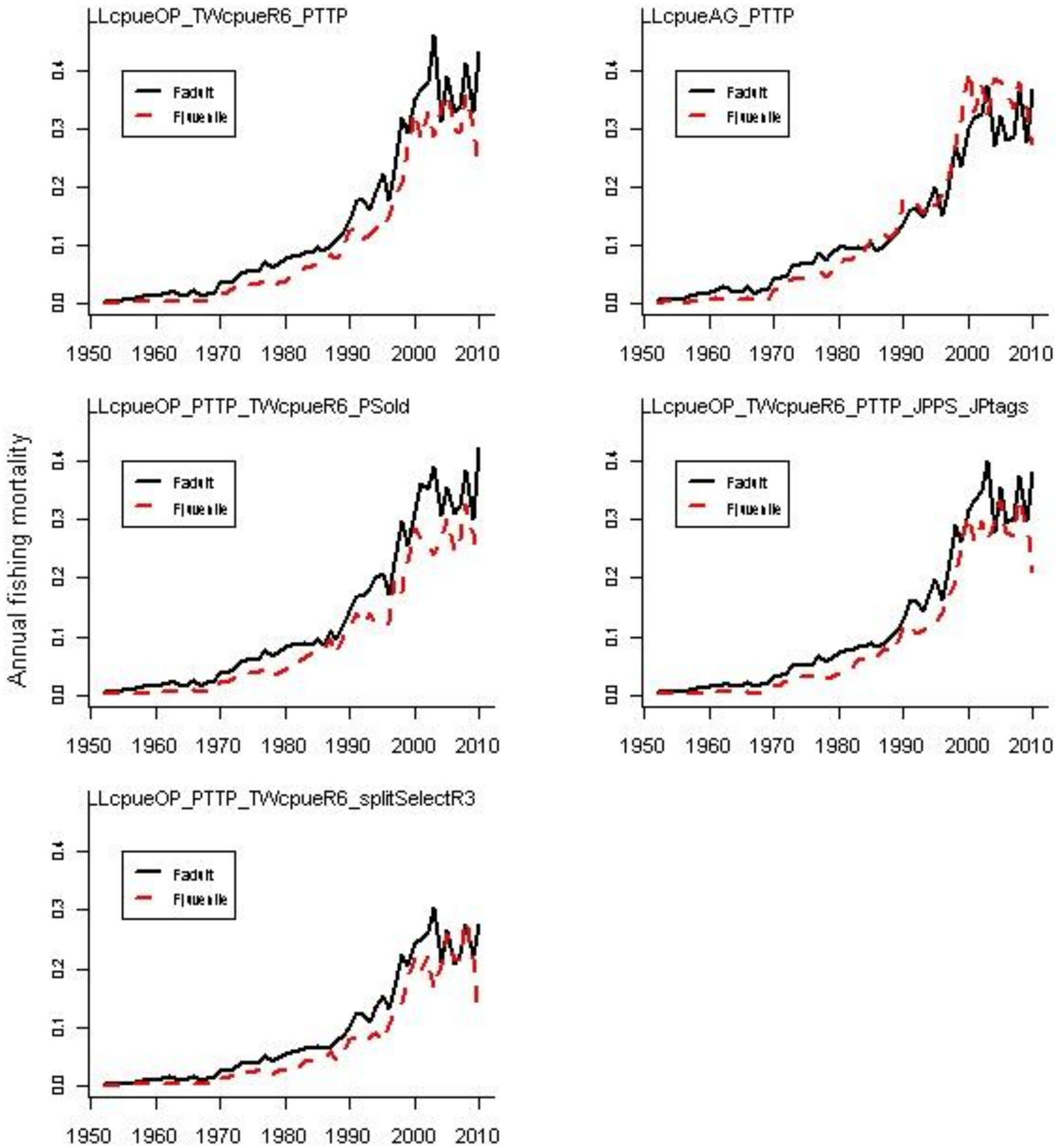


Figure 50. Estimated annual average juvenile and adult fishing mortality for the WCPO obtained from the reference model and four alternative model options.

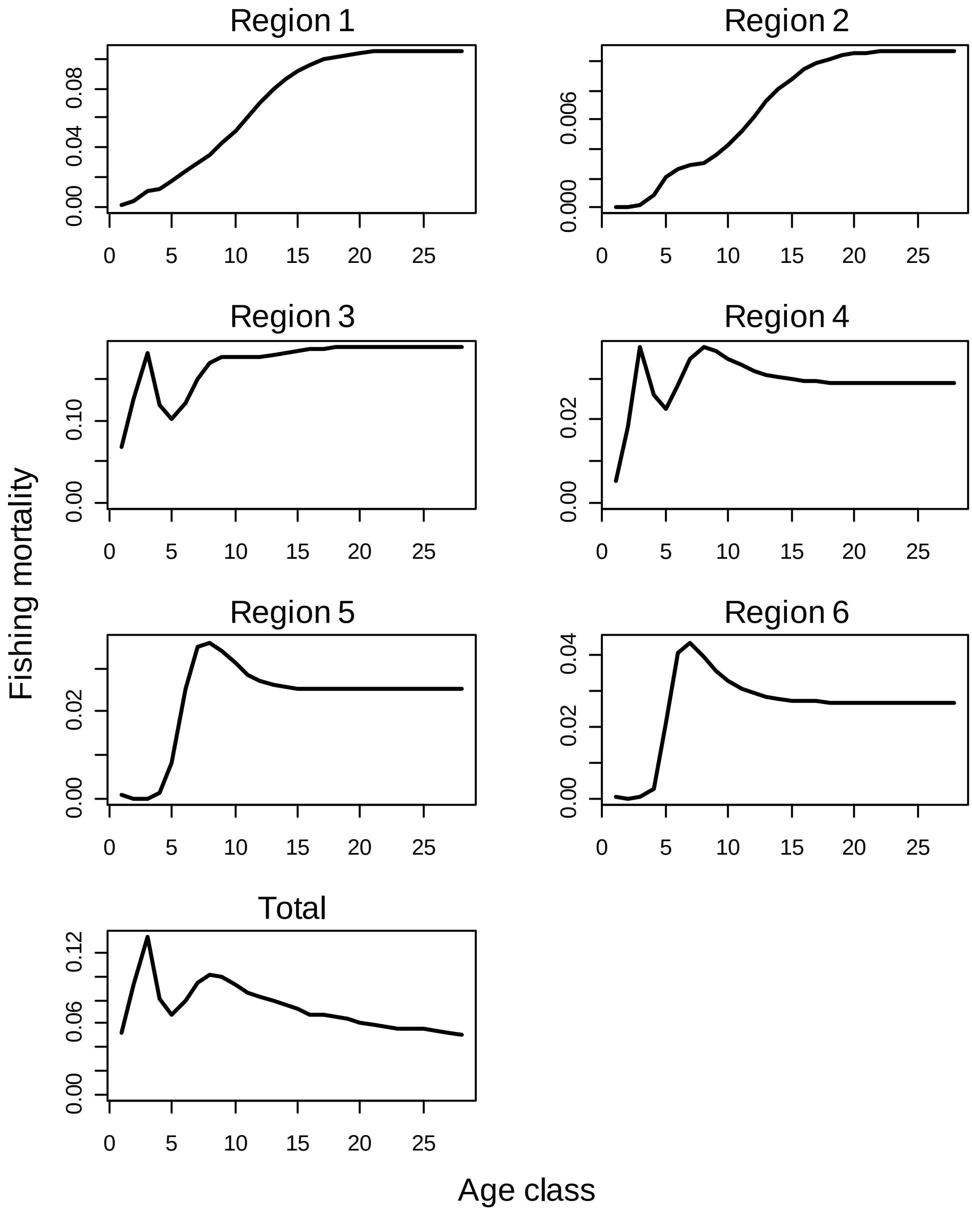


Figure 51. Fishing mortality by age class and region for the period used to determine the total F-at-age included in the calculation of MSY based reference points (2006–09). Note that the y-axis varies between plots.

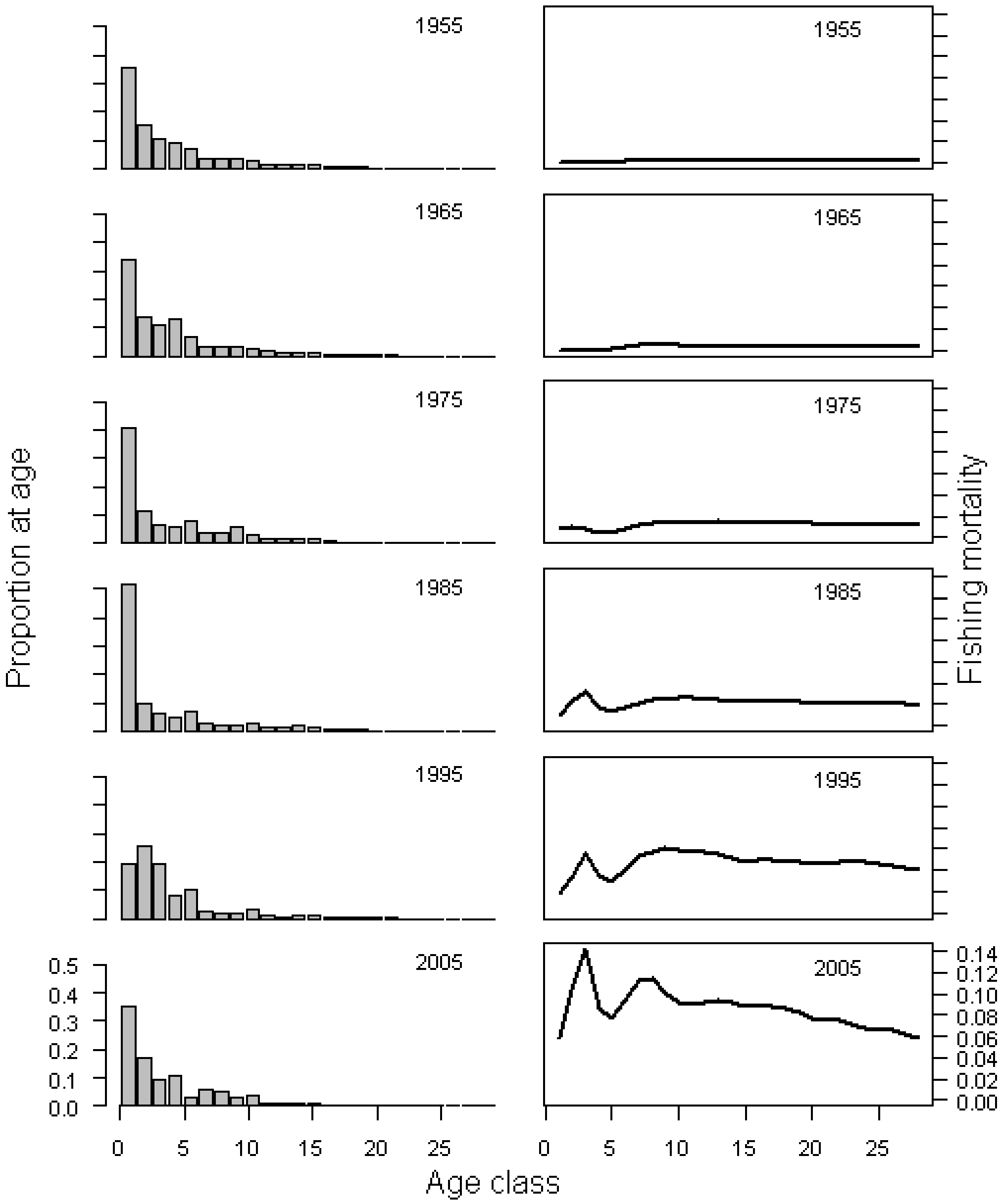


Figure 52. Estimated proportion at age (quarters) for the WCPO yellowfin population (left) and fishing mortality at age (right) by year at decade intervals.

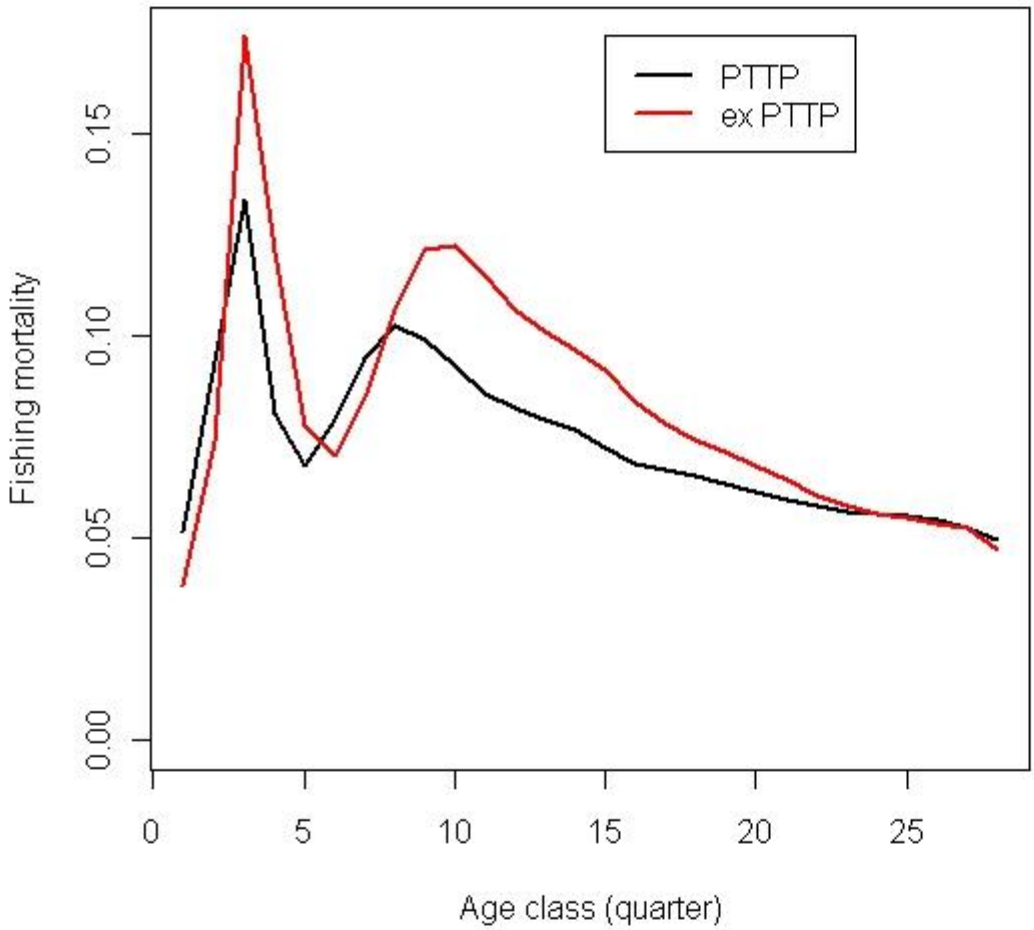


Figure 53. Average quarterly age specific fishing mortality for the reference period (2006-2009) for the reference model including PTTP tags and a comparable model excluding PTTP tags.

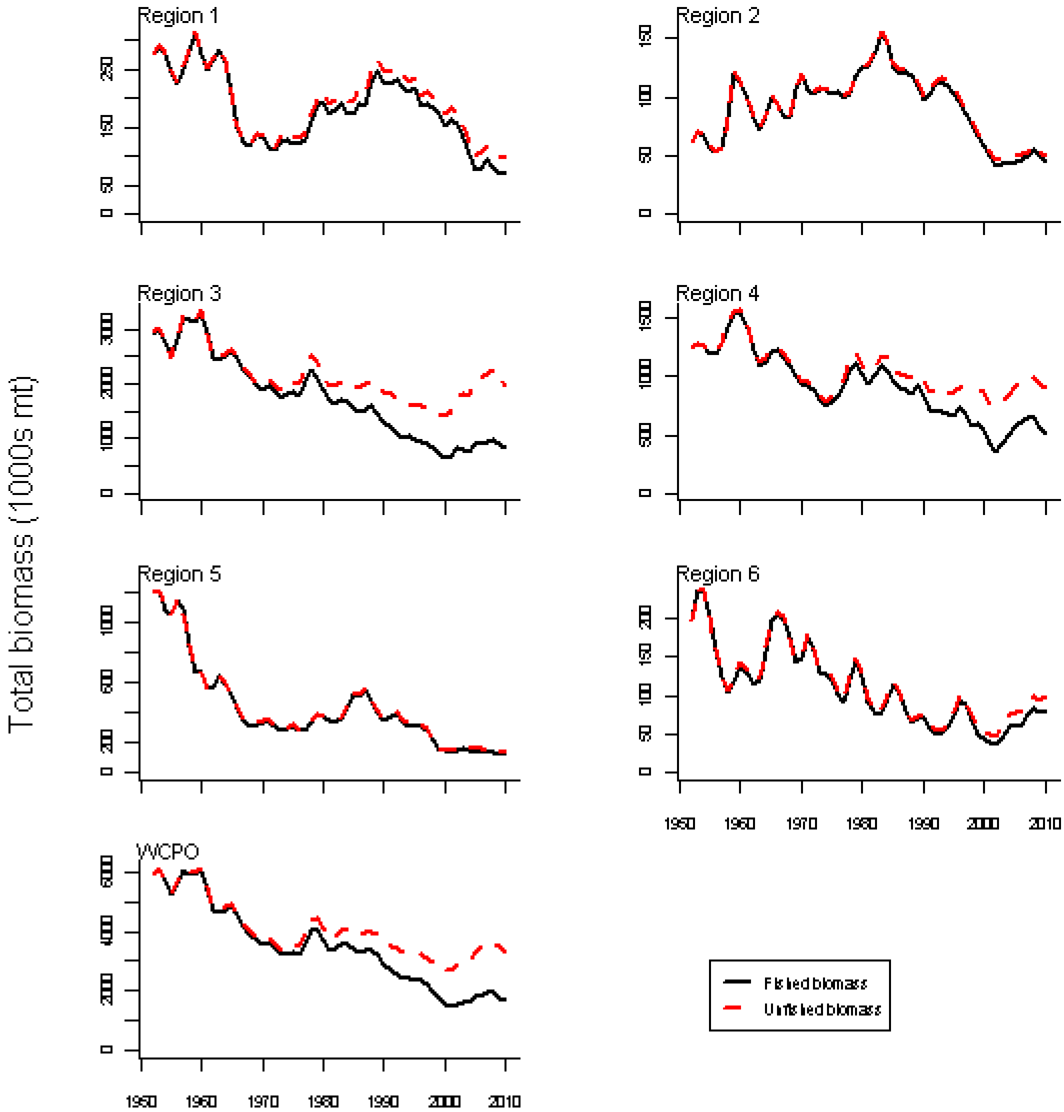


Figure 54. Comparison of the estimated total biomass trajectories (lower heavy lines) with biomass trajectories that would have occurred in the absence of fishing (upper dashed lines) for the refernce model for each region and for the WCPO.

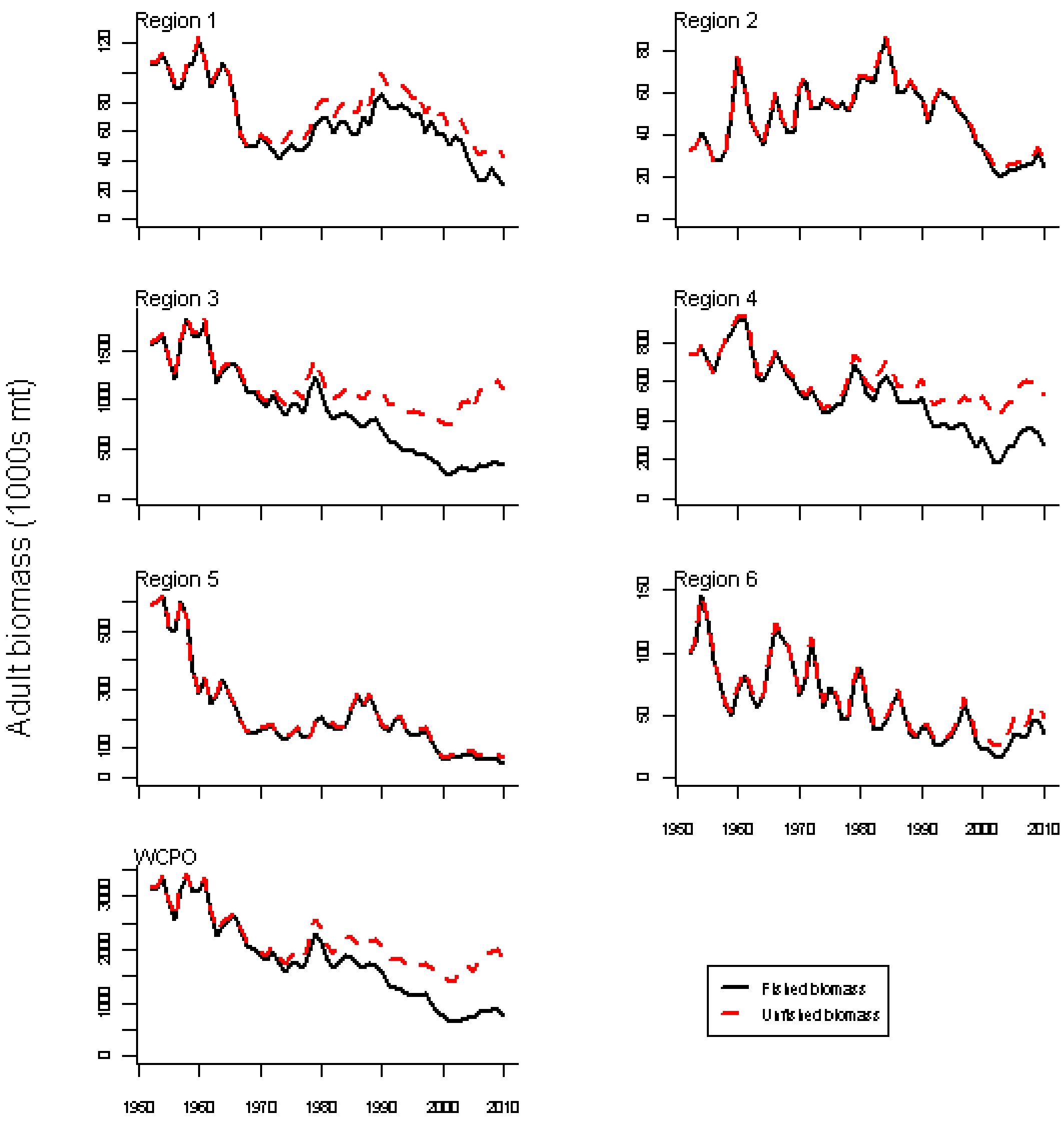


Figure 55. Comparison of the estimated adult biomass trajectories (lower heavy lines) with biomass trajectories that would have occurred in the absence of fishing (upper dashed lines) for the reference model for each region and for the WCPO.

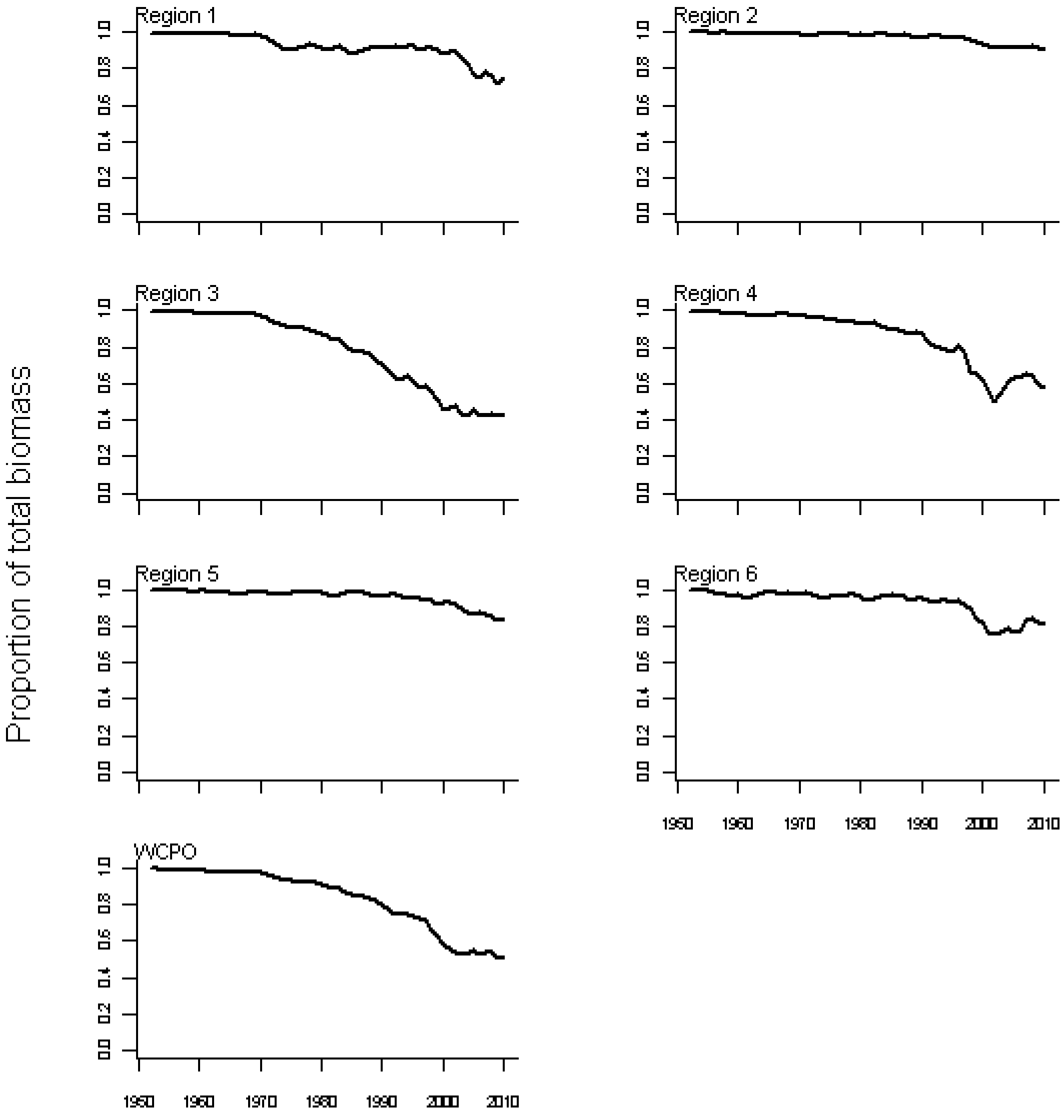


Figure 56. Ratios of exploited to unexploited total biomass ($B_t/B_{0,t}$) for each region and the WCPO.

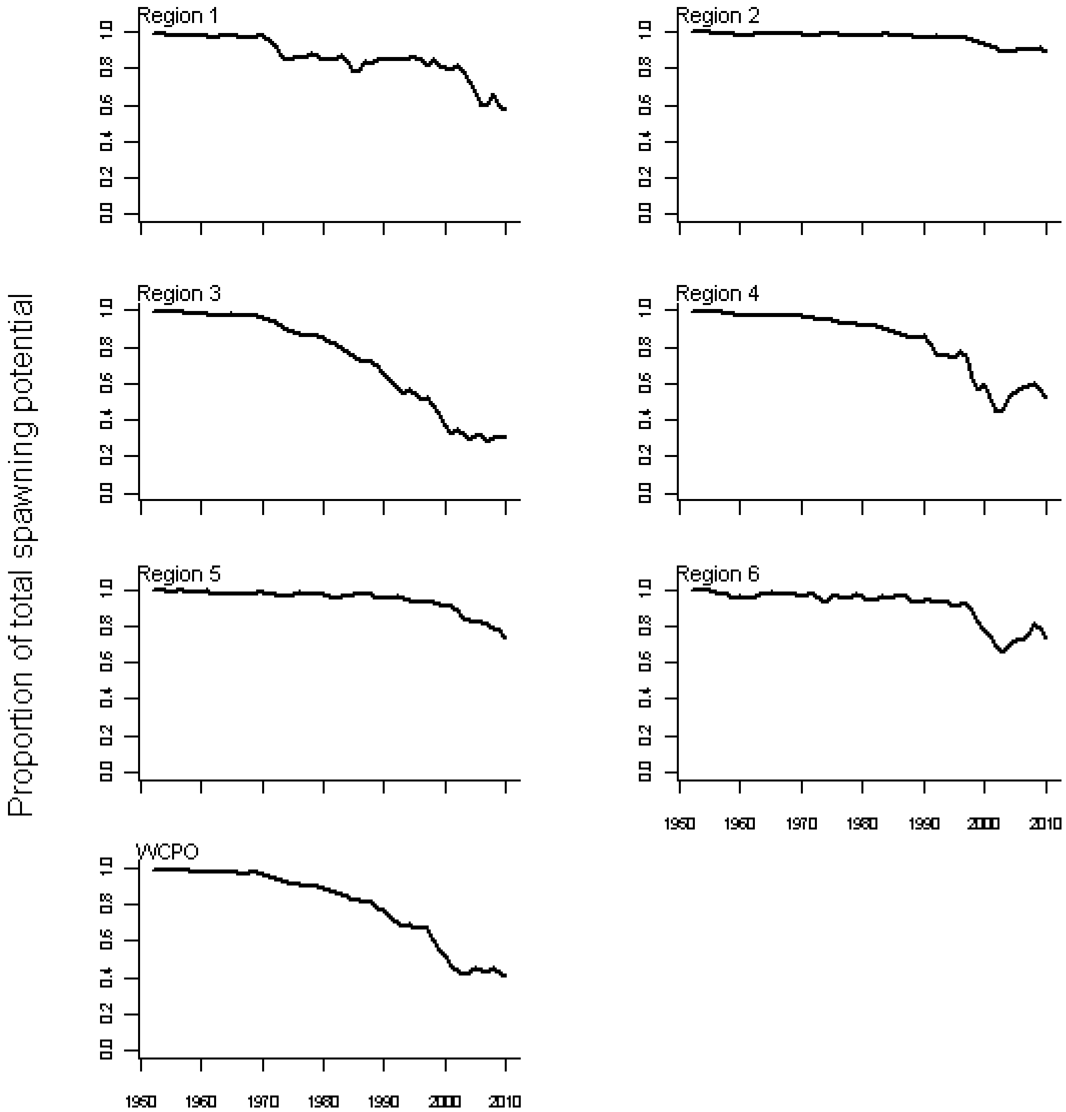


Figure 57. Ratios of exploited to unexploited spawning biomass ($SB_t/SB_{0,t}$) for each region and the WCPO.

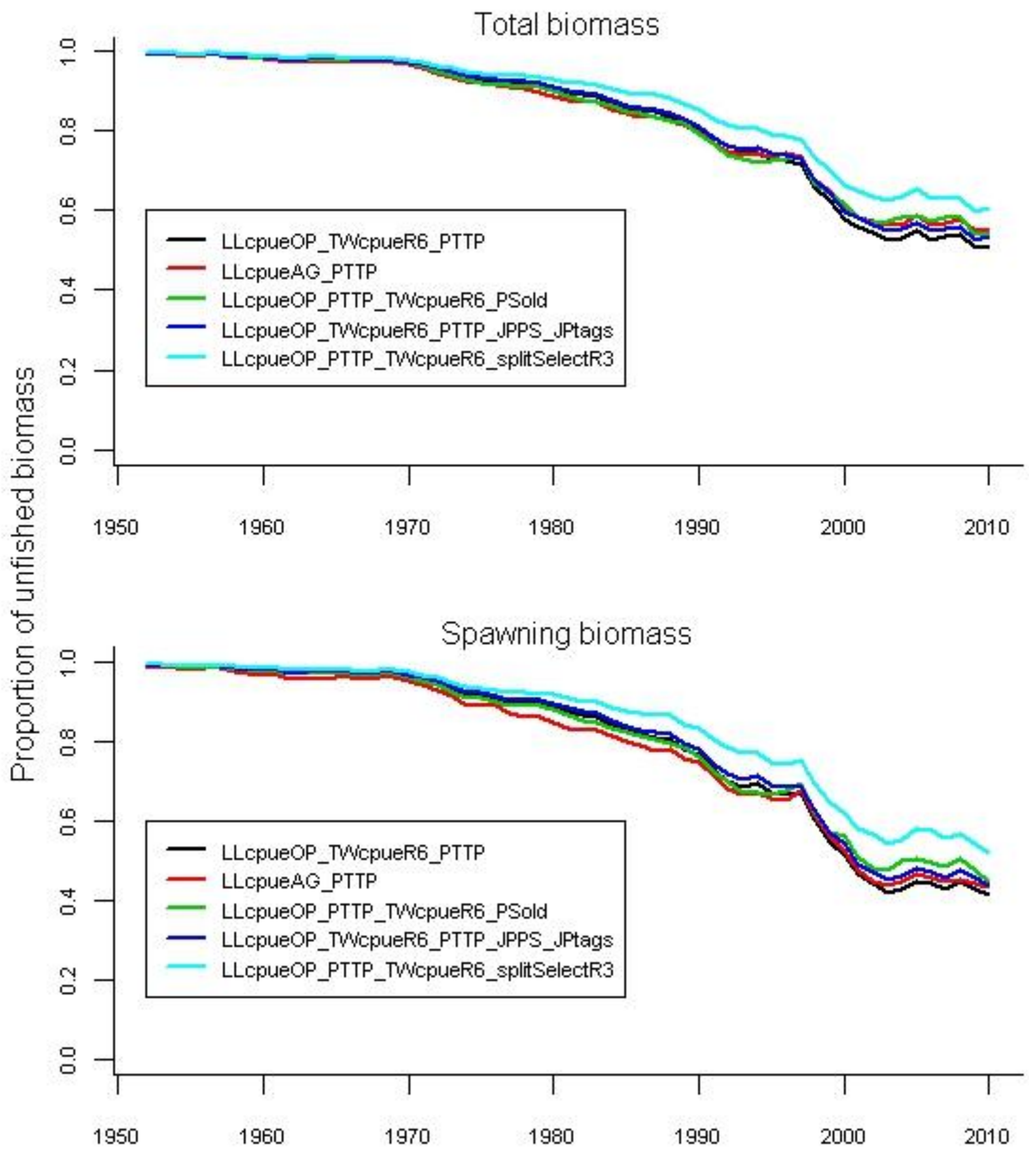


Figure 58. Ratios of exploited to unexploited total biomass (top) and spawning biomass (bottom) for the WCPO obtained from the separate analyses.

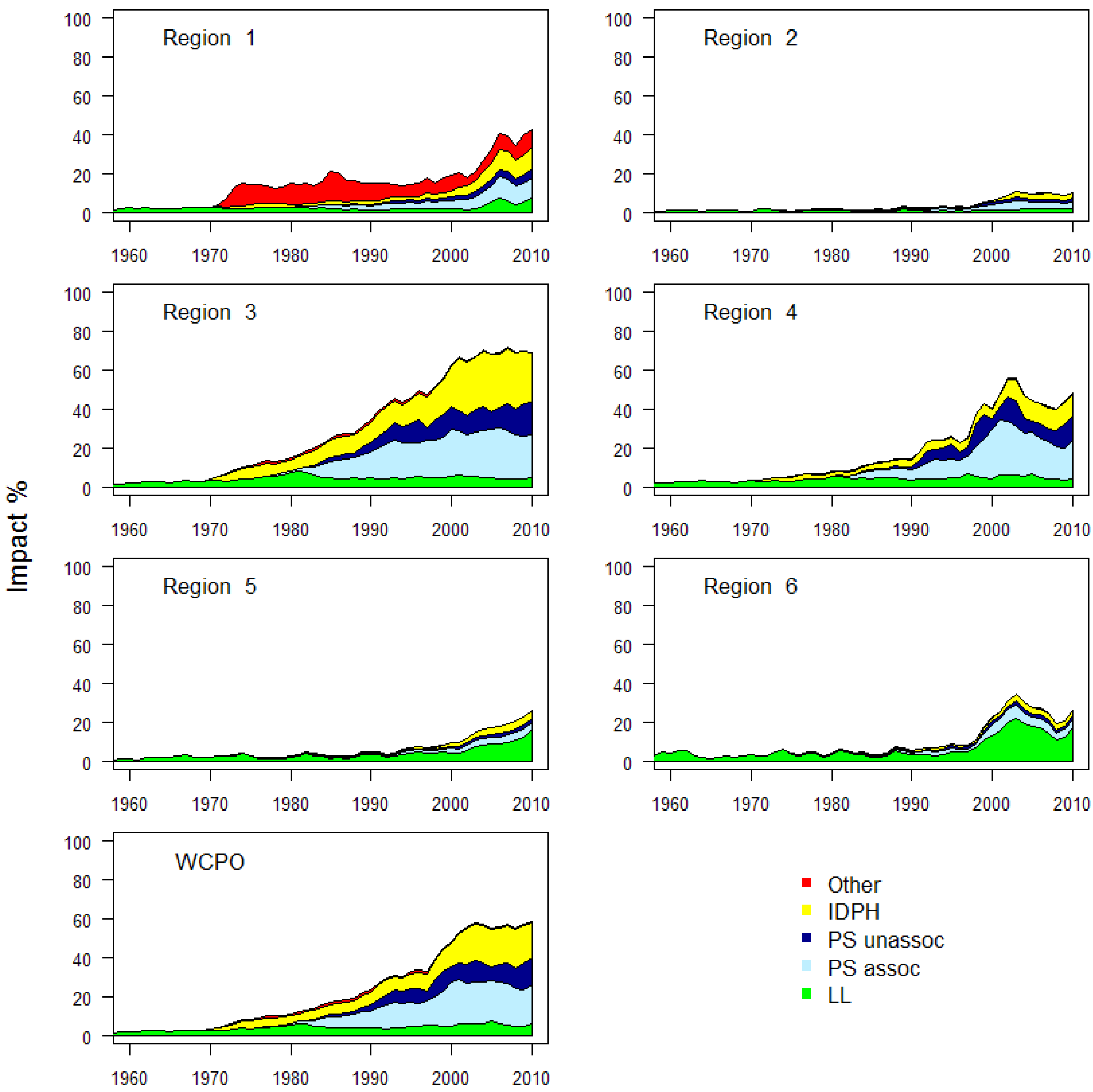


Figure 59. Estimates of reduction in spawning biomass due to fishing (fishery impact = 1-$SB_t/SB_{0,t}$) by region and for the WCPO attributed to various fishery groups. LL = all longline fisheries; PH/ID = Philippines and Indonesian domestic fisheries; PS assoc = purse seine FAD and log sets; PS unassoc = purse seine school sets; Other = JP coastal PL & PL and equatorial PL.

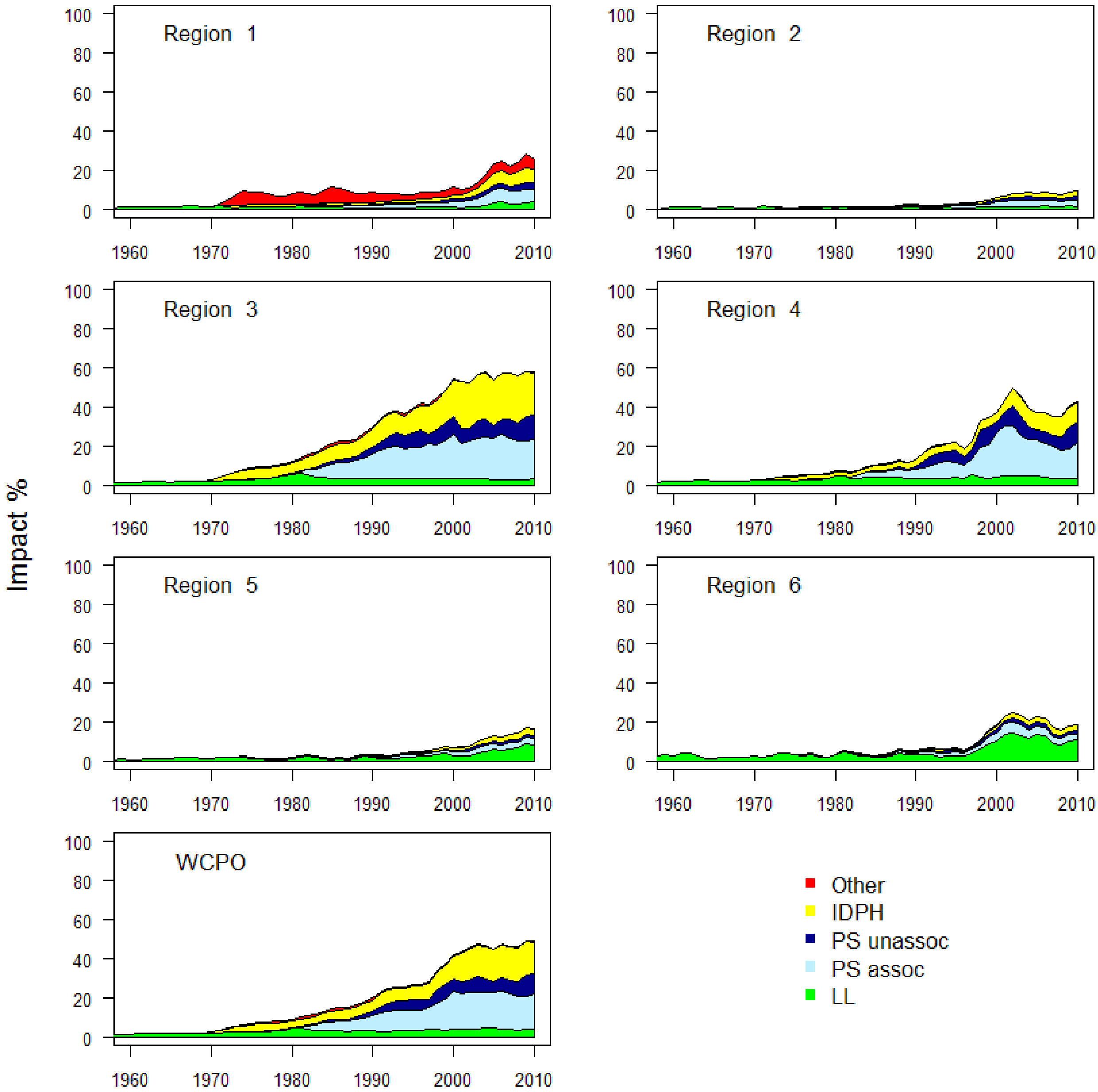


Figure 60. Estimates of reduction in total biomass due to fishing (fishery impact = 1-$B_t/B_{0,t}$) by region and for the WCPO attributed to various fishery groups. LL = all longline fisheries; PH/ID = Philippines and Indonesian domestic fisheries; PS assoc = purse seine FAD and log sets; PS unassoc = purse seine school sets; Other = JP coastal PL & PL and equatorial PL.

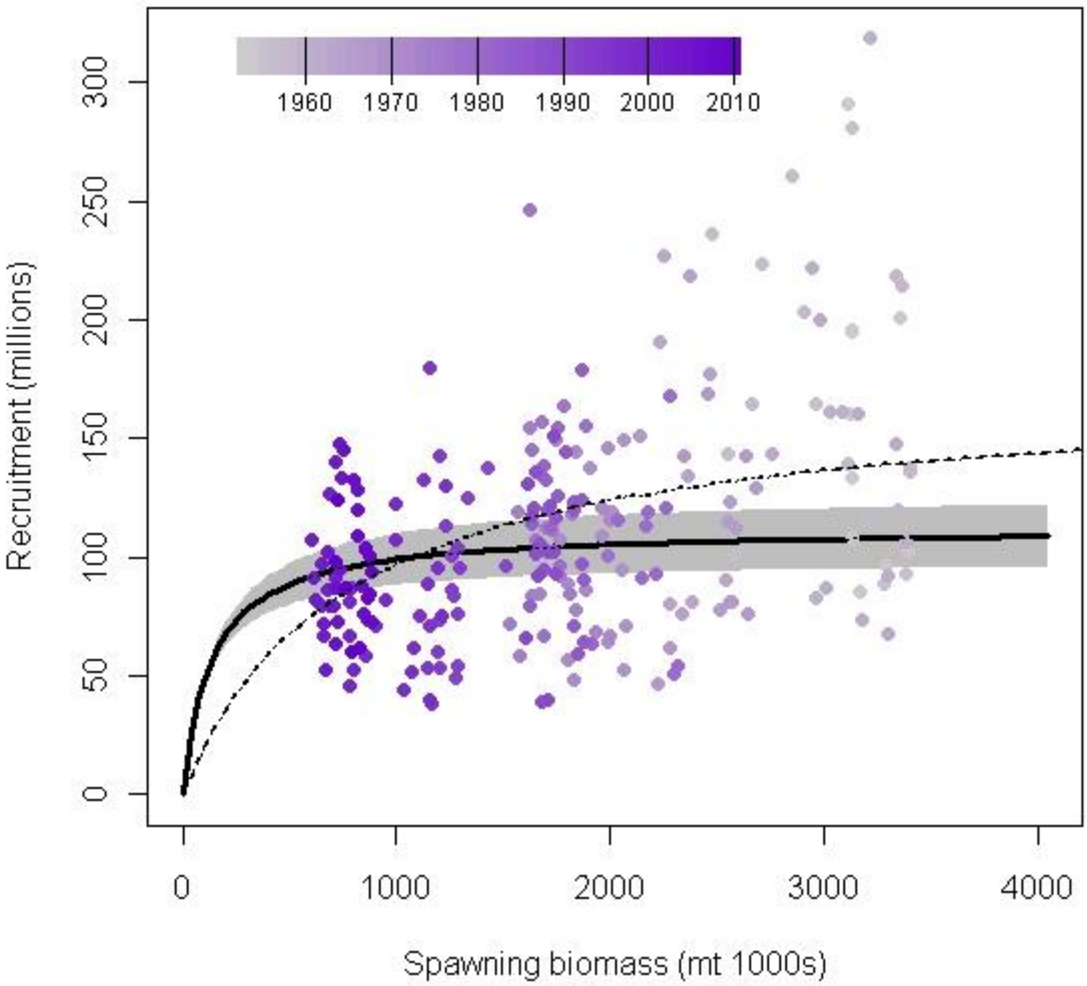


Figure 61. The assumed relationship between equilibrium recruitment and equilibrium spawning biomass (steepness fixed at 0.8). The points represent the estimated recruitment-spawning biomass and the colour of the points denotes the time period from which the estimate was obtained (see legend). The dashed line represents the estimated stock-recruitment relationship (model option _hEST).

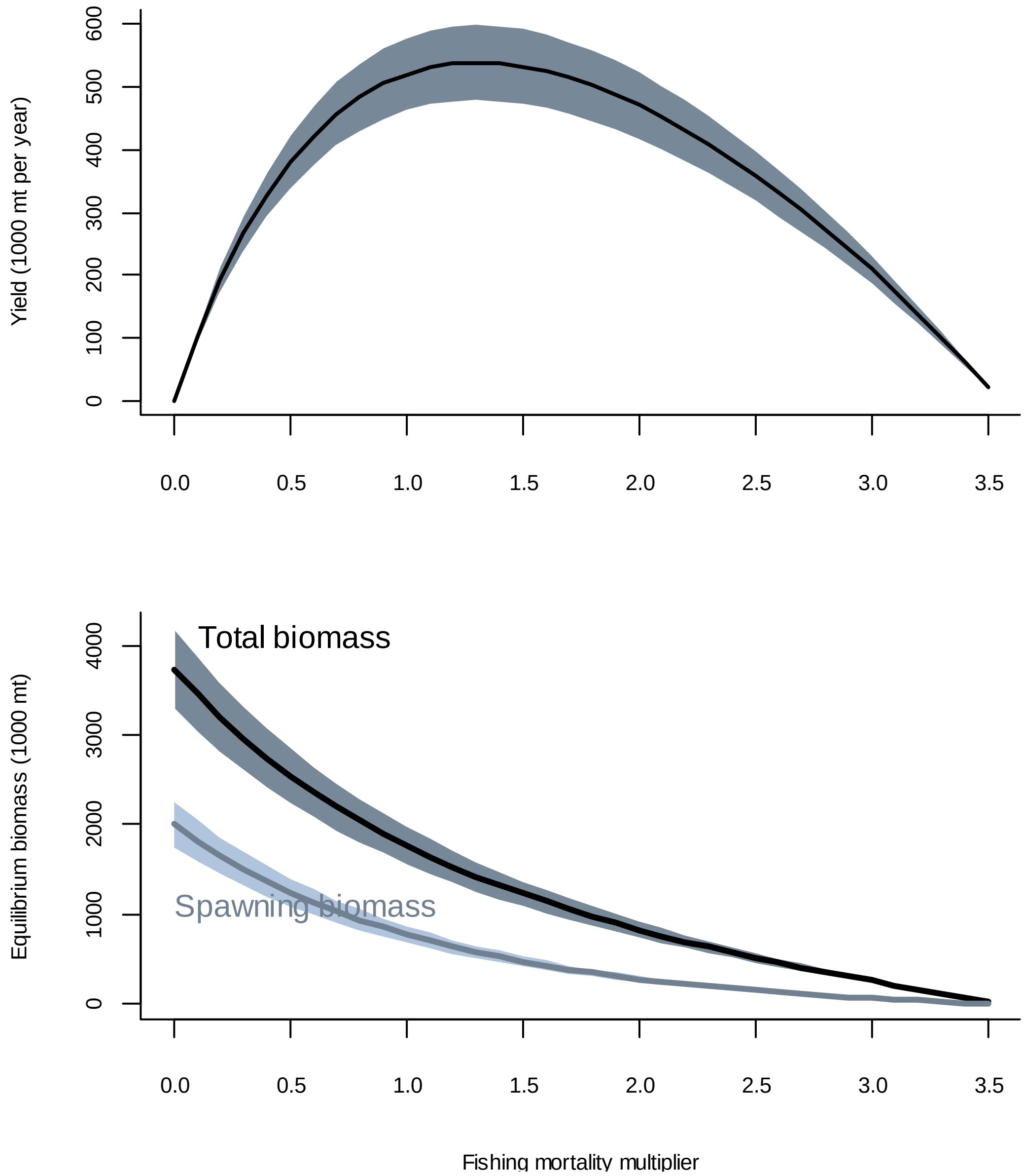


Figure 62. Yield, equilibrium biomass and equilibrium spawning biomass as a function of fishing mortality multiplier for the reference model.

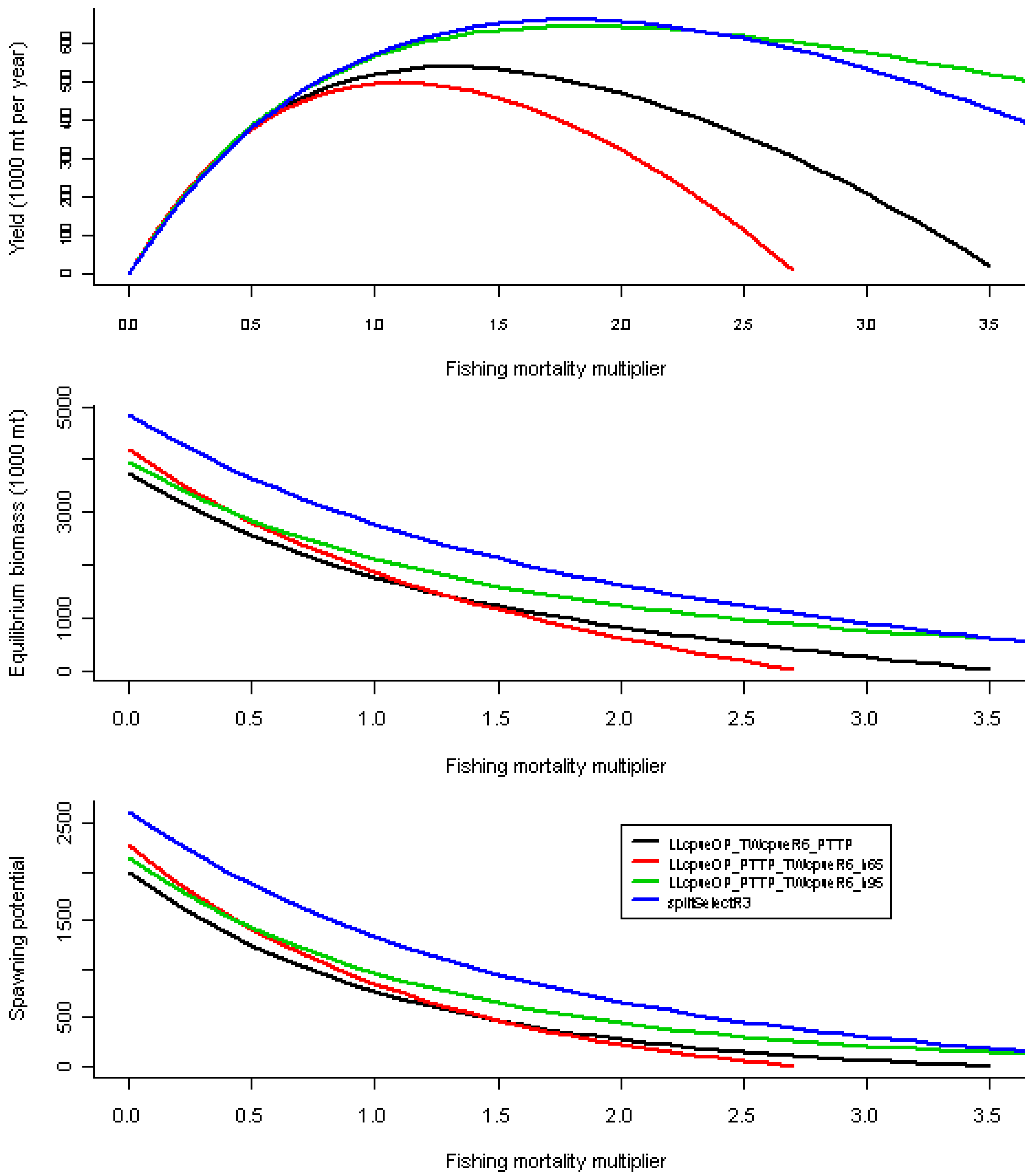


Figure 63. Yield (top), equilibrium total biomass (middle) and equilibrium spawning biomass (bottom) as a function of fishing mortality multiplier for the reference model and selected alternative model options.

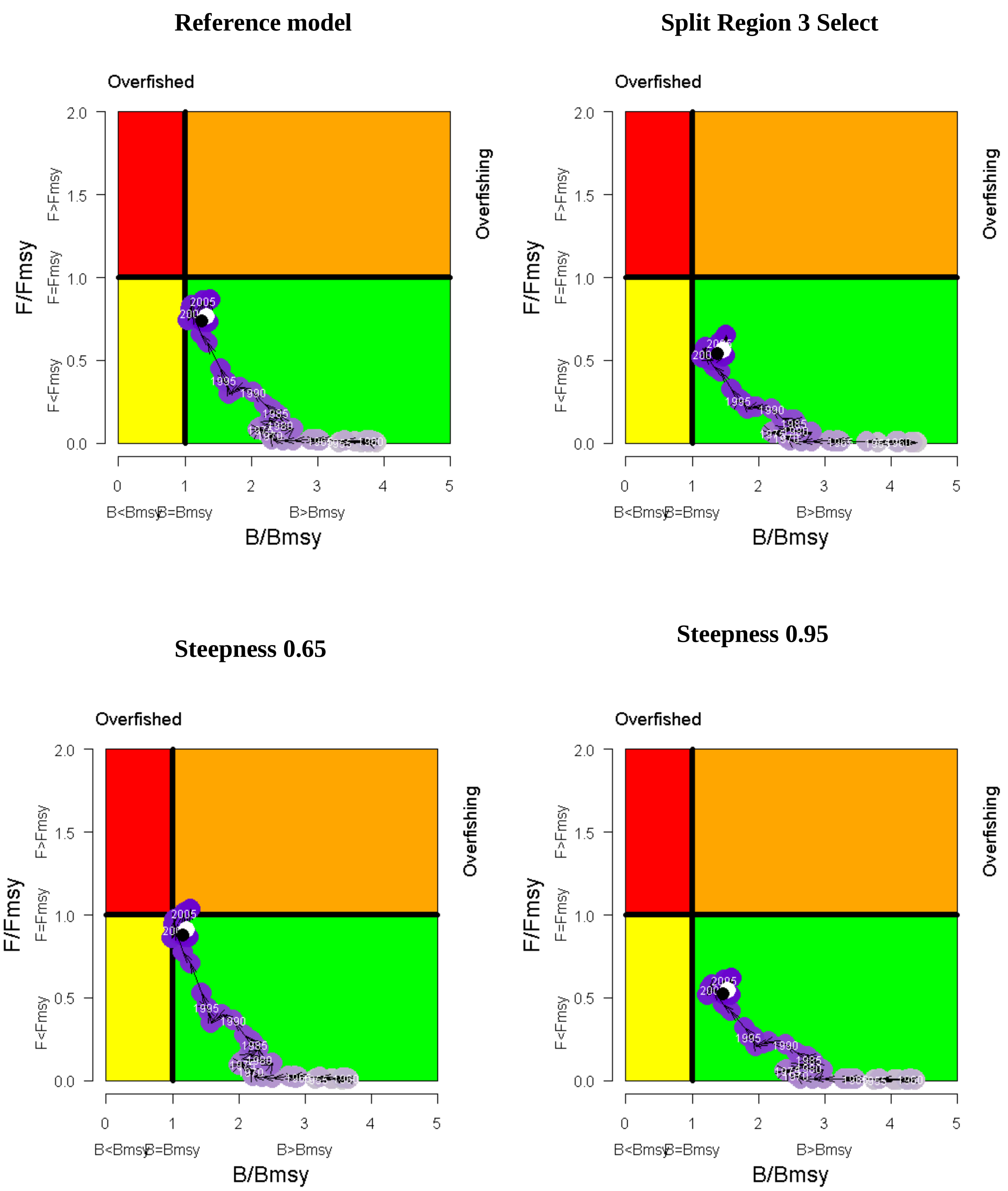


Figure 64. Temporal trend in annual stock status, relative to B_{MSY} (x-axis) and F_{MSY} (y-axis) reference points, for the model period (1952–2010). The colour of the points is graduated from mauve (1952) to dark purple (2010) and the points are labelled at 5-year intervals. The white circle represents the average for the period 2006-09 and the black circle the 2009 values.

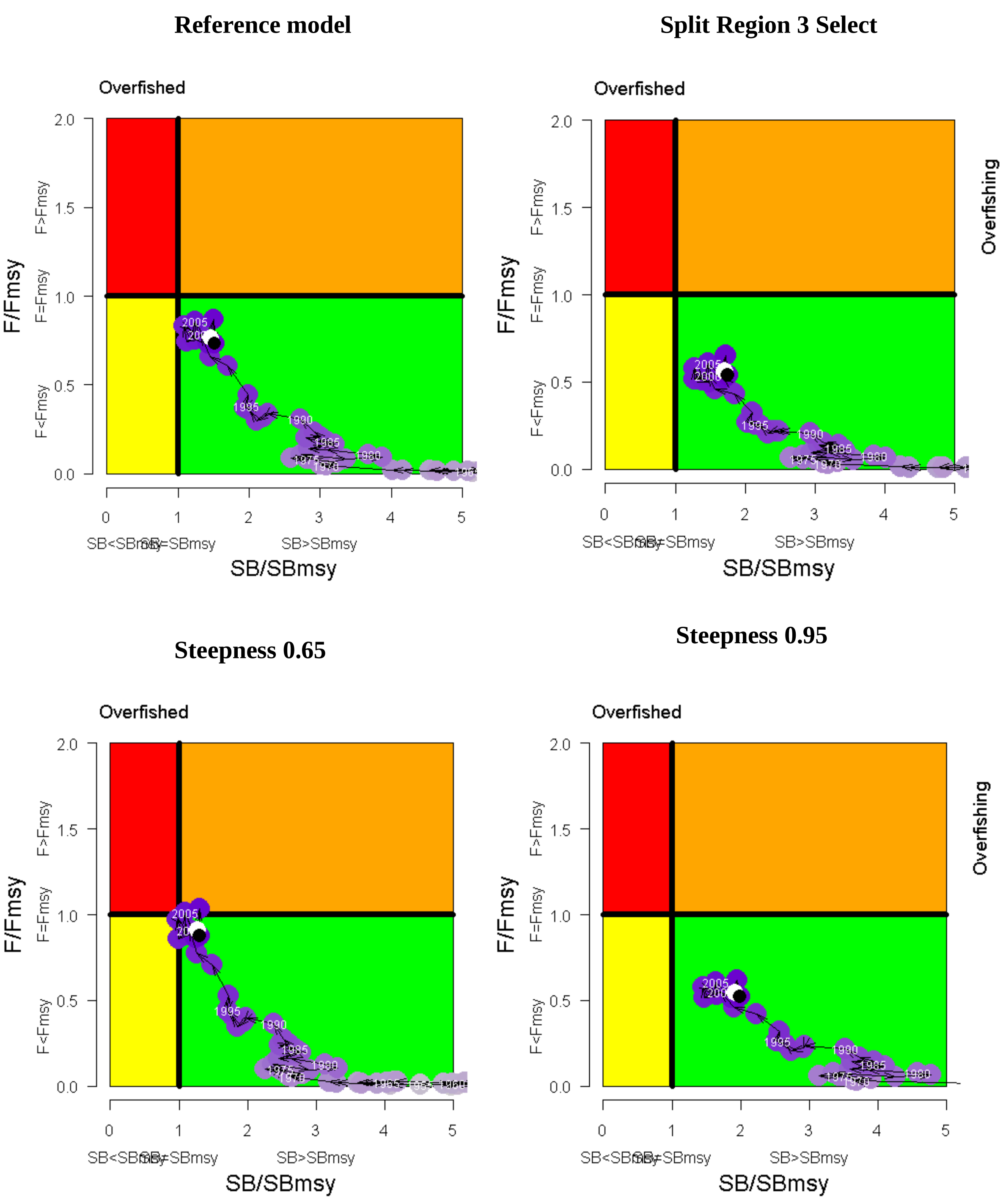


Figure 65. Temporal trend in annual stock status, relative to SB_{MSY} (x-axis) and F_{MSY} (y-axis) reference points, for the model period (1952–2010). The colour of the points is graduated from mauve (1952) to dark purple (2010) and the points are labelled at 5-year intervals. The white circle represents the average for the period 2006-09 and the black circle the 2009 values.

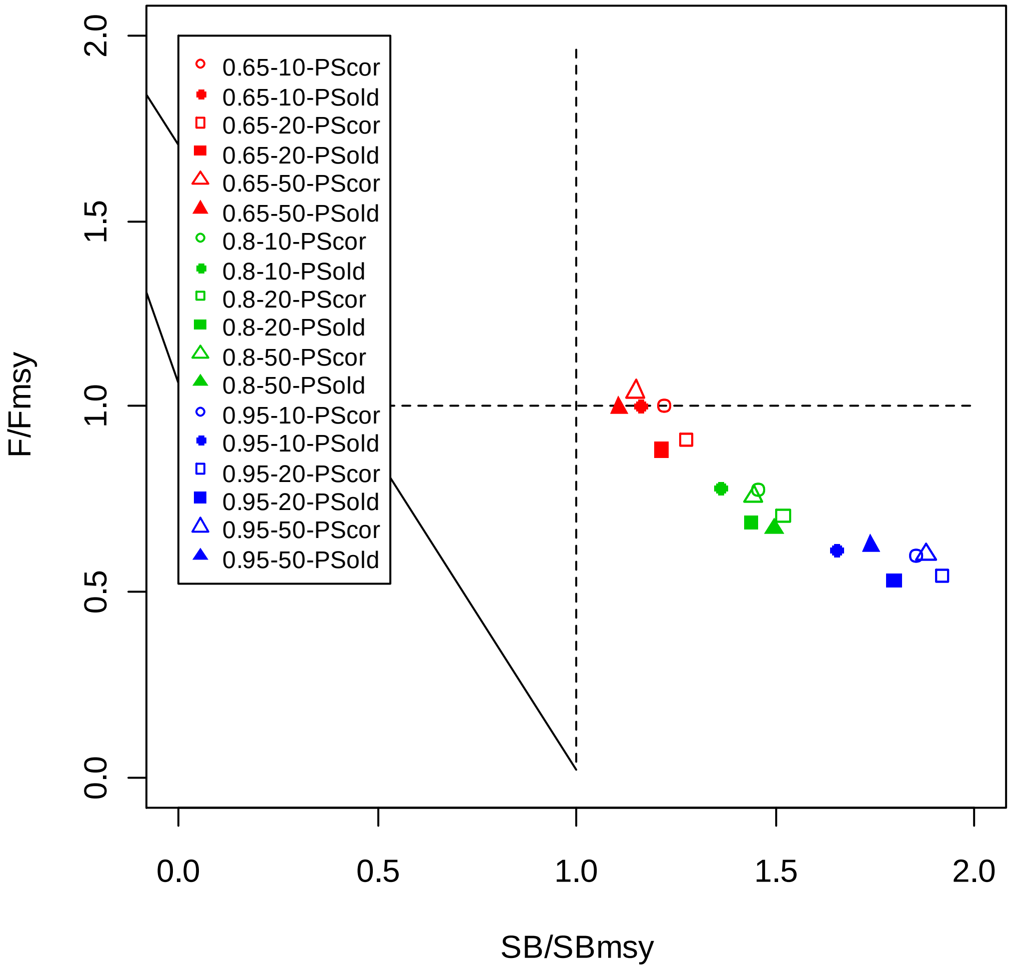


Figure 66. Comparison of F/F_{MSY} and SB/SB_{msy} reference points derived from the combinations of model sensitivities. The legend specified the steepness value, divisor of the sample size for the LL ALL size frequency data and the purse seine catch history (PScor, corrected; PSold, uncorrected).

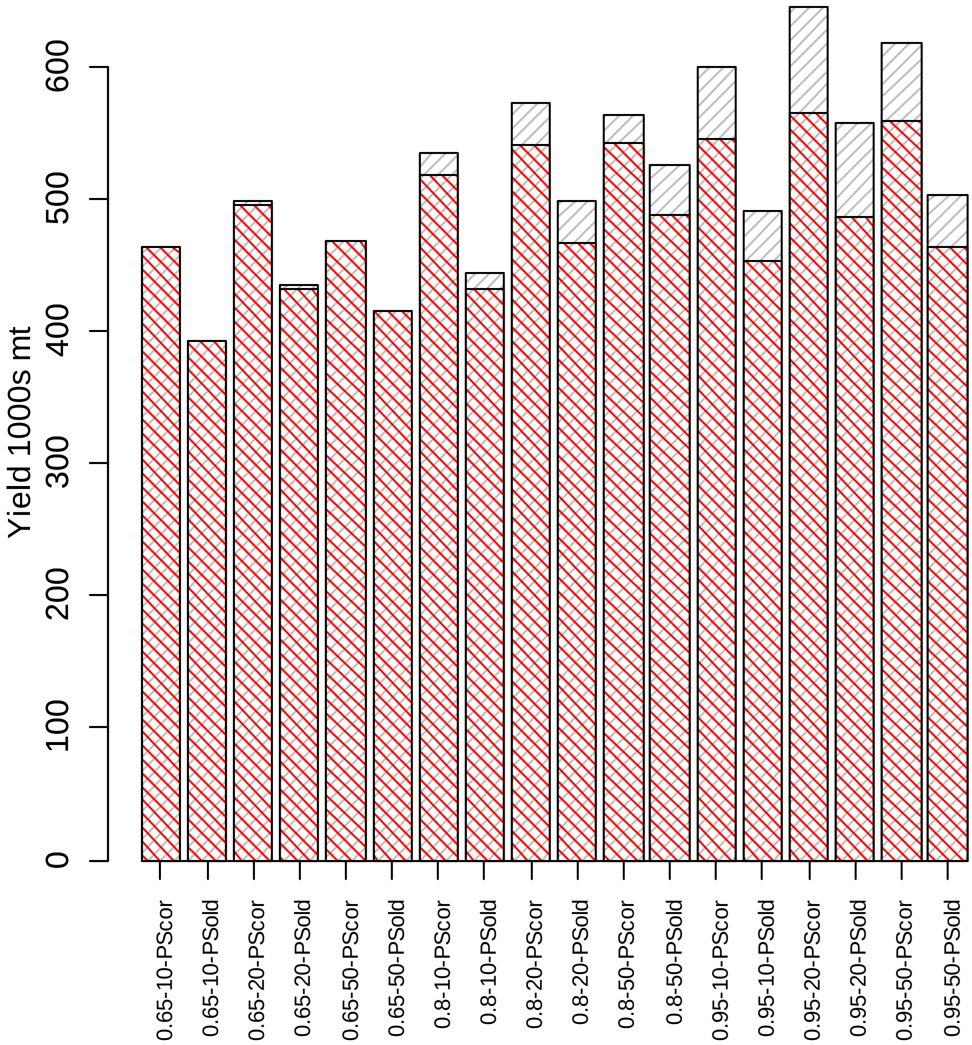


Figure 67. Comparison of the *MSY* (grey) and $Y_{Fcurrent}$ (red) for the combinations of model sensitivities. The legend specified the steepness value, divisor of the sample size for the LL ALL size frequency data and the purse seine catch history (PScor, corrected; PSold, uncorrected).

Appendix 1 *doitall.yft*

```
#  ------------------------
#  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 1         # 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
  -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 6          # sets control, but don't estimate growth
  1 111 4         # sets likelihood function for tags
  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       # sets no. mixing periods for all tag release groups to 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 1        # logistic selectivity for 3 TWCH fisheries
   -8 57 1
# grouping of fisheries with common selectivity
   -1 24 1        # Longline fisheries have common selectivity in reg. 1, 2, 7
   -2 24 1
   -3 24 2        # Longline fisheries have common selectivity in reg. 3, 4, 5, 6, 8
   -4 24 3
   -5 24 4        # TW/CH longliners use night sets -> generally bigger fish
   -6 24 5
   -7 24 3
   -8 24 4
   -9 24 6
  -10 24 3
  -11 24 7
  -12 24 3
  -13 24 8
  -14 24 9
  -15 24 10
  -16 24 9
  -17 24 10
  -18 24 11
  -19 24 12
  -20 24 13
  -21 24 14
  -22 24 15
  -23 24 16       # separate LL selectivity for smaller fish in PNG waters
  -24 24 17
  -25 24 18
# grouping of fisheries with common catchability
   -1 29 1        # Longline fisheries grouped
   -2 29 1
   -3 29 2        # HI LL fishery different
   -4 29 1
   -5 29 3        # TW/CH LL fishery different
```

```
  -6 29 4
  -7 29 1       # AU LL fishery different
  -8 29 5       # JP LL in Aust. region 5 are targeting SBT in the south
  -9 29 6       # AU LL fishery different
 -10 29 1
 -11 29 7
 -12 29 1
 -13 29 8
 -14 29 9
 -15 29 10
 -16 29 11
 -17 29 12
 -18 29 13
 -19 29 14
 -20 29 15
 -21 29 16
 -22 29 17
 -23 29 18
 -24 29 19
 -25 29 20
 -1 60 1       # Longline fisheries grouped
  -2 60 1
  -3 60 2       # HI LL fishery different
  -4 60 1
  -5 60 3       # TW/CH LL fishery different
  -6 60 4
  -7 60 1       # AU LL fishery different
  -8 60 5       # JP LL in Aust. region 5 are targeting SBT in the south
  -9 60 6       # AU LL fishery different
 -10 60 1
 -11 60 7
 -12 60 1
 -13 60 8
 -14 60 9
 -15 60 10
 -16 60 11
 -17 60 12
 -18 60 13
 -19 60 14
 -20 60 15
 -21 60 16
 -22 60 17
 -23 60 18
 -24 60 19
 -25 60 20
# grouping of fisheries for tag return data
   -1 32 1
   -2 32 2
   -3 32 3
   -4 32 4
   -5 32 5
   -6 32 6
   -7 32 7
   -8 32 8
   -9 32 9
  -10 32 10
  -11 32 11
  -12 32 12
  -13 32 13
  -14 32 14       # PS assoc. and unassoc. returns are grouped
  -15 32 14
  -16 32 15
  -17 32 15
  -18 32 16       # PH returns returns are grouped
  -19 32 17
  -20 32 18
  -21 32 19
```

```
   -22 32 20
   -23 32 4
   -24 32 21
   -25 32 22
# grouping of fisheries with common tag-reporting rates - as for tag grouping
    -1 34 1
    -2 34 2
    -3 34 3
    -4 34 4
    -5 34 5
    -6 34 6
    -7 34 7
    -8 34 8
    -9 34 9
   -10 34 10
   -11 34 11
   -12 34 12
   -13 34 13
   -14 34 14        # PS assoc. and unassoc. returns are grouped
   -15 34 14
   -16 34 15
   -17 34 15
   -18 34 16        # PH returns returns are grouped
   -19 34 17
   -20 34 18
   -21 34 19
   -22 34 20
   -23 34 4
   -24 34 21
   -25 34 22
# sets penalties on tag-reporting rate priors
    -1 35 1         # The penalties are set to be small for LL fisheries
    -2 35 1
    -3 35 50        # HI LL fishery thought to be high rep. rate
    -4 35 1
    -5 35 1
    -6 35 1
    -7 35 1
    -8 35 1
    -9 35 50
   -10 35 1
   -11 35 50        # AU LL region 4 thought to be high rep. rate
   -12 35 1
   -13 35 1
   -14 35 50        # WTP PS based on tag seeding
   -15 35 50
   -16 35 50
   -17 35 50
   -18 35 50        # PH/ID based on high recovery rate
   -19 35 50
   -20 35 1
   -21 35 1
   -22 35 1
   -23 35 1
   -24 35 50
   -25 35 50
# sets prior means for tag-reporting rates
    -1 36 50        # Mean of 0.5 and penalty of 1 -> uninformative prior
    -2 36 50
    -3 36 80        # HI LL
    -4 36 50
    -5 36 50
    -6 36 50
    -7 36 50
    -8 36 50
    -9 36 80
   -10 36 50
```

```
  -11 36 80       # AU LL region 4
  -12 36 50
  -13 36 50
  -14 36 45       # WTP PS based on tag seeding and discounted for unable returns
  -15 36 45
  -16 36 45
  -17 36 45
  -18 36 60       # PH/ID
  -19 36 60       # PH HL
  -20 36 50
  -21 36 50
  -22 36 50
  -23 36 50
  -24 36 60
  -25 36 60
# effort dev bpoundary
 2 35 10
# sets penalties for effort deviations (negative penalties force effort devs
# to be zero when catch is unknown)
  -999 13 -10
  -1 13 1
  -2 13 1
  -4 13 1
  -7 13 1
 -10 13 1
 -12 13 1
 -18 13 10
## use time varying effort weight for LL fisheries
  -1 66 1
  -2 66 1
  -4 66 1
  -7 66 1
 -10 66 1
 -12 66 1
# sets penalties for catchability deviations
  -18 15 1      # low penalty for PH.ID MISC.
  -24 15 1
  -25 15 1
 -999 33 1      # estimate tag-reporting rates
 1 33 90        # maximum tag reporting rate for all fisheries is 0.9
PHASE1
fi

dos2unix *.par
 dos2unix RR_pars_groups.txt
 dos2unix RRactivate_17f.txt
 dos2unix RR_pars_inits.txt
 dos2unix RR_pars_priors.txt
 dos2unix RR_pars_pens.txt
./replace.sh 01.par RR_pars_groups.txt
./replace.sh 01.par RRactivate_17f.txt
./replace.sh 01.par RR_pars_inits.txt
./RRinsert.sh 01.par RR_pars_priors.txt
./RRinsert.sh 01.par RR_pars_pens.txt

## 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
 2 198 1    # activate est of group specific RR for tags
 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
  1 189 1         # write graph.frq (obs. and pred. LF data)
  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
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 0        # only annual catches
  -24 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
  -6 10 1         # time-series
  -8 10 1         # for all
  -9 10 1         # non-longline
  -11 10 1         # fisheries
  -13 10 1
  -14 10 1
  -15 10 1
  -16 10 1
  -17 10 1
  -18 10 1
  -19 10 1
  -20 10 1
  -21 10 1
  -22 10 1
  -23 10 1
  -24 10 1
  -25 10 1
  -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
   -1 44 1
   -2 44 1
   -3 44 1
   -4 44 1
   -5 44 1
   -6 44 1
   -7 44 1
   -8 44 1
   -9 44 1
  -10 44 1
  -11 44 1
  -12 44 1
  -13 44 1
  -14 44 2
  -15 44 2
  -16 44 2
  -17 44 2
  -18 44 3
  -19 44 3
  -20 44 1
  -21 44 1
  -22 44 2
  -23 44 1
  -24 44 3
  -25 44 3
 -999 43 1        # estimate a for all fisheries
  1 13 1    # estimate mean length of largest age class
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
PHASE11
fi
#  ---------
#   PHASE 12
#  ---------
if [ ! -f 12.par ]; then
  nice $MFCL yft.frq 11.par 12.par -file - <<PHASE12
  2 145 1
  1 149 0
  2 146 1
  2 162 0
  2 163 0
  2 147 1
  2 148 20       # Current is defined as 2006-2009
  2 155 4
  2 153 31
  2 154 16
  1 1 4000
  1 50 -3
  -999 14 0
  -999 55 1 # fishery impact
  2 193 1  # initial impact for depletion
PHASE12
fi
```

Appendix 2 *yft.ini*

```
# ini version number
0
# number of age classes
28
# maturity at age
0 0 0 0.003112633 0.031087873 0.112437021 0.423024369 0.58577586 0.844926311 0.934591096 0.975401043
0.995264883 1 0.981462405 0.890010382 0.77144549 0.617121988 0.472944161 0.352073537 0.256720297 0.184325598
0.130839012 0.092100132 0.064441996 0.044896017 0.031182966 0.021611419 0.014954788
# natural mortality (per year)
0.2502986
# movement map
1 2 3 4
# diffusion coffs (per year)
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1
# age_pars
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
0.69195349 0.56412012 0.41751665 0.24566639 0.03802703 -0.22433724 -0.22433724 -0.2241689 -0.22380502 -
0.22148317 -0.21035369 -0.1715757 -0.08886825 0.15424345 0.19963184 0.25933392 0.19946889 0.11882525
0.04148199 -0.02433836 -0.0771884 -0.11795455 -0.14844786 -0.17073448 -0.18674878 -0.19811476 -0.20611103 -
0.21170159
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 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 0.06 0.4 0.35 0.05 0.09
# 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)
# Generic SD of length at age
6 3 15
# Length-dependent SD
0.4 -1 1
# The number of mean constraints
0
```