

**INTER-AMERICAN TROPICAL TUNA COMMISSION**

**2<sup>nd</sup> REVIEW OF THE STOCK ASSESSMENT OF BIGEYE TUNA IN THE  
EASTERN PACIFIC OCEAN**

La Jolla, California (USA)

11-15 March 2019

**REPORT OF THE MEETING**

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## EXECUTIVE SUMMARY

The 2nd review of the stock assessment of bigeye tuna in the eastern Pacific Ocean (EPO) was conducted

from 11-15 March 2019 at the Embassy Suites Hotel in La Jolla, CA. The aim of the review was not to conduct a review of the assessment in relation to the provision of management advice in the short-term, but rather to identify the research that needs to be undertaken to provide the best available science for tactical and strategic management advice. The assessment forms the basis for tactical (short-term) management advice, as well as the basis for Management Strategy Evaluation (MSE) work.

IATTC staff provided background documents, documents prepared specifically for the review, presentations, and responses to requests by the Panel that addressed topics related to data, biology, and modelling. The review focused on the research needed to improve the current assessment and as the basis for future MSE work. A focus for the meeting was an apparent “recruitment regime shift”, where the assessment model estimates an increase in average recruitment in the mid-1990s coincident with the increase in purse seine catches in the EPO.

The Panel concluded that the apparent recruitment regime shift arises because the substantial increase in purse seine catches (which are generally of small/young fish) does not have a proportionate impact on the trends in catch-rates or in the size-composition of the longline catches, which are predominantly larger/older fish. Essentially the same trends in the observations would have arisen without a recruitment regime shift had the purse seine catches been much smaller. Thus, while it cannot be definitively rejected that an actual recruitment regime shift has occurred, the balance of evidence is that the apparent shift is an artefact of some aspect of the model or the way it has been parameterized.

The Panel identified a range of future model explorations that should be conducted prior to selecting a new base-case model and identifying an operating model for MSE work. The suggested explorations include alternative natural mortality schedules, growth models and estimation procedures. The Panel also provided guidance on the construction and use of spatial models for bigeye tuna in the EPO, Central, and Western Pacific.

## 1. BACKGROUND

There have been substantial changes in the bigeye tuna fishery in the EPO over recent decades (**Figure 1.1**). Initially, most bigeye catch was taken by longline vessels. With the expansion of the fishery on fish aggregating devices (FADs) since 1993, the purse seine fishery has taken an increasing component of the bigeye catch, and is now the dominant fleet.

The assessment of bigeye tuna in the eastern Pacific Ocean (EPO) is based on fitting an age- and sex-structured population dynamics model to data on catches, catch rates, and length-frequency data. The first review of the assessment was conducted in 2010 (Sibert et al., 2012). That review focused on two key features of the assessment that were considered undesirable: (a) an apparent recruitment regime shift (henceforth referred to as Rshift<sup>1</sup>) in the mid-1990s that coincided with the expansion of the purse seine fishery and may be an artefact of model mis-specification (**Figure 1.2a**), and (b) a residual pattern in the fit to the longline length-frequency data. Since 2010, IATTC staff have conducted many analyses in response to the recommendations of the 2010 review, including examinations of the assessment data and modelling approaches. The Panel commends the IATTC staff for their work (documented in paper WSBET-02-04) to address the recommendations of the 2010 review.

Rshift remains a concern with the assessment, with several hypotheses identified for the cause during and after the 2010 review, including: (a) underestimated purse seine catches in the pre-1990 period, (b) higher natural mortality rates, (c) mis-specified growth, (d) density-dependent growth, (e) changes in migratory patterns, and (f) the “spatial mismatch” hypothesis. Each of these hypotheses was the subject of a paper

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<sup>1</sup> Rshift is also a value used to quantify the extent to which recruitment increases in the mid-1990s (ratio of the median of the recruitments after 1993 to that before 1993).

presented to the present review and was a focus for Panel deliberations, as outlined below.

Key changes to the assessment from 2010 have included revised longline fishery definitions and revised and updated length composition data (revised length and new weight compositions - which seem to have resolved the early residual pattern problem), pre-specified CVs for the catch-rate indices, estimation of the parameters of a Richards growth function using information from length-at-age sampling and tagging, development of a new growth model (the Growth Cessation Model; Maunder et al. 2018a), and exploration of spatially-structured assessment models. Rshift was “resolved” in the 2013 assessment (**Figure 1.2b**) by substantially downweighting the size-composition data. However, this problem has re-emerged in the 2018 assessment (**Figure 1.2c**). An additional finding of the 2018 assessment was that the F-multiplier was substantially lower in 2018 (0.87) compared to the 2017 assessment (1.15) even though the 2018 assessment was an ‘update’ assessment and was methodologically identical to the 2017 assessment. The Panel felt that this change in F-multiplier is consistent with recent declines in longline catch-rates coupled with recent increase in purse seine catches of small bigeye tuna, consistent with increasing fishing mortality. However, the Panel noted that there is a retrospective pattern in the recent F-multiplier estimates that requires further investigation.

The objectives of the Panel (see Appendix A for the Terms of Reference; Appendix B for brief Panel biographies; and Appendix C for the meeting participants) were to:

- a. identify the best available science for use in the assessment;
- b. provide an independent review of the assessment approach; and
- c. provide advice on future research and data collection that will improve the assessment and the provision of management advice.

Staff members provided the Panel with several documents (Appendix D) prior to, and during the meeting and gave presentations on four broad topics (Sections 2 to 5 of this report). The Panel had several requests to the IATTC staff to enable it to better understand and consider the issues. These are listed in Appendix E.

The review considered several versions of the model used for the assessment, with emphasis on two classes of model: (a) the 2018 base-case model that has two longline catch-rate indices (IATTC, 2018a, b; Xu et al., 2018) and (b) a new area-specific model with four re-defined areas (WSBET-02-02; WSBET-02-08) and five longline catch-rate indices. **Figure 1.3** contrasts the spatial strata used for the 2018 base-case model and those on which the new model is based. Appendix F describes the differences between the two classes of model in detail. The aim of IATTC staff is for future assessments to be based on modifications to the new model. The results of the two classes of model were sufficiently similar that conclusions drawn from one model should apply to the other.

The remainder of this report summarizes the review of each broad topic, the key issues identified during the document review, presentations and subsequent discussions, the findings based on the documents provided and the outcomes of the requests to the staff, and the recommendations arising from the findings. Section 6 of the report outlines broad conclusions based on the review of the material provided and the key general topics that arose during the meeting, as well as future data collection needs.

The Panel thanks the staff of the IATTC (Scientific Staff: Alexandre Aires-da-Silva, Leanne Fuller, Cleridy-Cody Lennert, Mark Maunder, Carolina Minte-Vera, Ricardo Oliveros-Ramos,

Juan Valero [contractor], Haikun Xu; Support Staff: Marisol Aguilar, Monica Galvan, Jeff Morgan, Robert Sarazen, Sofia Webber), for their hard work and willingness to respond to Panel requests, for their exceptional support, provisions, and general hospitality during the review.

## **2. DATA ISSUES**

### **2.1. Catch and discards**

#### **2.1.1. Purse seine catch and discard data**

Purse seine catch data come from four sources with differing degrees of spatial and temporal resolution and are processed by IATTC staff. Two issues were identified regarding the catch data.

- a. The need to partition the catch to species. Port sampling for species composition started in 2000, so 1975-1999 species composition is unknown and is characterized using 2000-2004 estimates, which could be affected by temporally-varying species composition. Species identification between juvenile bigeye and yellowfin is difficult, and small errors in species identification could result in greater impact on estimated bigeye catches because yellowfin are landed in larger quantities than bigeye by some components of the purse seine fleet.
- b. Estimation of discards. Estimates of the magnitude of discards come from onboard observer data. Discards were assumed to start after 1993 in the purse seine fishery. Before 1993, the purse seine fishery was small, and no discards were assumed. Discards of bigeye due to their small size are modelled as separate fleets in the assessment model. Estimates of the magnitude of discards are made separately for three size categories (small: <2.5kg; medium: 2.5-15kg; large: > 15kg) based on rationales for discarding. Regulations that require full retention since 2000 have decreased discards.

#### **2.1.2. Longline catch and discard data**

Longline catch data are reported by IATTC Members and Cooperating non-Members (CPCs) and appeared to be generally well determined. The primary source of uncertainty is related to the different units of reporting and the need for updated biometric relationships (see *Section 6*). Catch data are input to the model in the original units, whether in weight or number. Discards are assumed to not occur in the longline fishery. However, given the apparent differences in selectivity between the Japan Research and Training (JRT) and the Japanese commercial vessels (though these could be due to spatial differences in size-based availability), smaller bigeye might be discarded in the commercial fishery, and discards of fish that are damaged or unfit for consumption should be expected. Given the likely price differential between small and large bigeye, there is some incentive for high-grading. Although the magnitude of discards may be low, the assumption that discards are zero in the longline fleets should be re-evaluated, particularly given that the longline fleets have some observer coverage.

#### **2.1.3. Findings**

The major characteristic of the post-1993 fishery is the substantial shift from a longline (and large fish) dominated fishery to a mixed fishery dominated by catches of small fish in the purse seine fishery, a pattern that is observed across multiple spatial partitions of the EPO (**Figure 2.1**). Several analyses investigated how catch and discard data related to the historical landings time series affect estimates of initial conditions, whether the species partitioning of the purse seine fishery could be biased, and whether the treatment of purse seine discards could influence Rshift.

The species composition estimates, particularly for 1975-1993 could be biased low for bigeye due to misidentification of bigeye as the more abundant yellowfin. This underestimation of bigeye contribution to the catch could result in unaccounted catch during this time period, creating the appearance of an Rshift. Similarly, the treatment of the discards could create an Rshift because discards were assumed to only occur from 1993 to the present in the purse seine fishery, and discard magnitude and size composition are not well estimated.

Several requested sensitivity runs related to increasing the magnitude of historical discards addressed the issue of what magnitude of 1975-1999 removals, either as discards or catch, would be needed to reduce the appearance of an Rshift (see Requests D, E and F in Appendix E). These sensitivity runs partially addressed hypothesis (a) in Section 1. These runs indicated that discards prior to 1993 would have to have been 10-fold larger than those immediately thereafter to eliminate the regime shift (**Figure 2.2A**). A similar substantial hypothetical increase in 1975-1999 catch would also have been necessary to eliminate the Rshift.

Conversely, the magnitude of decrease in recent (1995-2015) catch that would have been necessary to eliminate the Rshift was investigated. The rationale behind this analysis was that the increase in purse seine catches could be due to influx of fish from outside of the EPO. To address this hypothesis, another hypothetical analysis was conducted that found that a 75% reduction in purse seine catch would have been needed (**Figure 2.2B**). Hence it is unlikely that hypothesis of underestimated purse seine catches (or discards) in the pre-1990 period (or conversely over estimated recent catches) is the cause of the Rshift.

## **2.2. Catch and discard composition data**

### **2.2.1. Purse seine composition data**

Size composition of the purse seine catch is obtained from opportunistic samples of wells with catch from the same month, sampling area, set type and vessel size category by multiplying the well-level estimates of proportion at length by the estimated total catch in numbers for the species in the month/area/set type and vessel size stratum. Different estimators were used for the time periods 1975-1999 and 2000-present. For discards of small BET, size composition is assumed to represent fish of quarters 1 to 3. This is a strong assumption, but removing the discard data had little effect on the final results (Request D of Appendix E).

Given the regulations implemented since 2000 that mandate full retention, it may be necessary to estimate a time block on selectivity pre- and post-implementation of these policies. Previous sensitivity analyses (IATTC, 2009) found slight differences, which could have been due to a phase-in of the regulations, and selectivity estimates might exhibit greater differences after more years of implementation.

### **2.2.2. Longline composition data**

Longline size composition data come from similar sources as the catch data, though catch compositions may be reported in weight or numbers. The length-composition data in the assessment currently comes only from the Japanese commercial fleet and the Japan Research and training vessels.

### **2.2.3. Findings**

One of the primary data issues was a substantial residual pattern identified during the 2010 review in the longline composition data pre- and post-1990. This was identified to be caused by the data being a mix of JRT vessel data and commercial data (Satoh et al., 2016). JRT vessels provided the majority of the samples before 1990 and appear to catch much smaller bigeye than the commercial fleet that provided the majority of the data after 1990. The recommended solution was to (a) separate out the JRT fleet and model the data for this fleet as a survey or (b) remove the JRT fleet data due to variable fishing strategies over time. The model was rerun with the JRT fleet separated into a different fleet, and this has eliminated the residual pattern but the Rshift remained. Rerunning the model without the JRT composition data had little impact (Request C in Appendix E). Spatial mapping of the JRT data indicate some spatial segregation from the Japanese commercial fleet, which may be one of the major causes of the different length composition. Minte-Vera et al. (2016) noted that part of the residual pattern could be due to the conversion of measurements in weight to length. Given that almost all of the pre-1990 data are recorded

in weight frequencies it may be useful to attempt to continue to include these data in their native units or with improved conversions, once issues with the JRT data are resolved.

The purse seine length-composition data appear to provide little information on average recruitment in the model. Profiles of  $R_0$  that show the contribution of each fleet to the log-likelihood indicated that length-composition data from the two longline fleets are most informative, with the purse seine fleets providing very little information (**Figure 2.3**; Request P in Appendix E). This is likely due to the small length range of fish in the purse seine catch. Given the potential for time-varying selectivity in the purse seine fishery, which may be due to either differential availability of fish by size, or other factors, a semi-parametric selectivity pattern such as that presented to the Panel by Haikun Xu might improve estimates of selectivity.

The information content of composition data is heavily influenced by the *ad hoc* data weighting scheme. The composition data are highly downweighted ( $\lambda = 0.05$ ). After other modelling issues are addressed, the weighting of the composition data should be increased (see *Section 5*).

Spatial maps of the mean size from the longline fisheries (**Figure 1.3**) provided valuable insight into potential size structure of the population. However, this map could be aliased by spatial patterns in the depth of the thermocline, which can bring larger fish closer to the surface, so more available to the longline fishery.

## 2.3. Indices of abundance

### 2.3.1. Issues

The primary sources of abundance information for EPO bigeye assessments are CPUE indices from longline fisheries. The 2018 base-case assessment uses two indices from the Japanese longline fishery, one in the central area and one in the south area (**Figure 2.4**). Both indices were standardized using a GLM that incorporates hooks between floats as a proxy for depth of set, which reflects changes in gear configuration often employed to differentially target bigeye rather than more surface-oriented species. The GLMs estimate independent year-quarter terms. Each index is linked to a specific fishery with different, but asymptotic, selectivities.

Several issues were raised regarding the longline CPUE indices. The first relates to whether the apparent differences between the central and southern indices (**Figure 2.4**) can be reconciled. The second issue relates to whether the indices adequately account for changes in targeting and in catchability or spatial fishing patterns. There appears to be a substantial shift in vessel composition over time in the Japanese longline fishery, with smaller vessels declining in number. This could change overall fleet catchability and hence a vessel effect should be incorporated in the CPUE standardization. In addition, the Japanese longline fleet has reduced effort after ~ 1990 and changed fishing locations over time (**Figure 2.5**; Request G in Appendix E), which could also affect catch rates.

Given the primacy of longline CPUE in providing information to this assessment, IATTC staff, CPCs and scientific colleagues have devoted noteworthy efforts to improve the treatment of the CPUE data through access to operational-level data of the main longline fleets (Japan, Korea, Chinese Taipei and China), obtaining more homogenous spatial partitioning, combining data across multiple fleets and through improved modelling methods. A joint CPUE standardization working group composed of the staff, CPC scientists and external collaborators developed two groups of indices using the combined operational-level data from Japan and Korea. One was based on methods widely used across tRFMOs to combine data across multiple fleets and using cluster analysis to identify differential species targeting. The second employed a spatio-temporal modelling approach based on the Vector-Autoregressive Spatio-Temporal analysis (VAST) method.

The longline indices could be affected by changing catchability due to environmental changes such as shallowing of the oxygen chemocline or thermocline and due to changing fishing efficiency over time. Several presentations raised the possibility that changes in the environment may affect indices either by changing catchability/availability or actually changing recruitment or abundance.

A purse seine index was developed and was considered as a possible indicator of recruitment. However, changes in catchability preclude the use of this index in the model at present (see Request N in Appendix E).

### 2.3.2. Findings

Both methodologies that use operational or close to operational level data from multiple fleets (GLM and VAST) are promising for improving the longline indices. In particular, combining operational level data from multiple fleets provides spatial and temporal coverage that may be impossible for one single fleet alone to cover, particularly in situations of changing effort and fishing ground. Clustering analyses are shown to be effective in differentiating targeting strategies. The Panel highlights the excellent, collaborative work by IATTC Staff, CPC scientists and external collaborators in pursuing these improvements.

The standardized index from VAST was affected by whether the catch rate data were aggregated by vessel, regardless of whether the vessel effect was used in the index. This is likely a result of the *de facto* spatial weighting that occurs when the data from the same vessel are aggregated to the resolution of the spatial grid cell. Essentially, the data aggregation downweights repeated observations of the same vessel in the same cell, which might be a useful downweighting exercise to consider for the standard GLMs.

The joint CPUE modelling exercise highlighted the utility of combining Korean and Japanese data to overcome the reduction in spatial extent and total effort in the Japanese fleet. Influence plots that show which model factors are changing inter-annual trends in the standardization (Request L in Appendix E), e.g., divergence from the nominal values indicate that vessel type and hooks per basket were highly influential factors that also had a clear trend over time, which indicates the need to account for these. Accounting for the changeover to more efficient vessels (the influence of vessels on the time series was more positive over time) and in the changes to deeper longline sets (the influence of hooks per basket on the time series was also positive) indicates the importance of accounting for two key changes in the fishery that have increased catchability.

The VAST indices and the Joint GLM indices were quite similar in trend except for Area 2 after 2000 (**Figure 2.6**; Requests K, S and V in Appendix E). Further, the indices were quite similar in trend across the four areas. The estimated CVs indicated substantial quarterly variability and substantial differences in precision between the indices from different areas (Request AA in Appendix E). Additionally, the precision of the indices in Area 2 decreased substantially due to reductions in fishing effort (**Figure 2.7**).

In the VAST context, the vessel effect seemed to be addressed in the aggregation step rather than the modelling. In large part the similarity of indices from different methods may result from the extensive work conducted *a priori* to define relatively homogenous spatial areas. Hence the spatio-temporal effects that VAST explicitly accounts for may have been addressed by the data aggregation step in the standard GLMs. It would be useful to apply VAST back in time and for a larger area of the Pacific given the substantial changes in the spatial distribution of the Japan longline catch and effort (**Figure 2.8**) and concerns that this could reflect either spatial depletion or range contraction.

A previous review recommended fixing the coefficients of variation (CVs) of the CPUE for the early and late longline indices at 0.15. Such an approach ignores the year-quarterly variation in the precision of an estimate. It may be desirable to (a) revisit the estimates of variance from VAST and the joint GLM index



approach to determine whether a CV of 0.15 remains appropriate and allow for year-quarterly variation around a common CV to reflect differential precision.

The Panel discussed that the indices likely have seasonality and that this seasonality (see Hyder et al., 2009) may be important to capture particularly for spatial models that require moving fish around. Declines in one area in a season, matched by increases in another area the next season could provide information to estimate movement rates.

The Panel discussed possible purse seine indices but felt that due to the numerous issues with obtaining standardized units of effort for this fishing method, such indices would be unlikely to solve any of the issues currently affecting the assessment. An exploration of the relationship between a purse seine index and lagged recruitment indicated that it did not fit as well with recruitment (Request N in Appendix E). The model did appear to fit better with the el Niño/La Niña index, indicating that this index may be more indicative of environmentally modulated catchability and availability rather than environmentally driven recruitment (**Figure 2.9**).

Several presentations raised issues related to environmental changes that might affect CPUE indices, noting that the el Niño/La Niña and Pacific Decadal Oscillation (PDO) cycle were the dominant large-scale oceanographic cycles. Given that the potential impacts of el Niño/La Niña events on observed indices, as well as on the appearance of small fish in purse seine composition data, there is a clear need to develop testable hypotheses regarding the mechanism whereby these changes could happen. It is particularly important that mechanistic hypotheses be developed to inform which specific model parameter or process would be affected by any putative environmental impact.

The Panel was encouraged by preliminary work exploring the effect of PDO and ENSO on longline CPUE. The Panel supports further work of this type, but express the well known cautions when exploring the potential influence of environmental factors. First there is the high probability of type I error when canvassing model output (which is not data) against multiple environmental indices (Brooks and Deroba, 2015). Second, absent mechanistic hypothesis (e.g., exactly what does the PDO or ENSO do that would either create more recruits or make the same number of recruits more vulnerable (e.g. through shallowing of the thermocline) to the fishery) there is a high potential of modelling it as the wrong process (Haltuch et al., in press; e.g., modelling environmentally-driven catchability as recruitment or vice versa). Further, potential environmental influences on recruitment are already implicitly included in the model in the form of estimated recruitment deviations and would not need an additional environmental time series to inform it. However environmentally-driven availability or catchability may require detrending to obtain accurate indices of abundance. Hence, while the Panel notes the value in exploring environmental influences on bigeye indices, these explorations require a mechanistic, hypothesis-driven approach.

## **2.4. Recommendations**

### **2.4.1. Catch data**

- a. Apply a retrospective approach to evaluate the performance of the method used to split purse seine catches to species.

### **2.4.2. Discards**

- a. Evaluate use of the difference in purse seine selectivity pre- and post ~2000 to estimate the retention function after the implementation of the ban on discards. Presumably the pre-2000 selectivity would not have included discarded fish. Post-2000, fish that previously were discarded should be included in size-compositions. The 'difference' between these two selectivity curves should approximate the sizes of fish previously discarded.

- b. The assumption that discards are zero in the longline fleets should be re-evaluated, particularly given that the fleets have observer coverage. The Panel encourages efforts to collect and understand discards in the longline fleets, including through use of observer reports.

#### **2.4.3. Composition data**

- a. The JRT composition data should be removed from the model, because it has negligible impact, is problematic to interpret and adds little to no information to the model.
- b. Given that there are longline catch data from multiple CPCs in addition to Japan in the 10 modelled fleets, the Panel encourages efforts to explore whether composition data from other CPCs can be incorporated into the current or revised fleet structure. This may be particularly important to characterize the selectivity of the joint CPUE that uses data from Japan and Korea.
- c. The benefits of increasing the data bin sizing in the models from 2 to 3 cm or higher at larger sizes (they do not need to be equal) should be explored to decrease run time, particularly for the MSE work. Increase population bin sizing as well.
- d. The quality of the Japanese size samples should be examined, because they are the only longline size-composition data included in the model. For example, compare time series of the average weights calculated from the size data (through the length-weight relationship) and from the reported catch from the logbook reports (Japanese logbooks started to record catch in both numbers and weights after the mid-1990s). Analysis in the Indian Ocean found major discrepancy of average weights calculated from these two sources for bigeye and yellowfin tuna (Matsumoto, 2016).

#### **2.4.4. Indices**

- a. The collaborative process of working with operational-level CPUE data and fine scale composition data should allow use for longer periods of time.
- b. The changing vessel ID over time in longline CPUE indices should be accounted for.
- c. The pre-1975 longline CPUE data should be re-considered through spatio-temporal modelling approaches (e.g., VAST).
- d. VAST should be applied back in time and for a larger area of the Pacific to account for these changes
- e. Mechanistic hypotheses of environmentally-mediated impacts on CPUE should be developed and tested with data.

### **3. STOCK STRUCTURE AND SPATIAL STRUCTURE**

Previous assessments and exploratory work conducted for the 2010 and for this review suggested that the Rshift may be an artefact of a spatially mis-specified model. This concern about 'spatial mismatch' is based on the presence of stock structure (i.e., spatial population structure formed by natural barriers to mixing) that is not reflected by the EPO management unit boundaries, which reflect fishing patterns or minor patterns of spatial heterogeneity. The current stock assessment of bigeye in the EPO (IATTC, 2018a,b; Xu et al., 2018) assumes a single stock and accounts for some spatial patterns using the "areas-as-fleets" approach. This approach can account for some spatial heterogeneity, but it assumes that catches taken in one area affect the resource in all areas. Results from several data investigations of stock structure and movement, as well as several model explorations, were presented to test the spatial mismatch hypothesis.

### 3.1. Stock structure hypotheses

Schaefer (2009), Schaefer and Fuller (2009), WPFMC (2014), Lennert-Cody et al. (2013), and Schaefer et al. (2015) offer background information for identifying stock structure of bigeye tuna in the EPO and adjacent areas. WSBET-02-02 outlines a multidisciplinary approach to identifying stock structure within the eastern EPO, including interdisciplinary conclusions, practical considerations and analogy to spatially-structured bigeye tuna populations in other ocean basins. The tagging analysis and multivariate regression tree analysis of size distribution and CPUE trends (Lennert-Cody et al., 2013; WSBET-02-02) provides a much stronger basis to investigate bigeye tuna spatial structure in the EPO and hence directly test the spatial mismatch hypothesis. The investigation is somewhat data limited, because almost all information on stock identity is from fishery-dependent sources (tag releases and recoveries, biological samples), and information from other disciplines (e.g., genetics, morphology, parasites, otolith chemistry, larval dispersal) is sparse or not available. Previous reviews on the topic (e.g., Schaefer, 2009; WPFMC, 2014) provide supporting information and a synthesis of information in the previous reviews and the new analyses offers a more comprehensive evaluation of stock structure.

#### 3.1.1. Findings

From a broad-scale perspective, the information available suggests that there is a single genetic population of bigeye tuna across the tropical and temperate Pacific with some regional sub-population structure, and there is considerable connectivity between the EPO management unit and the central Pacific Ocean (CPO; Schaefer, 2009; WPFMC, 2014; Schaefer et al., 2015). However, we caution that a single genetic population was also assumed for yellowfin tuna until next-generation sequencing revealed stock structure in the Pacific (Grewe et al., 2015; Pecoraro et al., 2018) and ongoing genetic work on bigeye may reveal previously undetected structure that may have bearing on modeling. WPFMC (2014) presented a paradigm of a continuous distribution across the Pacific Ocean, with primary spawning habitat across the Pacific from about 15°N to 15°S, substantial longitudinal movements between 120°W and 180°, as well as regions of less dispersal (e.g., west of 170°W, east of 120°W, northwest EPO). Regional sub-population structure within the Pacific reflects 'separation by distance' and oceanographic patterns, and some regional groups appear to have different maturity and growth rates (WPFMC, 2014). Movement between the EPO and the CPO should be considered in the stock assessment, either as a source of uncertainty in an EPO assessment, or explicitly by a combined EPO-CPO assessment model (see *Section 6*).

Within the EPO, there are geographic patterns in abundance trends that are consistent with spatiotemporal patterns in catch. **Figure 1.3** shows the proposed spatial strata that were used in many of the analyses presented to the Panel. Spatial patterns in CPUE trends, size distributions, and tag recoveries support spatial strata defined by 110°W, 10°N and 10°S (WSBET-02-02; **Figure 1.3**). The tagging information provided by Schaefer and Fuller (2009) suggests a boundary near 110°W, which is somewhat different than the 'putative stock boundary' at 120°W proposed by Schaefer et al. (2015). Tagging data show little movement between the northwestern EPO (north of 10°N and west of 110°W) and the rest of the EPO. Schaefer (2009) concluded that bigeye tuna in the northern EPO area are a separate 'substock' based on tagging and life history as well as observed spawning in both the northern and southern EPO substocks, as well as no evidence of geographic genetic variation.

Spatial patterns in longline CPUE and size structure suggest a boundary near 15°S in the eastern area, but a boundary at 10°S is proposed to simplify the final strata and reduce the number of transitions among adjacent strata. The southeast area (Area A4.5 in **Figure 1.3**; east of 90°W and south of 15°S) has some different patterns in fishery data, and the proposal is to account for that area as separate fleets (for longline and purse seine). The northern and southeastern strata (Areas A1 and A3) are also supported by catch distributions, and regional trends in CPUE are consistent with regional catch histories (e.g., greater

depletion in the central area, where the purse seine fishery expanded, **Figure 1.3**).

The proposed spatial strata in **Figure 1.3** may be suitable for revised fleet definitions in an areas-as-fleets approach, but they were proposed to define a spatially-structured stock assessment model so that the model can account for local depletion (e.g., different abundance trends within strata). Estimating movement among strata may be challenging, because there are some spatiotemporal and demographic gaps in tagging data (e.g., tagged fish are mostly juveniles, few tagged east of 140°W and south of 10°S). Movement estimates are uncertain, so multiple plausible scenarios should be used to condition operating models for management strategy evaluation.

### **3.2. Movement**

Patterns of bigeye tuna movement can be inferred from conventional dart tags and archival tags. Descriptive summaries of movement patterns in the EPO and adjacent areas are provided by Schaefer and Fuller (2009) and Schaefer et al. (2015). Estimates of movement were provided by Xu et al. (in prep.) based on tag-recovery analysis of conventional tag data and advection-diffusion analysis of archival tag data. The tag-recovery model attempted to account for movement, survival and recapture as a function of time-at-liberty and density of floating objects (around which the purse seine fishery is conducted). The advection-diffusion analysis fit an unscented Kalman filter to archival data to inform a particle dispersal simulation. The sensitivity of the advection-diffusion movement rates to fishing and natural mortality indicates that the application requires some further work to yield useful movement probabilities, because movement probabilities, as they are used in most spatial models, should be independent of fishing and natural mortality. Both approaches are promising for estimating movement, but each analysis needs further development to account for fishing patterns, inferring discrete transition probabilities among areas from a continuous dispersal and distributions. An alternative to independent analysis of tagging data is a tag-integrated stock assessment that explicitly accounts for spatio-temporal patterns in fishing mortality and selectivity and informs movement with both tagging data and fishery data. However, tag-integrated stock assessment models are complex and requires a thorough examination of tag mixing, reporting, and tag shedding assumptions.

#### **3.2.1. Findings**

Tagging data indicate 'constrained latitudinal dispersion' across the Pacific and within the EPO, some regional fidelity, some extensive eastward longitudinal dispersion, and substantial mixing of bigeye tuna between 95°W, 140°W, 155°W, 170°W and 180° release locations (Schaefer and Fuller, 2009; Schaefer et al., 2015). The tag-recovery model estimated 16% quarterly movement of juvenile fish eastward across 110°W and 23% quarterly movement eastward across 120°W (WSBET-02-02), but accounting for potential spatial patterns in fishing mortality or reporting rates effects on recapture probability was a challenge. By contrast, the advection-diffusion simulation model suggests 6-8% eastward movement per quarter and 10-15% westward movement per quarter across 110°W, but movement rates were sensitive to longitudinal variation in advection rate (Xu et al., in prep.). Results from the advection-diffusion model are considered to be more applicable to a spatially-structured stock assessment than those from the tag-recovery model because the simulations are less constrained by tag release positions, are designed to estimate transition probabilities among the proposed strata from fish distributed throughout the strata, are not affected by unknown processes such as tag reporting and shedding rates.

### **3.3. Modelling**

A series of exploratory stock assessment model applications were developed to investigate the influence of spatial patterns on perceptions of recruitment and general model performance (WSBET-02-08). This series of model explorations represent many alternatives for a spatially-structured assessment of bigeye tuna in the EPO and adjacent areas. The Rshift was used as a metric for compare results among alternative

models (estimated at 2.41 for the updated single-stock model).

Aires-da-Silva and Maunder (2010) developed independent Stock Synthesis applications for four areas in the EPO (inshore, central, northern and southern), assuming no mixing of fish among regions. McKenchie et al. (2015) developed a Pacific-wide, tag-integrated, spatially-structured using Multifan-CL, with the nine spatial strata defined in the western and central Pacific (WCPO) and three spatial strata in the EPO (north, southwest and southeast, with boundaries at 10<sup>0</sup>N and 120<sup>0</sup>W). Valero et al. (2018) updated and revised the assessment in the central EPO where most of the increase in purse seine catch occurred and investigated twelve alternative six-strata spatial configurations using an age-structured production model (ASPM). WSBET-02-08 explored several configurations of spatially-structured assessments of the EPO using a 3-strata structure (similar to Aires-da-Silva and Maunder 2010) and 4-strata structure (A1-A4 in **Figure 2.1**), with several alternative approaches to modelling movement, including independent assessments in four areas (i.e., no movement), several variants of four strata with movement at all ages (assuming the movement rates estimated by advection-diffusion analysis of archival tags), four strata with movement limited to 3-8 quarters, four strata with directional movement of ages 3-8, and east-west diffusion of age-15+. WSBET-02-09 developed a spatially-structured assessments of the Central and Eastern Pacific Ocean (CEPO), including the spatial strata in **Figure 2.1** plus the two adjacent areas in the CPO with alternative approaches to movement (no movement, eastward juvenile movement and westward adult movement, eastward juvenile movement and east-west adult movement, movement only between equatorial CPO and EPO strata) as a simpler alternative to the Pacific-wide exploratory assessment developed by McKenchie et al. (2015) that avoids the challenge posed by different growth in the WPO.

### 3.3.1. Findings

An exploratory assessment model that include local catch and longline CPUE indices in the central EPO area removed the Rshift and indicated a more depleted stock in that area (Valero et al. 2018). However, spatially disaggregating the entire EPO region did not remove the Rshift. This shift persists in all spatially-structured EPO-wide exploratory assessments that did not have major diagnostic problems (Aires-da-Silva and Maunder, 2010; Valero et al., 2018; WSBET-02-08; WSBET-02-09). Spatially-structured assessments of bigeye tuna in the EPO may be promising for further explorations or strategic analyses (e.g., conditioning an operating model for management strategy evaluation). However, these results suggest that spatially-structured assessments will not resolve the problems associated with the Rshift.

The Pacific-wide assessment (McKenchie et al., 2015) estimated high movement rates from the WCPO to the EPO, with mostly western-origin fish in the WCPO and a high proportion of western-origin fish in the EPO. A limitation of the Pacific-wide model is assuming common growth across the Pacific when growth may vary among areas. Results from the Pacific-wide model were similar to those from the WCPO-only model with respect to the stock status indicators, so McKenchie et al. (2015) concluded that it is reasonable to continue to provide management recommendations to the WCPFC on the basis of WCPO regional stock assessment models. Models estimated similar growth functions. Using a similar justification, continuing to assess bigeye tuna in the EPO with an EPO-only assessment is reasonable, because results for the EPO areas from the Pacific-wide assessment are similar to those from the EPO assessment with respect to 1985-2013 depletion and recruitment (including an apparent increase in recruitment in the southeast EPO). IATTC will continue collaboration with SPC for developing a Pacific-wide assessment.

The four independent assessments for areas within the EPO show differences in depletion among inshore, central, northern and southern areas of the EPO (Aires-da-Silva and Maunder 2010). Longline CPUE series and model estimates indicate more depletion in the central area, where much of the purse seine fishery fishes. A comparison of results from the aggregate-EPO assessment and the sum of estimates from the

four independent EPO area assessments shows that the aggregate results are not equal to the sum of its spatial components. The updated and revised Stock Synthesis application to the central EPO area did not show an Rshift and indicated a more depleted stock in the central area (Valero et al., 2018). These results suggested that the Rshift resulted from assuming a homogeneous stock when the expanded purse seine fishery caused local depletion in the central and equatorial areas that are not indexed by the longline CPUE. Further investigation of four independent assessments within the EPO found that growth estimates were substantially different among areas, indicating either geographic variation in growth or poor estimation of growth (WDBET02-08; WSBET-02-09).

Spatially-structured ASPMs with alternative spatial configurations show that the Rshift occurs in several areas (including 'grid K', which is the most similar to the proposed strata in **Figure 1.3**), indicating that the result is independent of the length composition of the catches (Valero et al., 2018).

More integrated spatially-structured Stock Synthesis applications with alternative spatial configurations explored the influence of spatial dynamics of bigeye tuna in the EPO but do not eliminate the Rshift (WSBET-02-08). The four independent areas assessments with no movement estimate increased recruitment in the western equatorial area (Rshift=2.44 for Area A1, **Figure 2.1**). Adding sub-strata to split the western equatorial area by longitude or latitude produced similar results (Rshift=2.39 and 2.05, respectively). The 3-strata model suggested an overall regime shift (Rshift=1.68) and recruitment regime shifts in all three areas (Rshift=1.91 in the northern area, 1.18 in the central area and 1.32 in the southern area). The 4-strata model with movement at all ages suggested that almost all recruitment is from the western equatorial area (A1). The 4-strata model with movement of ages 3-8 had a relatively poor fit to CPUE in the eastern equatorial area (Area A2), suggested that almost all recruitment is from Area A2, and produced an implausible difference in catchability among areas and infeasible longline selectivity in Area A2. Forcing a common catchability among areas did not allow the model to fit the CPUE series. The 4-strata model with movement of ages 3-8 and diffusion of age-15+ suggested increased recruitment in the western equatorial area (Area A1). These results suggest that spatially-structured assessment models with no movement do not remove the Rshift, and a quarterly movement rate of 16% appears to be too high, even if just for juveniles.

The explorations of spatially-structured assessments for the larger CEPO area (WSBET-02-09) had convergence problems. Accounting for apparent geographic differences in growth (e.g., estimating  $L_{inf}$ ) is also identified as a challenge. Despite convergence problems, the apparent regime shift persisted in all models (Rshift=1.18 to 2.55).

The investigation of catch by gear and stratum (**Figure 2.1**) shows that the purse seine catch has increased in each stratum. These spatial patterns in catch may explain why spatially-structured models do not resolve the Rshift.

### **3.4. Recommendations**

Although spatially-structured assessment explorations did not eliminate the Rshift, they suggest some recent spatial patterns in depletion, so such model explorations should continue. Future explorations should consider tag-integrated methods, alternative movement models and explorations of geographic variation in growth. Future tagging should be designed to represent all of the proposed areas and ages.

Connectivity of bigeye tuna in the EPO with the WCPO is an important context for the EPO assessment. Assuming a closed boundary at 150°W presents a source of uncertainty that should be considered in interpretations and management advice. Valero et al. (2018) conclude that there are benefits to continuing the collaboration with SPC on a Pacific-wide assessment of bigeye tuna, and the Panel concurs. The development and updates of the collaborative SPC-IATTC Pacific-wide assessment or continued development of a CEPO assessment should be continued for comparison to EPO assessment, and

potentially for conditioning an operating model to evaluate simpler Pacific-wide and EPO-only estimation models.

## **4. BIOLOGY**

### **4.1. Growth**

The current assessment uses the Richards curve, estimated outside the stock assessment model from a combination of otolith-aged and tag-recapture data (Aires-da-Silva et al., 2015).

#### **4.1.1. Findings**

A 'growth cessation model' (Maunder et al., 2018a) has been developed as an alternative to the Richards and von Bertalanffy models. This model provides greatly improved fits to the combined, otolith-aged and tag-recapture growth estimates. In particular, the model improves the fit to lengths from tag return data for older fish, which are overestimated by the Richards and von Bertalanffy models. However, this pattern could be influenced by a possible decline in selectivity for large fish.

Length composition data from 1950s Japanese longline fisheries have been used in an attempt to better estimate L2 (average length of fish at age 40 quarters). Given that the fishery was lightly exploited at the time, larger fish were comparatively more abundant. However, it is also likely that L2 at the time would have been lower than it is at present (by up to about 10%, see below) due to potential density-dependence in growth. However, that tendency would be countered by the effect of size-specific survivorship caused by the longline fishery.

The Panel discussed several data issues that had been identified by the IATTC staff. Otolith data have been collected by length bins, not at random. This presents a problem for the estimation of variation in length-at-age and is likely to bias L2 high in external modelling (Goodyear, In press). However, otolith data treated as conditional age-at-length data could be (and is) used within Stock Synthesis, which may partially address the bias in L2 due to size selective sampling for aging and size selectivity of the gear. Age determination based on daily growth rings of otoliths has been verified up to age 4, but it is unlikely that this can be extended to much older fish.

The Panel concurred with the aim of the IATTC staff to explore estimating the growth function within the model. Since tagging data cannot currently be directly integrated in Stock Synthesis to inform growth, the Panel recommended fitting to size-at-age data with priors on growth parameters derived from a tagging analysis conducted externally.

Some evidence for spatial variation in growth was discussed, in particular the possibility that growth in the Western Pacific is slower than in the East. Geographic variation in growth presents a complication for spatially-structured stock assessment models, particularly for Pacific bigeye tuna (McKenchie et al., 2015; WSBET-02-09).

Temporal variation in growth, whether density-dependent or environmentally-driven, is increasingly recognized as a potentially important process in population dynamics and fisheries assessment (Lorenzen, 2016; Stawitz and Essington, 2019, Stawitz et al., 2019). The impact of growth variation in assessments can be complex, particularly when fitting to length-composition data (Lorenzen, 2016; Stawitz et al., 2019). Density-dependence in growth has been documented in many fishes, and may contribute to the compensatory reserve of exploited stocks, though its contribution is typically less important than that of density-dependence in the stock-recruitment relationship (Lorenzen and Enberg, 2002; Lorenzen, 2008; Zimmerman et al., 2008). Density-dependence is expected to predominantly affect asymptotic size in the von Bertalanffy growth model. Comparative data suggest that density-dependence in growth is also somewhat predictable from comparative information, with a 'rule of thumb' that  $L_{\infty}$  (or L2, as defined

above) in unexploited stocks is typically around 0.9 of the  $L_{\infty}$  at very low abundance (Lorenzen, 2016). In tunas, density-dependent growth has been demonstrated in southern bluefin tuna (Polacheck et al., 2004; Farley and Gunn, 2007; Kolody et al., 2016).

Environmentally-driven variation can take many forms, from short-term noise to long-term directional changes or pronounced shifts in the growth regime. Long-term directional changes or regime shifts are less likely to have assessment and management implications (Lorenzen, 2016; Stawitz et al., 2019), but little can be said about environmentally-driven growth variation unless stock-specific data are available. Since growth data for bigeye are insufficient for the analysis of temporal patterns, the Panel suggested a sensitivity analysis be conducted to explore the potential effects of density-dependence in growth, but not to take action with respect to possible environmental variation at this stage. Continuation and expansion of growth data collection should allow this issue to be revisited in the future.

#### **4.1.2. Recommendations**

- Consider whether to transition from the Richards model to the growth cessation model in the assessment.
- Explore whether it is possible to estimate the growth parameters within the assessment model, e.g., including the age data in the model with priors for the parameters based on external fits to the tagging data (since tagging data cannot currently be integrated in Stock Synthesis directly for estimating growth).
- Evaluate sensitivity to the potential effects of density-dependence in growth.

#### **4.2. Natural mortality**

The natural mortality ( $M$ ) schedule used in the current assessment is pre-specified, as in SAC-09-05 (**Figure 4.1**). The schedule assumes a constant mortality of  $0.4 \text{ year}^{-1}$  for males aged 1 and older, and an additional mortality component for older females. Mortality of juveniles decreases from above  $1.0 \text{ year}^{-1}$  at age 0 to  $0.4 \text{ year}^{-1}$  for age-1 animals. The constant  $0.4 \text{ year}^{-1}$  for older males has been assumed consistent with expectations from multiple empirical predictors for  $M$  in recruited fish (see below). The increase in female  $M$  for older ages is estimated from observed changes in the sex ratio, assuming that these changes reflect mortality rather than patterns in availability and/or growth. The mortality pattern assumed for juveniles is the least informed aspect of the mortality schedule in that it lacks any particular empirical or theoretical justification. The assessment team explored the sensitivity of the model to alternative assumptions about juvenile mortality patterns in the 2016 assessment (IATTC, 2018), and showed that higher juvenile mortality rates led to a reduction in the magnitude of the Rshift. The assessment team felt, however, that these higher juvenile  $M$  patterns were unrealistic and did not pursue this approach further.

##### **4.2.1. Findings**

The Panel revisited all aspects of the natural mortality schedule. Driven by physiological (internal) and ecological (external) processes, lifetime mortality schedules of fishes show strong patterns of regularity but are also influenced by environmental factors and density-dependence, particularly for early life stages and juveniles. Lifetime mortality schedules in fish arise from a combination of size-dependent and life history stage/age-dependent processes. Strong size dependence of mortality rates is a well-established feature of aquatic ecosystems and communities. The same basic size-dependence is reflected in lifetime mortality schedules of organisms where it may be modulated by additional age-dependent mortality associated with survival costs of reproduction/senescence for adults and by density-dependent natural mortality for juveniles. The resulting lifetime patterns of natural mortality tend to be 'L' or 'U' shaped, declining rapidly with age for the early life stages and juveniles, stabilizing for adults and possibly increasing again at old ages.



The size-dependent component of natural mortality is subject to a broadly consistent scaling at the fish population, species and community level, with all major empirical studies showing allometric weight exponents between -0.28 and -0.37 for fishes. Multiple, alternative or related biological explanations for this scaling pattern can be found in physiological, population and community ecology. Predation probably accounts for a large share of natural mortality in fish communities, and is often seen as the primary driver of size-dependence. However, many other sources of mortality are also size-dependent (Lorenzen, 1996).

A constant M assumption is inappropriate for assessments of fishes for which fishing (or other human impacts) on juveniles occurs. For example, purse seine fisheries in the EPO primarily catch juvenile bigeye tuna. Juvenile mortality is governed primarily by size-dependent processes and described well by a simple length-inverse model (Lorenzen 2000):

$$M(l) = M_r \frac{l_r}{l}$$

where  $M_r$  is the natural mortality rate at reference length  $l_r$ . The model implies consistent allometric scaling of mortality (at a weight exponent of -0.33) among fish populations, regardless of the overall level of mortality. This assumption is supported empirically by analyses of post-release mortality in hatchery fish (Lorenzen, 2000). The reference length may be fixed at an arbitrary value (e.g., where mortality rates are to be compared between studies involving different species) or set to a stock-specific life history endpoint such as asymptotic length  $L_\infty$  or length at maturity  $L_m$ . Lorenzen (2000) provides age-dependent survival equations based on this model for different growth curves.

The parameter  $M_r$  may be estimated directly in integrated assessment models, from mark-recapture studies or from catch curves. However,  $M_r$  is often obtained by re-scaling the length-inverse mortality curve to approximate a constant M value used in previous assessments or derived from empirical models. In applications where  $M_r$  is derived from empirical M estimators (e.g., Hoenig 1983),  $l_r$  is often fixed at the length of full selection or the (often similar) length at maturity, because the empirical estimators have been derived from individual M estimates for the age/size groups most strongly represented in catches.

Empirical estimators of M for bigeye yield the following results: Based on a longevity of 15 years, M is estimated as 0.27 year<sup>-1</sup> by the Hoenig (1988) estimator and as 0.41 year<sup>-1</sup> by the Then et al. (2014) estimator. Growth in EPO bigeye tuna appears not to be well-described by the von Bertalanffy model, which limits the scope for using growth-based M estimators. However, using the median von Bertalanffy growth parameters for all bigeye stocks of  $K=0.36$  year<sup>-1</sup> and  $L_\infty=216$  cm (Murua et al., 2017), M is estimated as 0.37 year<sup>-1</sup> by the Pauly (1980) estimator and as 0.54 year<sup>-1</sup> by the Beverton and Holt (1959) invariant  $M=1.5K$ .

The Panel discussed potential use of the Lorenzen M curve in the bigeye assessment. As shown in **Figure 4.1**, the M pattern used in the current bigeye assessment assumes substantially lower mortality rates in juveniles than have been estimated in the Hampton (2000) tagging study or would be implied by the Lorenzen M curve scaled to intersect the currently assumed M (0.4 year<sup>-1</sup>) or the Hoenig M estimate (as 0.27 year<sup>-1</sup>) at the age at maturity, or to approach the currently assumed M in older fish. In the light of the empirical support for the scaling of mortality with body size implied in the Lorenzen M and the bigeye-specific M values from the tagging study, the Panel considered the use the Lorenzen M model as a plausible and more empirically and theoretically grounded alternative to the current juvenile M pattern. Furthermore, Lorenzen M models are currently used in several other bigeye tuna assessments, including those of the Western and Central Pacific, the Atlantic, and the Indian Ocean (McKechnie et al., 2017; ICCAT, 2018; Langley, 2016).

A comparison of the Lorenzen M curves suggested for bigeye (**Figure 4.1**) with mortality-weight data used

in Lorenzen (1996) (**Figure. 4.2**) shows that the bigeye M curves are relatively high, but within the range of M estimates in the meta-analysis, and close to the two estimates for bigeye in the data set. Tunas can be expected to show exceptionally high natural mortality rates compared to other fish of the same size due to their extremely high metabolic and growth rates (Graham and Dickson, 2004; Murua et al., 2017). Metabolic rates are good predictors of mortality rates in fish and other organisms (McCoy and Gillooly, 2008; Bevacqua et al., 2011), and the von Bertalanffy growth parameter K is a well-known correlate of M (e.g., in the Beverton-Holt life history invariant  $M=1.5 K$ ). High M values have also been estimated for tunas in tagging programs (Hampton, 2000) and are routinely used in other tuna assessments including the IATTC yellowfin assessment.

The Panel also considered the possibility that mortality patterns in juvenile bigeye could be influenced by density-dependence. A recent meta-analysis by Lorenzen and Camp (In press) suggests that density-dependent mortality is most likely to occur, and is potentially strongest, for fish that are smaller than 10% of population asymptotic length  $L_{\infty}$  and to diminish in fish larger than 20% of  $L_{\infty}$ . The length composition data indicate that the smallest bigeye tunas are harvested at around 20% of  $L_{\infty}$ , so the Panel considered that density-dependence in juvenile post-recruit mortality was unlikely to affect the EPO bigeye tuna assessment.

The age/stage-dependent cost-of-reproduction/senescence component of mortality affecting older fish is less understood than the size-dependent component and appears to be far more variable among species. There is empirical evidence for both survival costs of reproduction (e.g., due to depletion of reserves or exposure to predation at spawning sites) and senescence (metabolic damage) in certain species. Life history theory and ageing research suggest that appreciable senescence is most likely to be found in fast-growing, early maturing animals. Tunas may be expected to show increases in natural mortality in older fish given their exceptionally high metabolic and growth rates as well as high allocation to reproduction. The pattern of increase in female M therefore has some theoretical as well as empirical support.

#### **4.2.2. Recommendations**

The Panel recommended to further explore empirically-based relationships between M and size or age, such as the Lorenzen M, for use in the bigeye tuna stock assessment, particularly as it relates to the juvenile stages. The panel requested model runs using the Lorenzen natural mortality schedule (Appendix E, Request X) and the IATTC team performed those runs.

### **4.3. Recruitment and spawner-recruitment relationship**

#### **4.3.1. Issues**

The notable issue regarding recruitment for bigeye tuna in the EPO is the Rshift. A corollary of this apparent increase in mean recruitment is that the stock shows no evidence of density-dependent compensation in the early life stages. Previous efforts to estimate the steepness of the spawner-recruitment relationship have resulted in steepness=1.0 and steepness is fixed at that value in the base-case model for most recent assessment for bigeye tuna in the EPO.

The Rshift is nearly coincident with the large expansion of the purse seine fishery in the central equatorial region (Galapagos). This purse seine fishery captures young bigeye (0-2 years old) but purse seine catch rates are not considered to be a reliable index of stock abundance. The historical longline fishery is used as the basis a stock index, but it targets older bigeye and tends to operate more to the west.

#### **4.3.2. Findings**

The longline CPUE index is for the older age groups according to the selectivity pattern of the longline

fishery. This means that the Rshift is an emergent property of the assessment and is susceptible to aliasing by misspecifications in the model. There is no source of data that directly measures recruitment and could support or dispute an increase in mean recruitment. The Panel examined several possible model misspecifications: spatial structure, growth, natural mortality, fishery selectivity, ecosystem effects, and environmental effects.

#### **4.3.2.1. Spatial structure effect on regime (see also Section 3.3)**

The rationale for investigating spatial structure is the fact that there is incomplete overlap of the areas fished by the longlines and the purse seine fleets and the two fleets target different ages, but stock indices are limited to the longline fleet. This raises the possibility that the population segment fished by the longline fleet and indexed by the CPUE of that fleet is somewhat separate from the population segment fished by the purse seine fishery. For example, an exploratory model run showed that using only 25% of the purse seine catch eliminated the Rshift. However, that what-if scenario is not achieved by area-specific models. The assessment team's efforts to create spatially structured models do not achieve such a clean separation of the longline and purse seine catches, and the resulting models do not eliminate the Rshift, especially if there is no movement between areas. Spatial models with movement between areas were more successful in reducing the Rshift, but movement rates used seemed unrealistically high and are highly uncertain.

#### **4.3.2.2. Growth effect on regime**

There is considerable uncertainty regarding the length after 40 quarters (L2) for bigeye and there is evidence that the current value in the model (196 cm) is too large. Model runs that estimate this parameter produce values closer to 172 cm. This reduction in L2 means that the historical recruitment levels must have been higher to produce a biomass large enough to support the historical longline catch and produce the same trend in longline CPUE index. The preliminary model runs with growth estimated also eliminate the Rshift, presumably because smaller asymptotic size leads to a larger population size as the model can explain the lack of large fish in the longline size-composition by slower growth rather than higher fishing mortality.

#### **4.3.2.3. Natural mortality effect on regime**

An age-specific pattern of  $M$  is used in the bigeye assessment to provide higher  $M$  values for younger bigeye that are more vulnerable to predators, and higher  $M$  for female spawners. The pattern is logical, but *ad hoc* (not empirically or theoretically based). When juvenile  $M$  is scaled to a higher value, for example based on the Lorenzen mortality curve (see *Section 4.2.1*), the model creates a population with higher recruitment and a reduced value for Rshift. At higher levels of  $M$  for young fish, the magnitude of fishing mortality needed to support the purse seine catches is a lower fraction of total mortality, so the increase in purse seine catch in the 1990s does not require increased estimates of recruitment to support those catches. Thus, higher juvenile  $M$  and lower adult L2 both reduce the Rshift through a similar effect on the model.

#### **4.3.2.4. Ecosystem effect on regime**

Changes in the ecosystem could lead to a change in the production and mortality of young bigeye. A presentation of diet composition data for yellowfin tuna showed a shift in prey from the early 1990s to the 2000s. This information does not provide evidence for a shift around 1990, but shows that shifts are possible. Evidence for cannibalism in bigeye is weak, so reduction in abundance of adults is unlikely as a reason for increased production of recruits after 1990. However, changes in abundance of other predatory tunas (skipjack and yellowfin) also could affect survival of young bigeye. Results from ecosystem models were inconclusive regarding potential changes in bigeye recruitment.

#### 4.3.2.5. Environmental effect on regime

Large-scale changes in the ocean environment are indexed by the PDO on the decadal scale and shorter term by the El Niño-Southern Oscillation (ENSO). Neither of these show a change around 1990 that could be related to the Rshift.

#### 4.3.2.6. Recruitment modelling effect on regime

Several aspects of recruitment modelling could have an impact on the value of Rshift. First is the shape of the stock-recruitment curve. Currently only an asymptotic curve is considered, but a Ricker curve could allow for higher recruitment levels from intermediate abundance of spawners. Second is the application of a bias adjustment factor to account for the differential over time in the degree of information regarding recruitment. The Panel notes that the current base-case model inappropriately applies bias adjustment =1.0 for nearly all years. A lower value is more consistent with good modelling practices and preliminary runs indicate some reduction in the Rshift when the bias adjustment factor is lower. Alternative steepness levels and allowing for autocorrelation in recruitment deviations also has some impact on the Rshift. Finally, the current model has low weight on the length-composition data, so currently estimated recruitment deviations reflect mostly season-to-season changes in the CPUE index. This statistical weighting impedes close investigation of patterns in recruitment.

#### 4.3.3. Recommendations

- a. Adjustments to growth and to M are highly recommended as model improvements that will remove the Rshift.
- b. Maintaining steepness=1.0 is illogical. Lower values should be explored after growth and M are updated with recommended changes.
- c. Appropriate recruitment bias-correction protocols available in Stock Synthesis should be implemented, along with estimation of  $\sigma_R$  following Methot and Taylor (2011).

### 4.4. Fishery structure and selectivity

#### 4.4.1. Fishery structure

The 2018 base-case model assumed a single well-mixed assessment area. The areas-as-fleets approach was used to deal with the spatial patterns observed in the fishery data. Fleets were defined by gear, area, catch accounting (weight or numbers) and time period. Country (flag) of vessel was not used to separate fleets. Three general groups of gears were defined: purse seine that captures smaller fish, longline that captures larger fish, and discards from the purse seine fleets. Based on those definitions, a total of 19 fleets with catch (**Table 4.1**) were included in the 2018 base-case model. Spatial areas characterizing fleet operations were defined differently for the purse seine and discard fleets relative to the longline fleets. Separate fleets were defined for longline based on whether the catch was recorded as weight or numbers. The discard fleet did not have associated composition data, but rather had age-specific selectivity pre-specified.

In addition to the 19 fleets with catch data, 8 additional fleets (**Table 4.1**) were defined which had composition data but not catches. These fleets were included to provide information on recruitment strength and to incorporate weight-composition data. In the 2018 assessment, only the training vessel fleets (4 of 8) were contributing to the model likelihood because of uncertainty in the conversions between gilled-and-gutted weight and total weight for the EPO. The analysis of spatial structure (section 3) offers alternative spatial definitions for fleets.

#### 4.4.2. Selectivity

Different functional forms for selectivity were used for the three gear groups. The 2018 assessment estimated a length-based, time-invariant and domed selection pattern for each purse seine fleet. Removals by the discard fleet were modelled using a pre-specified, age-based selection pattern, with quarter /ages 1-3 fully selected and all other quarter/ages not selected. The selectivity patterns for longline fleets were assumed to be asymptotic when associated with a CPUE series and domed shaped when not. All longline selectivity patterns were time-invariant. Selection patterns and estimated parameters are summarized in **Table 4.1**.

#### 4.4.3. Catchability

Two CPUE series are included in the 2018 base-case model (**Figure 2.4**). Both CPUE series are standardized and treated as an index of relative abundance. Alternative CPUE standardizations produced similar time series. The relationship between the observed CPUE and estimated biomass was modelled with an estimated time-invariant catchability parameter (one for each CPUE).

#### 4.4.4. Time-varying purse seine selectivity

Previous presentations documented that the purse seine fleets take smaller fish offshore. It was also shown that purse seine fleets expanded effort in offshore regions during the 1990's (**Figure 2.1**). Investigations were presented using alternative methods for modelling time-varying selectivity for a single purse seine fleet, combined for all areas. The largest difference in results between models assuming time-invariant and time-varying selectivity occurred in terminal year quantities. This sensitivity to selectivity treatment is related to the decreasing observations for the terminal year. The current 2018 base-case model defined spatial purse seine fleets using separate time-invariant selectivity patterns, which may have also accounted for the spatial shift in purse seine effort.

#### 4.4.5. Fishery start-year

The model starts in 1975, requiring estimation of initial conditions using only the length composition data (as the initial equilibrium catch penalty is turned off in the likelihood). The model estimates the biomass to be relatively low (~33% of virgin conditions) in 1975, a result that may be due to how the initial conditions are specified. The model also estimates an initial equilibrium catch that is much greater than the observed historical catches from the fishery prior to 1975.

The original rationale for the model to start in 1975 was the availability of hooks per basket starting in 1975 for the Japanese longline fishery and port sampling for length composition starting in 1975 (Request R in Appendix E). Japanese longline catch data provide a time series back to 1954 (**Figure 4.3**) and could therefore be used to justify starting the model further back in time as this fleet accounted for most of the catches prior to 1975. A series of model runs going back to 1954 resulted in some substantive differences in the scaling parameter ( $R_0$ ) (Figure 27 of WSBET-02-08), indicating sensitivity of the model outputs to how the initial conditions are specified.

### 4.5. Recommendations

- a. Consider removing the composition data for the training vessels from the assessment if these data are not representative or are uninformative.
- b. Continue the investigations on implementing time-varying selectivity and any potential trade-offs with areas-as-fleets or spatially structured models.
- c. Investigate the trade-offs between using length-based, age-based or combinations of age-and length-based selection patterns. Potentially consider the results from Lee et al (2017) regarding

the use of selectivity to account for both the effects of gear and spatial availability in an areas-as-fleets model configuration.

- d. Continue to evaluate the optimal bin size structure for the model.
- e. The current approach for specifying the initial conditions needs to be more fully justified. This could be achieved by:
  - i. Fitting models that start earlier than 1975 (e.g., 1954).
  - ii. Implementing an equilibrium catch penalty.

## **5. DATA WEIGHTING, UNCERTAINTY, AND DIAGNOSTICS**

### **5.1. Data weighting**

Data weighting determines the relative contribution of observations to the likelihood function and can have a large influence on model results if the data conflict with each other or are inconsistent with model specifications. Data weighting in the bigeye assessment model (Xu et al. 2018) is determined by the lognormal standard deviation for the CPUE indices and the multinomial sample size for the length-composition data. A constant CV of 0.15 was assumed for the CPUE time series. The initial sample sizes for the purse seine length-composition data were based on the number of wells sampled, whereas the initial sample sizes for the longline length-composition data were set to values representing comparable weights to the main purse fishery while retaining the relative weighting of individual samples based on the number of fish sampled (see **Table 4.1**). The size-composition data were further downweighted in base-case model ( $\lambda=0.05$ ), and alternative weightings ( $\lambda=1$ , the Francis (2011) method, Dirichlet-Multinomial) were considered in the sensitivity or exploratory models.

#### **5.1.1. Findings**

The CV (0.15) for the CPUE indices is based on the estimated value from an earlier assessment. This assumed error appeared to be able to avoid over-constraining the model while achieving a reasonable fit to the CPUE series. The final effective sample sizes for the size-composition data in the base-case model were low compared to values typically used in assessments and much lower than those obtained from the Francis or the Dirichlet-Multinomial weighting approach for most fleets (Request AB in Appendix E). The weighting of size-composition data had a strong influence on abundance estimates. The downweighting was intended to ensure that the size-composition data do not dominate the abundance signals and it also helped alleviate the Rshift, although it did not eliminate it (Minte-Vera et al., 2017). The Panel welcomed the exploration of the Dirichlet-Multinomial weighting approach but noted that the assumption of independence amongst size classes required for the Dirichlet-Multinomial distribution is not realistic, because there are almost 100 length bins for the size-composition data. The scaling of the longline composition data should be independent of the purse seine scaling.

### **5.2. Diagnostics**

The bigeye assessment implemented a suite of diagnostics including retrospective analysis,  $R_0$  profile, ASPM, catch-curve analysis, and residual analysis. The retrospective analysis showed stable estimates of spawning biomass but a strong pattern in the  $F_{\text{multiplier}}$  estimates when data from recent years were removed sequentially. The Panel noted that the estimated  $F_{\text{multiplier}}$  for 2017 from the full model (including all data) was significantly higher than the estimate (for 2017) from the retrospective run when the 2018 data was dropped. This discrepancy may be related to the additional data being included in the model or the change in the reference period used for the calculation of  $F_{\text{MSY}}$ .

Minte-Vera et al. (2017) showed that the size-composition data had a strong influence on the estimated

population size (i.e.,  $R_0$ ), and the recruitment deviations must be estimated to allow the model to explain the variations in the population trend. This is also the rationale for down-weighting the size composition data. The  $R_0$  profiling showed that when the size-composition data were down-weighted, the model estimates were essentially determined by a compromise of the likelihood contribution from the CPUE and recruitment deviates. This may be due to the model's overfitting of an environmentally-driven signal in the CPUE through use of the recruitment deviations. This overfitting may be dampened by increasing weighting on the composition data and perhaps by including environmental effects on CPUE catchability.

### **5.3. Uncertainty**

Uncertainty is currently quantified using precision estimates (confidence intervals based on asymptotic approximation) for management quantities. Sensitivity analysis (alternative model and parameter settings) is conducted to explore uncertainty qualitatively. The management advice is related to stock status relative to a target reference point and a biomass limit reference point. The latter is evaluated probabilistically.

#### **5.3.1. Findings**

Many tuna RFMOs evaluate assessment uncertainty by identifying and incorporating a range of parameter or structural assumptions (e.g., a range of steepness values, which data sets are included in the model, and how much weight is assigned to each dataset). Models are constructed for combinations of the levels for each source and the resulting ensemble is summarized to quantify uncertainty (Anonymous, 2018). Typically, all models in the ensemble are given equal weight, and little attention is given to evaluating the diagnostics of individual models, except for the base-case model. IATTC does not use this "grid" approach because of concerns about how to specify the probability of each model. Rather a base-case model is developed and uncertainty quantified. Status relative to reference points is provided for alternative models (e.g., different values for stock-recruitment steepness). However, this approach is equivalent to assigning a probability of 1 to the base-case model and 0 to all alternative models.

The current assessment fixes many parameters (e.g., those related to growth, natural mortality, and steepness) and hence makes assumptions that likely lead to an underestimation of uncertainty. Thus, the ability to apply management strategies that require estimates of 'low' probabilities (such as 10%) is compromised.

### **5.4. Recommendations**

#### **5.4.1. Data weighting**

- a. The initial effective sample sizes for the composition data should be documented in the assessment report (together with how they were derived).
- b. Alternative approaches for setting the initial sample sizes should be explored in future assessments, e.g., linking the initial sample size to the CV of the sampled size distribution.
- c. A minimum of three iterations should be conducted to ensure convergence when applying the Francis (2011) method.

#### **5.4.2. Diagnostics**

- a. The assessment should examine the pattern of residuals in the fit to the aggregated size-composition data as well as the fits to the time series of average length for each fleet. These average length calculations are available in the output from Stock Synthesis.
- b. Continue to use the ASPM analysis to explore the information content of the CPUE and length composition data, and any potential conflict between them.

- c. Conduct retrospective analyses (including fishing mortality of reference ages as well as the F-multiplier).
- d. Plot the aggregated fits to the size-composition data.
- e. Construct profiles for  $R_0$  as well as other key quantities such as  $L_{inf}$ , steepness, and initial depletion.

#### 5.4.3. Uncertainty

- a. A European Commission Joint Research Centre workshop on ensemble modelling is scheduled for 26-30 August 2019 in Seattle. Attendance by IATTC scientists at this workshop would be beneficial.
- b. As many parameters should be estimated as possible, with informative priors set based on analyses of data to better quantify estimation uncertainty. Specifically, the growth parameters could be estimated with priors based on analyses of the tagging data. Estimating too many parameters risks parameter confounding so care should be taken when extending the set of estimable parameters.
- c. Management procedures that do not require accurate estimates of probabilities should be considered in the MSE.

## 6. CONCLUSIONS AND FUTURE WORK

The Panel identified three primary issues in its review of the material presented: (a) the base-case assessment model for EPO bigeye tuna and explorations of many model revisions, (b) the use of spatially-structured models for assessment and strategic evaluation of harvest policies, and (c) future data collection needs.

### 6.1. The assessment model for EPO bigeye tuna

Much of the discussion during the meeting focused on the causes for the perception of a “recruitment regime shift” under the current model specifications, and hence whether this shift is real or an artefact of the assumptions of or data in the assessment (see **Table 7.1** for a staff summary of the causes and conclusions drawn from past analyses). The Panel concludes that, while it cannot be definitively rejected that an actual recruitment regime shift has occurred, the balance of evidence is that it is an artefact of some aspect of the model and/or the way it has been parameterized. Specifically, the Rshift most likely arises from the substantial increase in purse seine catches (which are generally of small fish) that does not, within the model, have the expected impact on the trends in longline catch-rates or in the size-composition of the longline catches (essentially the same trends would have arisen had the purse seine catches been much smaller). The model creates higher recruitment that coincides with the period of increased purse seine catches so that the impacts of these catches on longline catch rates and perceptions of stock depletion are lessened.

The IATTC staff found that changes to the base-case model specifications can eliminate the Rshift (WSBET-02-08) and that many of these changes could be supported by data, stock assessment best practices as well as many of the previous model explorations (Minte-Vera et al., 2017). While it was not the aim of the meeting to identify a replacement for the current base-case model, the Panel identified several aspects of the base-case model that should be explored further with a view to improving this model. **Table 7.2** summarizes these aspects and the features of those aspects that should be explored further. In particular, model configurations that lessen this effect are increased M for the youngest fish and reduced L2 for the oldest fish.

The model takes a long time to run and attempts should be made to reduce its complexity once a base-case model is identified. Model simplification and decreased run time will facilitate model explorations



and further improvements. For example,

- a. Several fleets can share the same selectivity pattern.
- b. Combining fleets to simplify the model could be considered. The discard fleets can be combined without impacting the model outputs as selectivity is pre-specified, and there are no composition data for these fleets
- c. Consider broader population and length data bins, especially for larger lengths.
- d. Fleets included in the data file but not included as a likelihood component could be dropped from the assessment.
- e. Consider dropping sex from the model; particularly for analyses that are computationally very intensive such as MSE. This should not be done if the sex ratio data are included in the assessment, as suggested in **Table 7.2**.

## **6.2. Spatial structure**

Spatial structure is relevant to (a) the design of the model on which management advice is based, (b) the selection of operating models to evaluate management procedures for EPO bigeye tuna, and (c) understanding the population dynamics of bigeye tuna throughout the North Pacific. The IATTC staff have constructed a wide range of models (see *Section 3.3*; WSBET-02-08, and **Table 7.1**). This work has not identified stock and spatial structure as the cause for the Rshift, but it has increased understanding of spatial models, and specifically those for bigeye tuna.

Spatial structure has been included in models for EPO bigeye tuna to explore whether the “spatial mismatch” hypothesis is the cause for the Rshift. The nature of the trends in longline and purse seine catch by area suggests that a spatial model will not eliminate this shift (and that was confirmed by model runs presented to the Panel; **Table 7.1**). Thus, the Panel does not consider the development of spatial model for the EPO a high priority in the short-term compared to the other suggestions outlined in **Table 7.2**, as it will lead to a more complicated model that will not necessary eliminate the Rshift. The recommended order of investigation is to adjust M and growth before further extensively exploring spatial structure. Nevertheless, the development of spatial models could potentially allow an exploration of the use of the tagging data in the model to inform abundance and fishing mortality rates in areas where the assumption of full mixing is less likely to be violated.

The development of spatial models should be preceded by construction of a conceptual model (or models) that would define where animals are by sex and age, and how they move annually and seasonally. Such models could be informed by the data included in stock assessments but also by ancillary information (e.g., tagging data, larval surveys), summaries of the outputs of models such as VAST, spatial distributions of mean size and mean weight, as well as by the opinions of experts (biologists and fishers), including scientists working on WCPO bigeye tuna. The meeting briefly described aspects of a conceptual model, but such a model does not currently exist, which limits the ability to develop spatial models for bigeye tuna, particularly for the whole Pacific.

### **6.2.1. Spatial considerations and MSE**

The current operating model for the MSE has spatial structure. This is due to the desire to have an operating model that does not exhibit a Rshift. However, analyses in the papers presented to the meeting and those presented to the Panel suggest that adding spatial structure to the existing areas-as-fleets model will not achieve this goal nor will simple models with movement. The Panel considers that multispecies aspects such as maximizing yield from the longline fishery while purse seine catches focused on skipjack increase juvenile bigeye tuna mortality, along with evaluating the performance of candidate

management procedures/harvest control rules as more important for the MSE work than evaluating the effects of spatial structure. This is particularly true as the current Fmultiplier control rule modifies purse seine effort directed at skipjack but that also captures juvenile bigeye and yellowfin tuna. Thus, the Panel recommends that initial iterations of the MSE work should focus on an areas-as-fleets operating model. If there is interest in the consequences of an influx of juveniles (or adults), this can be modelled without resorting to a spatial model. Based on a comparison of results from the EPO base-case model to those from the exploratory Pacific-wide model it appears that results are not that sensitive to movement across the EPO-CPO boundary, but the issue has yet to be addressed in detail. If connectivity with the CPO becomes a greater source of uncertainty, future iterations of the MSE might consider spatially-structured operating models.

### **6.2.2. A spatial model for the whole Pacific**

The Panel recommends that a staged approach be taken to the development of such a model, with the first step being implementation of a “simple” model with few areas. For example, analyses of assessment data and ancillary information could identify the major boundary within the EPO for a two-area model with highly aggregated catch, size-composition and catch-rate data. The results of this model and ancillary information on spatial structure can guide the development of more complex models if they are needed.

### **6.3. Data collection**

The Panel identified the following priority needs for data collection:

- a. The model assumes zero discards from longlines. Observer data and observer reports should be analysed to evaluate discards, and it may necessary to modify observer protocols to obtain data on discards.
- b. Data on length and weight are needed from both purse seine and longline catches from a sampling design that allows spatial and seasonal variation in the length-weight relationship to be quantified.
- c. Additional age-length data are critical for estimating growth and for time-varying growth to be identified and quantified.
- d. Continued tagging of juveniles and adults across the EPO will help to inform movement as well as growth rates.
- e. Information from promising stock identification methods (e.g., genetics, otolith chemistry, morphology, parasites, larval dispersal) can further refine spatial boundaries and explore possible stock structure of bigeye tuna in the Pacific.
- f. More tissue samples, particularly from animals that are to be tagged, will enable application of (future) genetic techniques (e.g., sex determination, stock origin, close-kin mark-recapture).
- g. Satellite pop-up tags will help to further explore movement dynamics, specifically focusing on estimating movements of large fish across major spatial boundaries.

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**Table 4.1.** Summary of the fleet structure in the 2018 base-case model

Fishery	Gear	Set type	Years	Sampling areas	Catch data	Selectivity at size pattern	Average Stage 1 sample size	Parameter estimates (se)						Not estimated	Not estimated
								Par1	Par2	Par3	Par4	Par5	Par6		
<b>FISHERIES</b>															
1	PS	OBJ	1975-1992	13-Jan	Retained catch only--	24	3.774	48.46(5.54)	-0.64(0.61)	4.33(1.07)	7.11(1.15)	-15	-15		
2	PS	OBJ	1993-present	12-Nov	Retained catch + discards from inefficiencies in fishing process--	24	18.284	45.66(3.05)	-10.86(61.73)	4.14(0.6)	8.16(0.31)	-15	-15		
3	PS	OBJ	1993-present	7, 9		24	13.309	49.52(4.06)	-0.77(0.7)	4.39(0.7)	6.99(1.48)	-15	-15		
4	PS	OBJ	1993-present	5-6, 13		24	1.974	39.88(4.72)	0.27(0.64)	2.94(1.71)	5.48(3.87)	-15	-15		
5	PS	OBJ	1993-present	1-4, 8, 10		24	12.188	43.8(5.84)	-10.97(60.55)	3.91(1.22)	7.97(0.41)	-15	-15		
6	LP, PS	NOA, DEL	1975-1989	13-Jan		Retained catch only	24	6.450	96.23(10.23)	-9.27(77.69)	6.76(0.56)	7.85(0.58)			
7	LP, PS	NOA, DEL	1990-present	"1-13"	Retained catch + discards from inefficiencies in fishing process	24	2.772	54.93(19.69)	0.5(0.57)	5.45(2.25)	5.41(2.86)	-15	-999		
8	PS	OBJ	1993-present	"1-13"	Discards of small fish from size-sorting the catch by Fishery 2	0									
9	PS	OBJ	1993-present	7, 9	Discards of small fish from size-sorting the catch by Fishery 3	0									
10	PS	OBJ	1993-present	5-6, 13	Discards of small fish from size-sorting the catch by Fishery 4	0									
11	PS	OBJ	1993-present	1-4, 8, 10	Discards of small fish from size-sorting the catch by Fishery 5	0									
12	LL	-	1975-present	N of 10°N	Retained catch only (in numbers)	24	3.917	140.1(11.29)	-9.08(79.63)	7.1(0.48)	6.51(1.11)	-15	-999		
13	LL	-	1975-present	N of 0° & S of 10°N	Retained catch only (in numbers)	1	4.604	108.08(3.05)	11.26(3.36)						
14	LL	-	1975-present	S of 0° & W of 100°W	Retained catch only (in numbers)	1	16.478	114.36(5.07)	25.8(4.4)						
15	LL	-	1975-present	S of 0° & E of 100°W	Retained catch only (in numbers)	24	6.906	130.54(8.39)	-2.31(2.92)	6.71(0.37)	6.65(1.03)	-15	-999		
16	LL	-	1990-present	N of 10°N	Retained catch only (in weight)	5									
17	LL	-	1990-present	N of 0° & S of 10°N	Retained catch only (in weight)	5									
18	LL	-	1990-present	S of 0° & W of 100°W	Retained catch only (in weight)	5									
19	LL	-	1990-present	S of 0° & E of 100°W	Retained catch only (in weight)	5									
<b>SURVEYS</b>															
Survey	Gear	Set type	Years	Sampling areas	Catch data	Selectivity at size pattern	Average Stage 1 sample size	Parameter estimates (se)						Not estimated	Not estimated
<b>SURVEYS</b>															
1	LL-T	-	1975-present	N of-de 10°N	No catches, length-composition data	24	8.693	96.89(5.6)	-0.92(0.51)	5.59(0.55)	6.39(0.85)	-15	-999		
2	LL-T	-	1975-present	N of-de 0° & S of 10°N	No catches, length-composition data	24	1.786	140.25(13.86)	-2.42(5.1)	7.18(0.49)	6.78(1.48)	-15	-999		
3	LL-T	-	1975-present	S of-de 0° & W of 100°W	No catches, length-composition data	24	4.301	99.72(7.87)	-0.18(0.8)	5.97(0.61)	6.43(1.83)	-15	-999		
4	LL-T	-	1975-present	S of-de 0° & E of 100°W	No catches, length-composition data	24	9.887	117.33(19.5)	-3.2(13.42)	6.57(0.92)	7.33(1.52)	-15	-999		
5	LL-C	-	1975-1994	N of-de 10°N	No catches, weight-composition data (not used to fit the model)										
6	LL-C	-	1975-1994	N of-de 0° & S of 10°N	No catches, weight-composition data (not used to fit the model)										
7	LL-C	-	1975-1994	S of-de 0° & W of 100°W	No catches, weight-composition data (not used to fit the model)										
8	LL-C	-	1975-1994	S of-de 0° & E of 100°W	No catches, weight-composition data (not used to fit the model)										

**Table 7.1** IATTC Staff provided summary of hypotheses that have been proposed as potential causes of the estimated regime change in age-0 bigeye tuna. For more details see WSBET-02-08 and WSBET-02-09. See also Aires-da-Silva et al. (2010) for additional description of hypotheses reviewed during the 2010 bigeye stock assessment review.

HYPOTHESIS	SUMMARY
<b>Spatial mismatch</b>	
<b>Rationale</b>	Under this hypothesis, the two-regime pattern is the result of a spatial misspecification in the stock assessment model; in other words, it is an artefact of the model, caused by the assumption that bigeye in the EPO form a single homogeneous stock. Therefore the increase in purse seine catch does not appear to reduce the longline CPUE, and hence the index of relative abundance, since the longline CPUE index measures abundance over a wider, or different, area than where the increased purse seine catch occurred.
<b>Outcome</b>	Spatial models of the EPO with no movement do not remove the recruitment regime shift <sup>1</sup> . This is in contrast with what was found by Aires-da-Silva and Maunder (2010) and Valero et al. (2018). Updating Aires-da-Silva and Maunder (2010) work with current data does not resolve the regime change <sup>2</sup> . Valero et al. (2018) thought to have removed the regime change based on SS runs for the only EPO sub-area (Central) with data available at the time, however subsequent work with alternative partitions of the EPO identified that the regime change is still present in the offshore equatorial area. Spatial models with movement both for the EPO (4-area models) <sup>3</sup> and CEPO <sup>4</sup> (6-area models including adjacent assessment model boxes from the central Pacific Ocean) showed that movement at 16% per quarter seems too high, even if just for juveniles. Including hypothetical E-W diffusion of adults remove the recruitment shift; however movement rates or general movement patterns for adult bigeye are unknown (further investigations are needed) and results are highly sensitive to assumed movement general patterns and rates. CEPO models had convergence issues and did not remove the recruitment shift.
<b>References</b>	<p><sup>1</sup> Section 3.1.1, WSBET-02-08. 4-area models of the EPO and 4 separate 1 area models (A1, A2, A3, A4) for the “Default” spatial structure from WSBET-02-02). Runs with 3 additional partitions of the EPO.</p> <p><sup>2</sup> Section 3.1.1, WSBET-02-08, “Alternative 3” model runs.</p> <p><sup>3</sup> Section 3.1.1, WSBET-02-08. 4-area models of the EPO with alternative movement scenarios.</p> <p><sup>4</sup> WSBET-02-09. CEPO 6-area models including adjacent assessment model boxes from the central Pacific Ocean</p>
<b>Growth issues</b>	
<b>Rationale</b>	Growth in the EPO bigeye tuna assessments has been fixed at an externally estimated Richards growth model (WSBET-02-07). The 2018 bigeye stock assessment starts in 1975 estimating an initial fishing mortality non-constrained by equilibrium catches and informed by the length composition data, which is down weighted in the assessment. The value at which the length of older fish (L2) is fixed at, coupled with the assumption of asymptotic selectivity in the longline fishery, will influence the initial depletion level, therefore if L2 is misspecified it could impact the robustness of the model. In addition the Richards growth model may not be the most appropriate for bigeye growth, particularly for the few large-size tagged bigeye recovered (WSBET-02-07). Maunder et al. (2018a) developed the Growth Cessation Model and found that it fits better to the data.

<b>Outcome</b>	Estimating growth reduces markedly the recruitment shift <sup>1</sup> ; it also estimates faster growth K, smaller lengths for the older fish (L2) and larger CVs of variation of length at age and results in larger estimated time series of biomass and healthier stock status than the base-case <sup>2</sup> .
<b>References</b>	<sup>1</sup> Model runs for the area A1 of the “Default” spatial structure and for the 2018 base-case bigeye assessment. <sup>2</sup> Section 3.1.2, WSBET-02-08
<b>L-W issues</b>	
<b>Rationale</b>	The L-W used in the assessment was collected more than 50 years ago (Nakamura and Uchiyama, 1964) and even if collected only from longline it is currently applied to purse seine catches as well in the assessment and in the preparation of data for the assessment.
<b>Outcome</b>	Using a newly estimated purse seine-only L-W relationship varies at most 6% from the LL L-W relationship <sup>1</sup> . At least with the data available so far this is not enough to remove the regime change <sup>2</sup> .
<b>References</b>	<sup>1</sup> Section 3.1.3, WSBET-02-08 <sup>2</sup> Model runs for the area A1 of the “Default” spatial structure and for the 2018 base-case bigeye assessment.
<b>Model time span</b>	
<b>Rationale</b>	Current stock assessment model starts in 1975 when exploitation was already ongoing for at least two decades <sup>1</sup> . The model calculates equilibrium initial conditions estimating initial fishing mortality but not fitting to equilibrium catch, it therefore relies on other data such as the index of abundance, but particularly also the length composition data (which is greatly down weighted) whose interpretation depend on the asymptotic assumption of the longline fishery and the assumed growth. There is the potential for misspecified initial depletion if growth and/or selectivity is misspecified that could lead to the estimated regime shift.
<b>Outcome</b>	Historical models starting in 1954 rather than 1975 reduce the recruitment regime shift, although not to the degree that estimating growth does. Historical models also produced similar estimated trends to the shorter base-case model, although with larger biomass series and healthier stock status.
<b>References</b>	<sup>1</sup> See Section 3.1.4, WSBET-02-08 and request number 1 from Day 1 of the 2 <sup>nd</sup> bigeye review.
<b>Selectivity issues</b>	
<b>Rationale</b>	The base-case model uses a length-based selectivity, which is asymptotic for the longline fisheries and has implications for the ability to estimate initial conditions properly, given the model starting after the history of exploitation started. There may be some degree of dome-shaped selectivity if larger/older bigeye tuna are less vulnerable to the longline fisheries by for example going deeper in the water column with age/size. Perhaps an age-based selectivity could perform better.
<b>Outcome</b>	Using dome-shaped selectivities for all gears also reduced the recruitment shift and produced similar results as runs with estimated growth, with larger biomass series and healthier stock status. Using blocks in LL selectivity around the increase in FAD catch or using LL age-based selectivity did not reduce the regime change.
<b>References</b>	Section 3.1.5., WSBET-02-08. Runs were conducted allowing for dome shape length-based selectivity for the longline fishery for area A1 of the “Default” bigeye spatial structure.
<b>Catchability issues</b>	



<b>Rationale</b>	Either longline catchability may have changed in the mid 1990s due to the expansion of FAD fisheries, or there may be hyperdepletion or hyperstability in catchability if the longline index is not proportional to biomass. These potential issues had not been evaluated in the assessment but can affect the way the model interprets changes in the longline index of abundance.
<b>Outcome</b>	Using time blocks for catchability and selectivity in the mid 1990s of the longline fisheries did not produced markedly different results from the base case. Estimating non-proportionality in catchability does not reduce the regime change.
<b>References</b>	Section 3.1.6, WSBET-02-08. Runs implemented for the A1 of the “Default” spatial structure
<b>LL Index issues</b>	
<b>Rationale</b>	The only index of abundance the base-case assessment has been fitted to it is the Japanese CPUE longline index. However there are other longline fleets that fish for bigeye and recent work (see recent longline IATTC Workshop) has provided alternative uses of data and standardization approaches.
<b>Outcome</b>	The alternative indices for abundance using different standardizations or data are remarkably similar and they did not produce markedly different SS model results or reductions in the regime change. In addition to the block in q, a block in longline selectivities (inflection and 95% width of the logistic curve) was also included for the three alternative indices of abundance but did not result in meaningful changes in overall model results (neither biomass trends, q values, selectivities nor recruitment shifts) from the base case.
<b>References</b>	Section 3.1.7, WSBET-02-08. Runs implemented for the A1 of the “Default” spatial structure
<b>Environmental or ecosystem regime shift</b>	
<b>Rationale</b>	Most of the hypotheses evaluated during the first and second review of the bigeye assumed that the estimated regime change in recruitment is due at least in part to one or a combination of hypotheses leading to misspecification of the model, rather than being caused by actual environmental or ecosystem changes. However, there may be an actual regime change whose cause has not being identified yet.
<b>Outcome</b>	There is no evidence so far that the change in recruitment may be environmentally driven. However, there are physical changes in the pelagic EPO such as Oxygen Minimum Zone expansion and shoaling, primary production is decreasing, ocean temperatures are rising and food web changes: the average cell size of plankton organisms has decreased; prey community has changed (see Olson, 2013 SAC-04-08). Similar recruitment patterns to bigeye are not observed in yellowfin tuna recruitment time series in the EPO. However, a similar pattern is seen for bigeye tuna recruitment in some areas of the WCPO ( <sup>1,2</sup> ). Indicators for skipjack tuna in the EPO show changes after the mid-1990s <sup>3</sup> . The skipjack model for the western and central Pacific Ocean estimates an increase of recruitment in the early 1980s <sup>4</sup> , coincidental with increased purse seine catches in the WCPO. There are changes in yellowfin diet that could be inferred as originating from ecosystem change, but the information for bigeye is limited. There is also some evidence of tuna eating juvenile tunas, which hypothetically could result in higher recruitment as the tuna populations are fished down, but the consumption rates seem low.
<b>References</b>	<sup>1</sup> Harley et al. (2009) <sup>2</sup> McKechnie et al. (2017)

	<p><sup>3</sup> <a href="http://www.iattc.org/Meetings/Meetings2018/SAC-09/PDFs/Docs/_English/SAC-09-07-EN-REV-23-Apr-18_Skipjack-tuna-indicators-of-stock-status.pdf">http://www.iattc.org/Meetings/Meetings2018/SAC-09/PDFs/Docs/_English/SAC-09-07-EN-REV-23-Apr-18_Skipjack-tuna-indicators-of-stock-status.pdf</a></p> <p><sup>4</sup> Mathew Vincent, SPC, personal communication</p>
<b>Ricker stock recruitment</b>	
<b>Rationale</b>	The estimated increase in recruitment with concurrent decreasing estimates of biomass could potentially be explained by cannibalism.
<b>Outcome</b>	This hypothesis has not been evaluated.
<b>References</b>	Suggested during the second review but not evaluated (see ecosystem effects above).
<b>FAD early catch underestimation</b>	
<b>Rationale</b>	If purse seine catches were underestimated before the 1990s this could affect the relative magnitude of the estimation of the recruitment regime shift. Aires-da-Silva et al. (2010) reported that increased floating-object catches during the early period did not eliminate the recruitment pattern. The purported underestimation was proposed by Fonteneau and Ariz (2008) by applying species composition ratios estimated after the 2000s to pre-1994 catches.
<b>Outcome</b>	Aires-da-Silva et al. (2010) reported that increased floating-object catches during the early period did not eliminate the recruitment pattern. The purported underestimation was proposed by Fonteneau and Ariz (2008) by applying species composition ratios estimated after the 2000s to pre-1994 catches. Runs performed during this review showed that discards during the early period where no discards were assumed had to be 10 times those in the first 5 years discards are available to remove the regime shift.
<b>References</b>	
<b>FAD recent catch overestimation</b>	
<b>Rationale</b>	If purse seine catches were overestimated after the 1990s this could affect the relative magnitude of the estimation of the recruitment regime shift. This could have happened due to species misidentification or misreporting in the catches, particularly as BET is a small proportion or very large catches of skipjack tuna.
<b>Outcome</b>	In order to remove the regime change, FAD catches would have to be reduced by 75%.
<b>References</b>	
<b>Higher natural mortality rates</b>	
<b>Rationale</b>	Higher natural mortality of small juveniles will essentially imply that the increased catches of FAD do not have such an impact on the dynamics of BET since fish of those sizes would have died due to natural causes anyways. The Lorenzen natural mortality curve has been used for other species, including tunas such as bigeye in the Atlantic.
<b>Outcome</b>	Aires-da-Silva et al. (2010) considered that alternative patterns of higher natural mortality for juvenile and adult BET that were shown to reduce the regime change were unrealistically high. The Lorenzen natural mortality curve was proposed during the review as an alternative and runs that include them reduce greatly the regime shift. Using Lorenzen M while estimating growth removes the regime shift completely and allows for estimation of steepness. It is still unclear if the higher M for juvenile BET is realistic or too high or if the estimates of steepness are realistic.
<b>References</b>	Runs were conducted with the 2018 bigeye base-case model.
<b>Density-dependent growth</b>	

<b>Rationale</b>	Density-dependent growth could explain the recruitment pattern as well. Bigeye growth rates could increase in areas of high exploitation. Faster growth rates would imply greater proportions of larger fish, which, without density dependent growth, the model might explain by increased recruitment. However there is no evidence to support this hypothesis.
<b>Outcome</b>	Computational issues prevented these being evaluated during the review.
<b>Changes in migratory patterns</b>	
<b>Rationale</b>	If availability of larger fish greatly increased due to immigration of adult bigeye to the fishing grounds, the model could try to explain higher observed proportions of large fish by increasing recruitment. Emigration of juvenile fish could have the same effect, since the juveniles would be vulnerable to purse seine but not to longline. However there is no evidence to support this hypothesis.
<b>Outcome</b>	This hypothesis has not been completely evaluated, although some relevant runs were implemented with alternative movement patterns and rates of bigeye of different ages.
<b>References</b>	See WSBET-02-08 and WSBET-02-09

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**Table 7.2.** Features of the stock assessment that should be considered further as part of the process of developing a revised base-case model.

Feature	Current approach	Recommended areas for future work
Growth	The growth curve is modelled using the Richard curve with pre-specified parameter values	<ul style="list-style-type: none"> <li>Consider use of Growth Cessation Model.</li> <li>Estimate the growth parameters including the age data in the model likelihood with priors for the parameters based on fits to the tagging data.</li> <li>Consider a sensitivity test in which growth is density-dependent.</li> </ul>
Natural mortality	Pre-specified, as specified in Xu et al. (2018)	<ul style="list-style-type: none"> <li>Explore use of a Lorenzen-type relationship between natural mortality and age/length, perhaps with an estimated scaling parameter.</li> <li>Include the sex-ratio data explicitly in the model fitting procedure; care should be taken when using these data given the possible difficulties associated with sexing young / small animals.</li> </ul>
Selectivity for fleets 13 and 14	Asymptotic as a function of length	<ul style="list-style-type: none"> <li>Consider dome-shaped selectivity for these fleets (once a model configuration for natural mortality and growth is selected).</li> </ul>
Selectivity for the purse seine fleets	Time-invariant and dome-shaped	<ul style="list-style-type: none"> <li>Consider the support for a time block at year 2000 given the changes in regulations regarding discarding (using a model configuration that addresses the Rshift).</li> <li>Consider modelling selectivity for the fleets using a non-parametric (or semi-parametric) smoother; this may allow some of the purse seine fleets to be combined.</li> </ul>
Initial conditions	An R1 parameter, two initial fishing mortality parameters and initial age-structure parameters estimated for 1975; no equilibrium catch assumption	<p>The current approach needs to be more fully justified. This could be achieved by:</p> <ul style="list-style-type: none"> <li>Fitting models that start earlier than 1975 (e.g., 1954).</li> <li>Implementing an equilibrium catch penalty.</li> </ul>
Stock-recruitment relationship	Steepness pre-specified at 1; bias correction factor of 1	<ul style="list-style-type: none"> <li>Set the bias correction factor using the algorithm of Methot and Taylor (2011), and implemented in R4SS.</li> <li>Consider estimating steepness once a model configuration for which the Rshift has been eliminated is identified.</li> </ul>
Size-composition data	Stage 1 weights based on the approach outlined the response to Request 1; stage 2 weights (lambda) set to 0.05 or 1.	<ul style="list-style-type: none"> <li>Estimate stage 2 weights by fleet using the Francis approach.</li> <li>Remove the training vessel data from the assessment.</li> <li>Consider including Korean and China-Taiwan length-composition data in the assessment (the China-Taiwan data will be reviewed / understood prior to inclusion in the assessment).</li> </ul>
Catch-rate data	A CV of 0.15 for all years, areas and quarters	<ul style="list-style-type: none"> <li>Based on an average CV (e.g., 0.15) over all years, quarters and areas, define the CV by year, quarter and year as square root of the sum of square of the GLM or VAST CV and a scaling factor.</li> <li>Conduct model runs using the VAST and the GLM catch-rate series.</li> <li>Explore catch-per-unit-set as an index of recruitment.</li> </ul>
Diagnostics		<ul style="list-style-type: none"> <li>Conduct retrospective analyses (including fishing mortality of reference ages as well as the F-multiplier).</li> <li>Routinely apply the ASPM diagnostic.</li> <li>Plot the aggregated fits to the size-composition data.</li> <li>Explore residual patterns.</li> <li>Construct profiles for <math>R_0</math> as well as other key quantities such as <math>L_{inf}</math>, steepness, and initial depletion.</li> </ul>

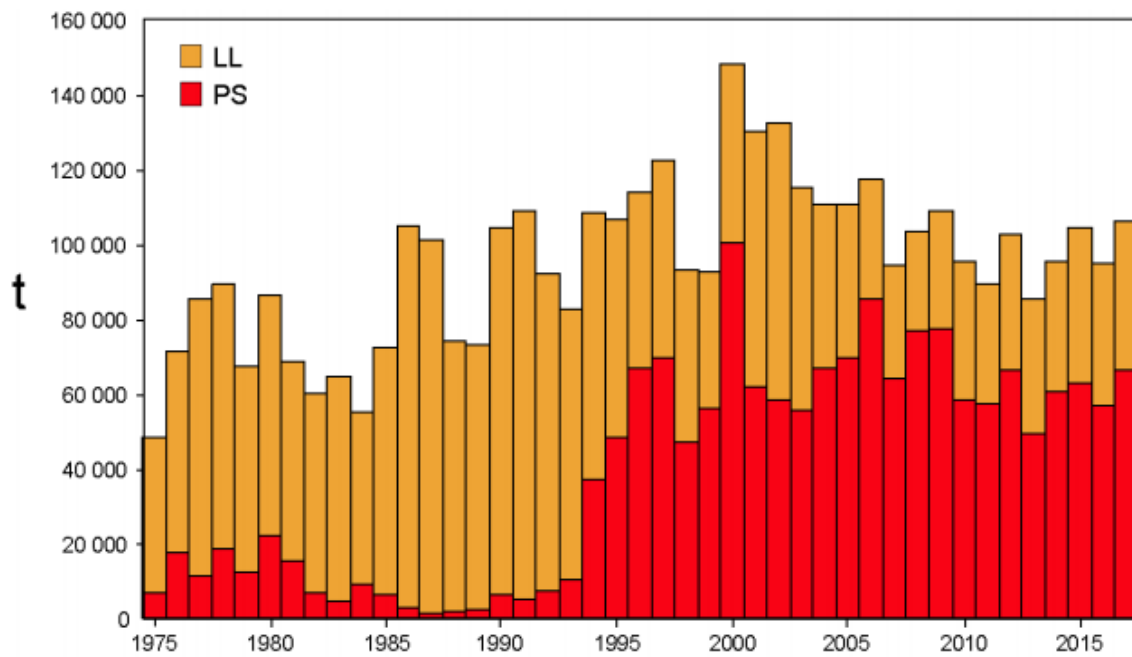
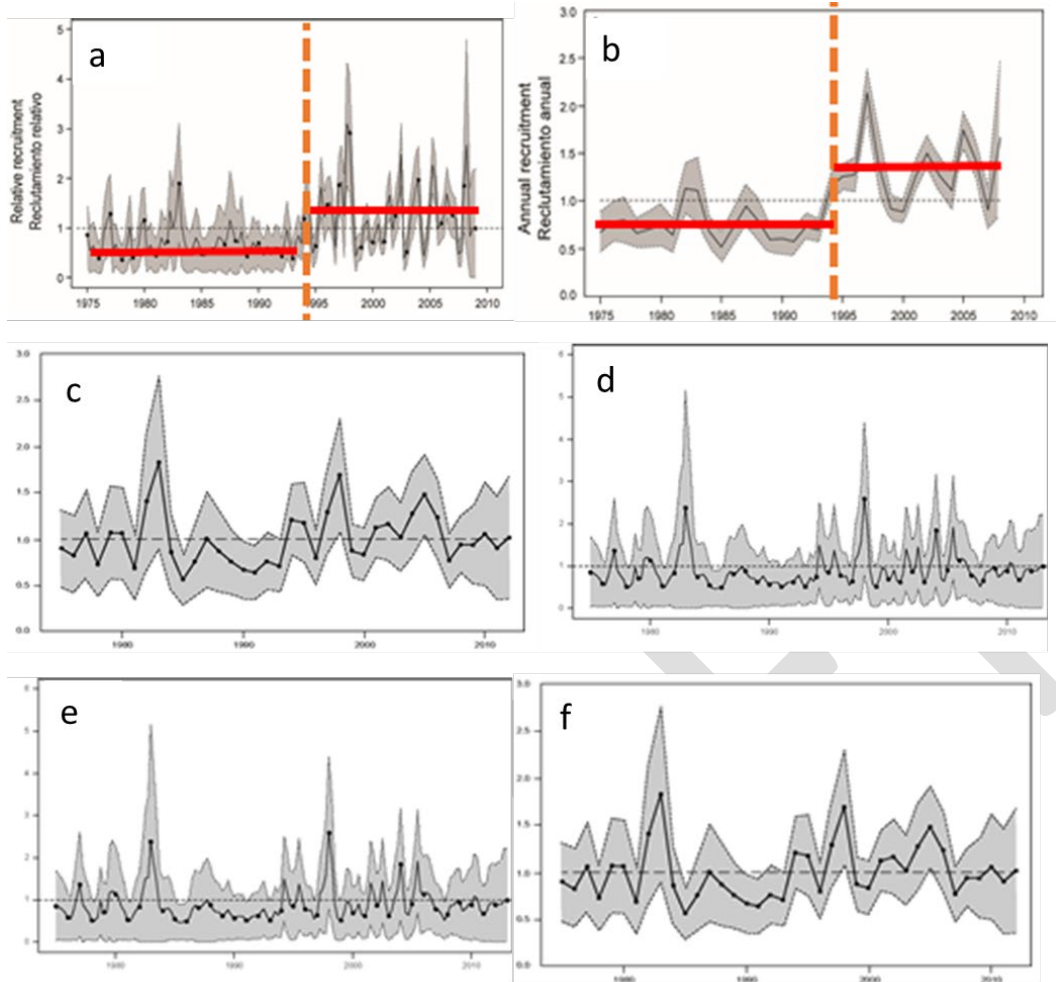
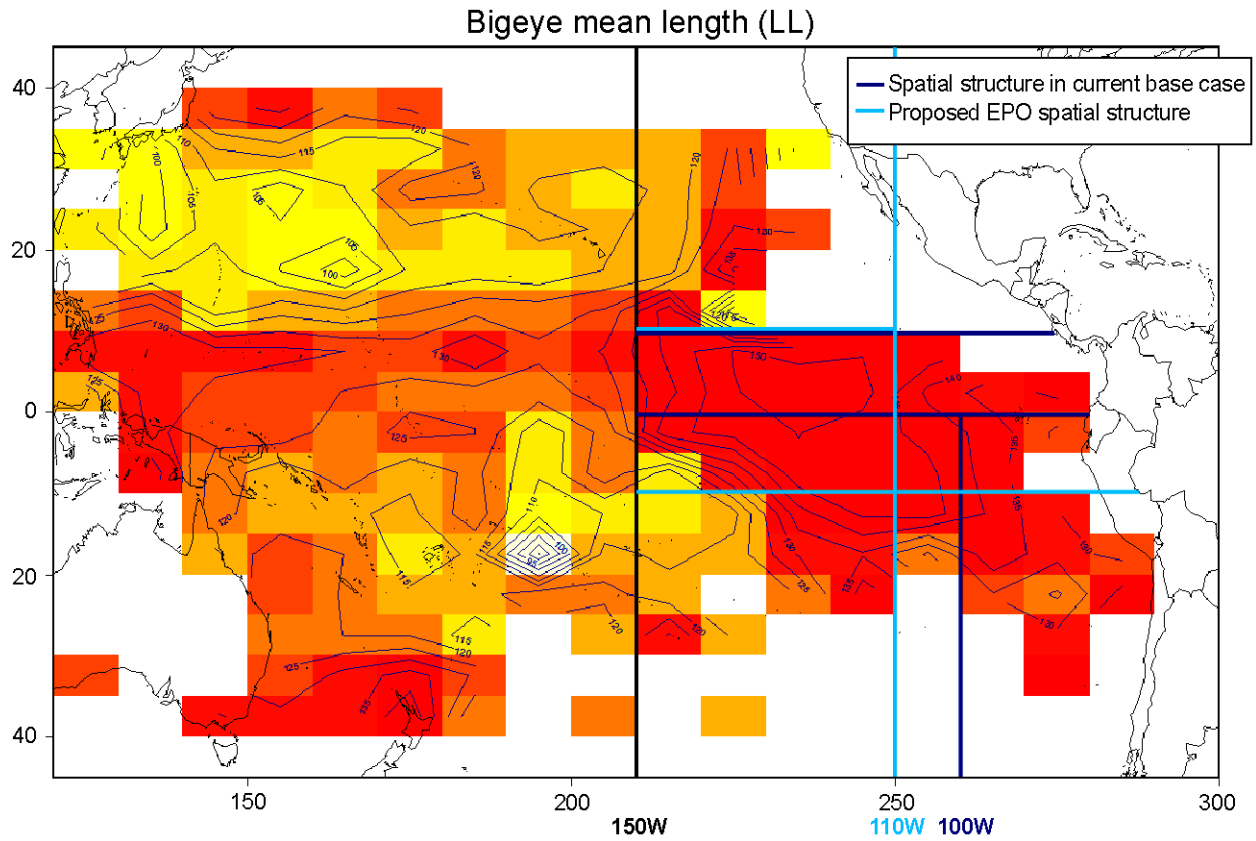


Figure. 1.1. Bigeye tuna catches by fleet over time in the EPO.

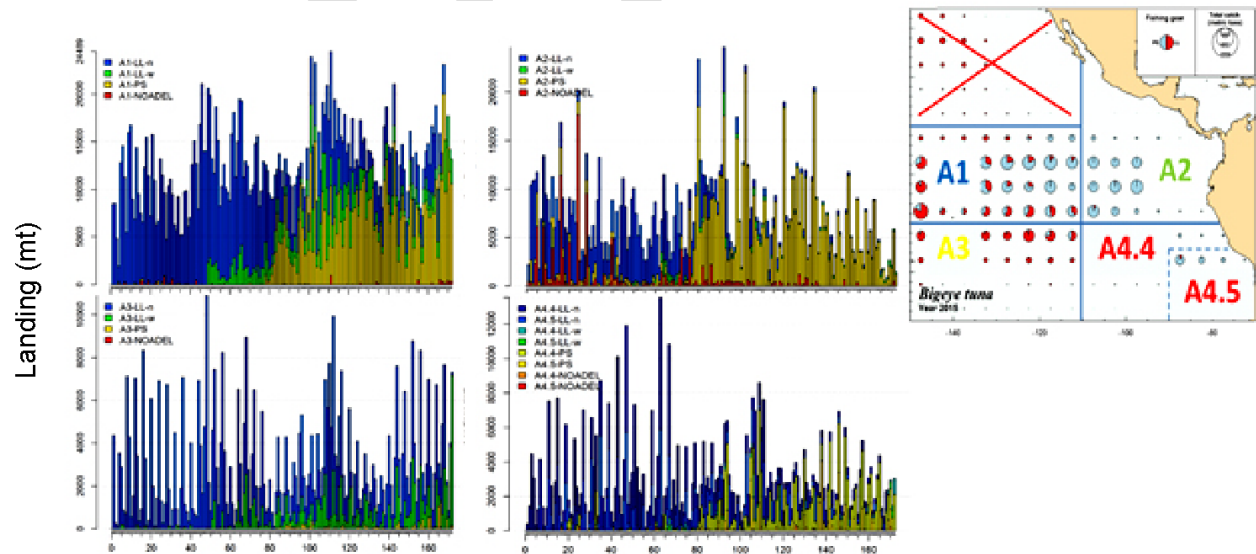
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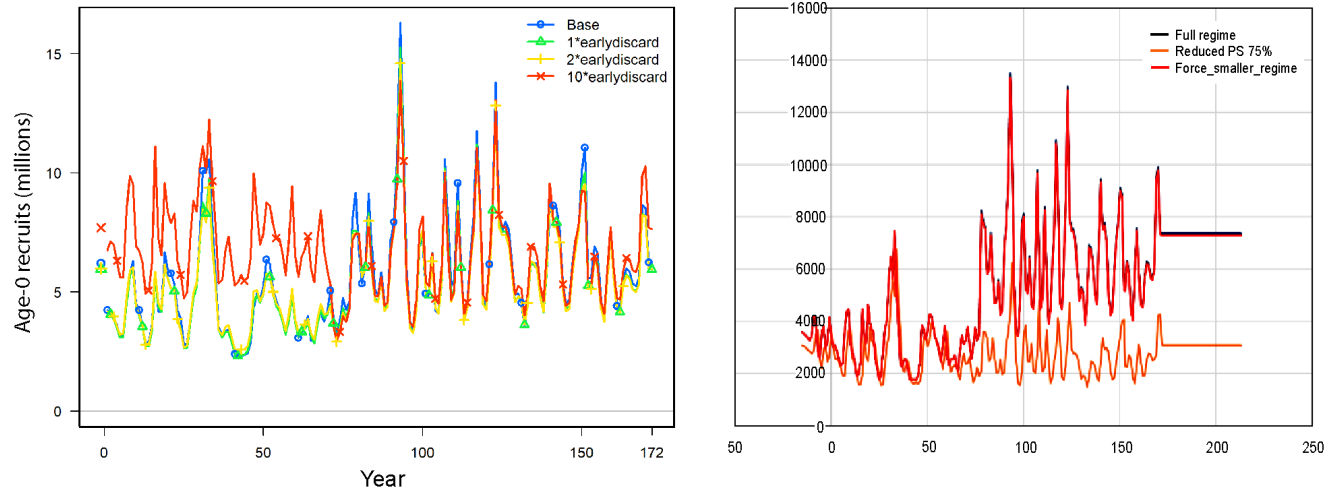
**Figure 1.2.** Estimates of recruitment by quarter (a) and by year (b) that was a key focus of the 2010 review; Recruitment by quarter (c) and by year (d) from the 2013 assessment; Recruitment by quarter (e) and by year (f) from the 2018 assessment.



**Figure 1.3.** Map showing the strata in the 2018 base-case model and that from WSBET-02-20 overlaid on predicted mean length from longline data obtained from a generalized linear model (Hoyle, pers comm).



**Figure 2.1.** Catches by fleet over time for four spatial partitions of the EPO region.



**Figure 2.2.** A. Sensitivity to increasing the early discards to determine what magnitude of unaccounted removals would have been needed to eliminate the regime shift. B. sensitivity analysis of a 75% reduction in recent purse seine catch, which completely eliminates (orange line) the regime shift. The "force\_smaller\_regime" in panel B is a less extreme reduction in recent purse seine catch.

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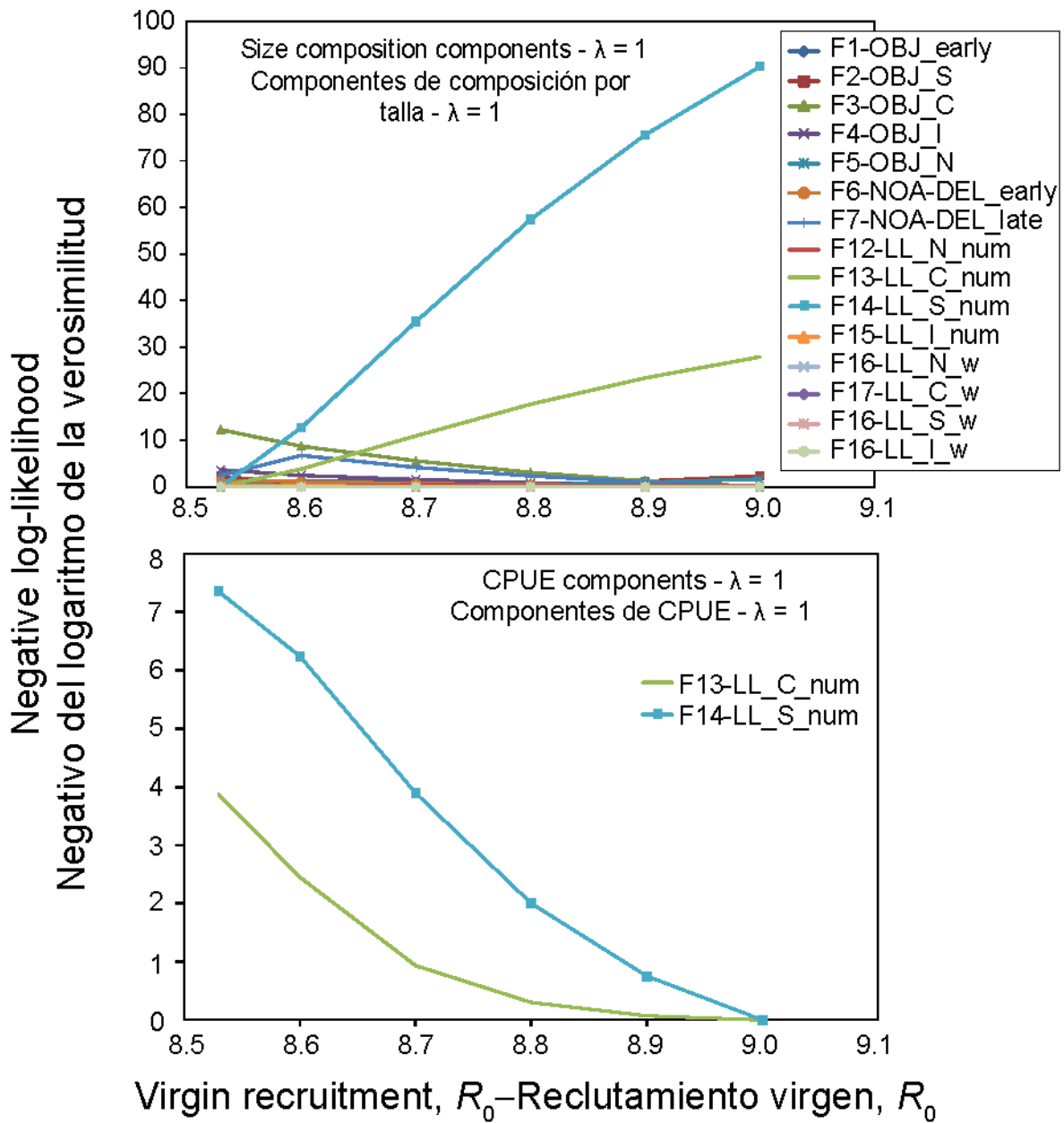
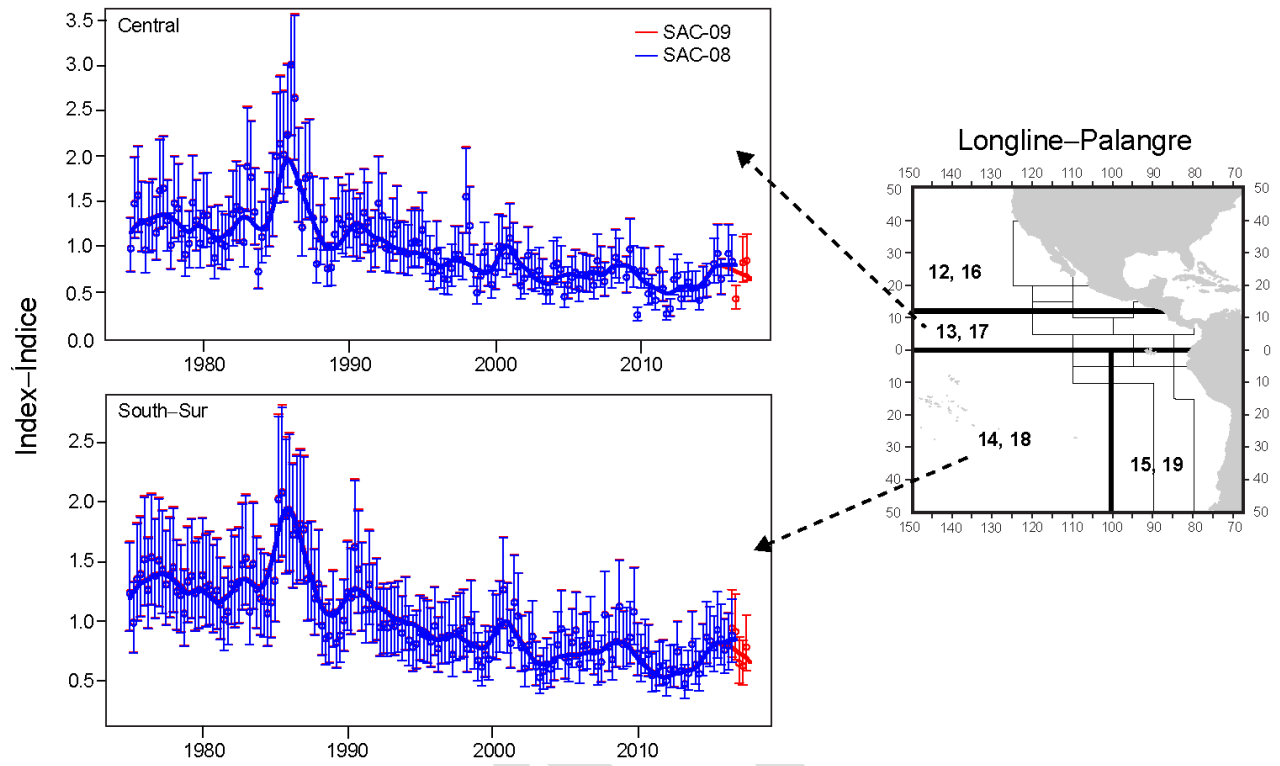
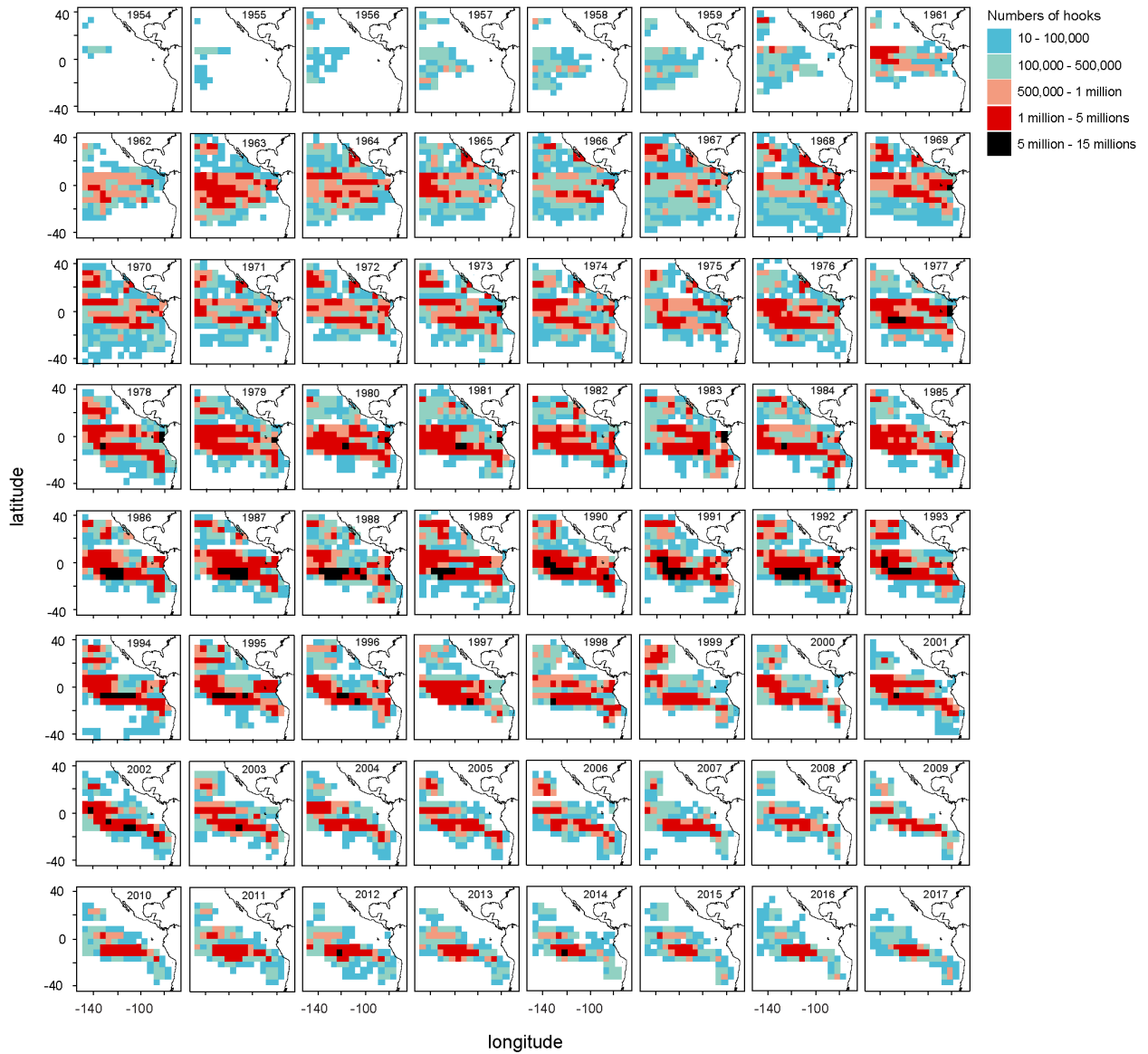


Figure 2.3. Likelihood profiles for  $R_0$  by model component from SAC-07-05a.

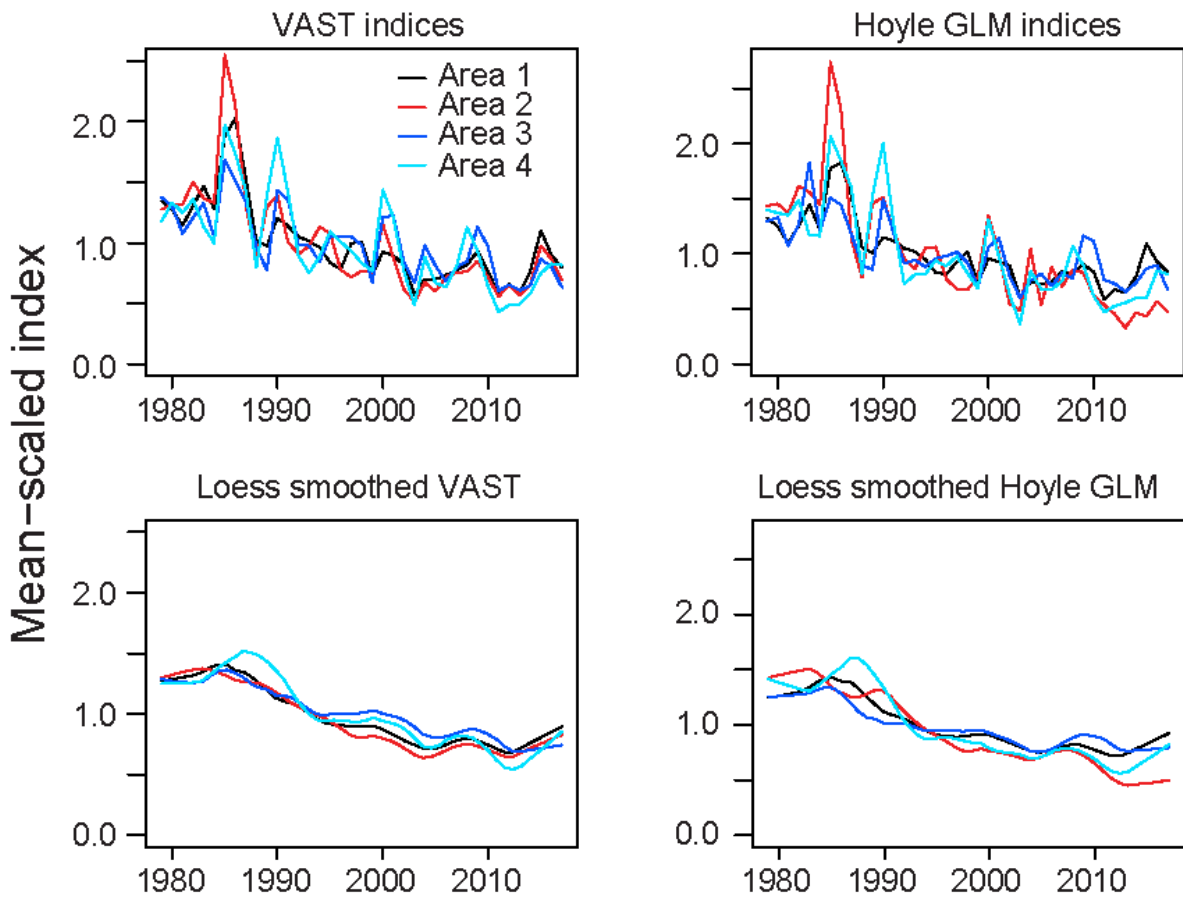


**Figure 2.4.** Indices of abundance used in assessment. Solid lines are fits to the indices and the red lines are the updated SAC-09 index values.

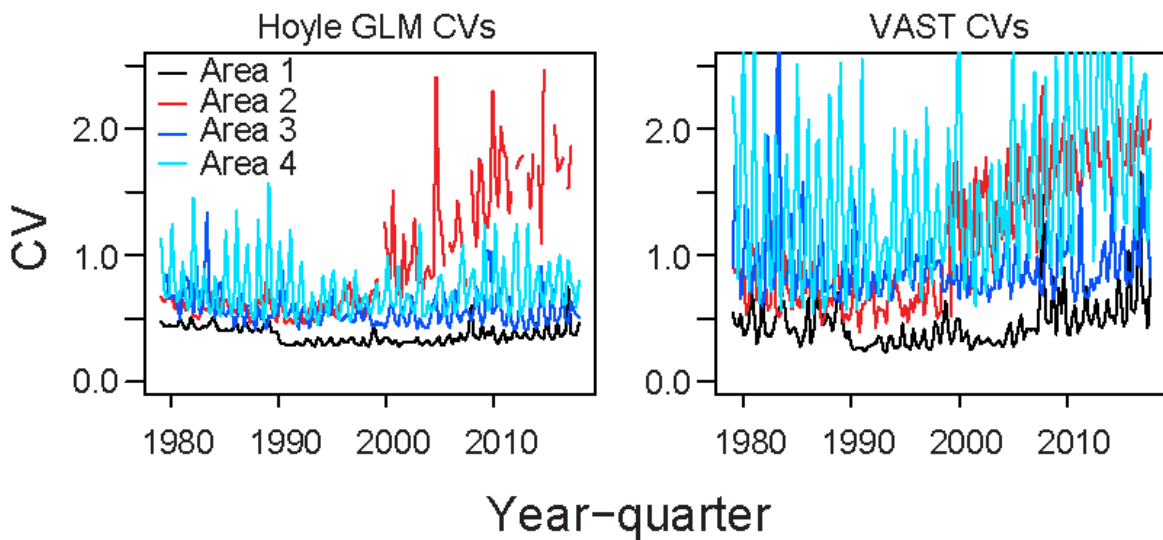
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**Figure 2.5.** Maps of the effort of the Japanese fleet in the Pacific Ocean over time.



**Figure 2.6.** A. VAST CPUE indices, B. Joint CPUE indices, C. Loess smoothed VAST indices and D. Loess smoothed joint CPUE indices.



**Figure 2.7.** A. Model-estimated CVs from the joint CPUE analysis. B. Model-estimated CVs from the VAST CPUE analysis.

Japan: BET CPUE (#indivs/100 hooks)

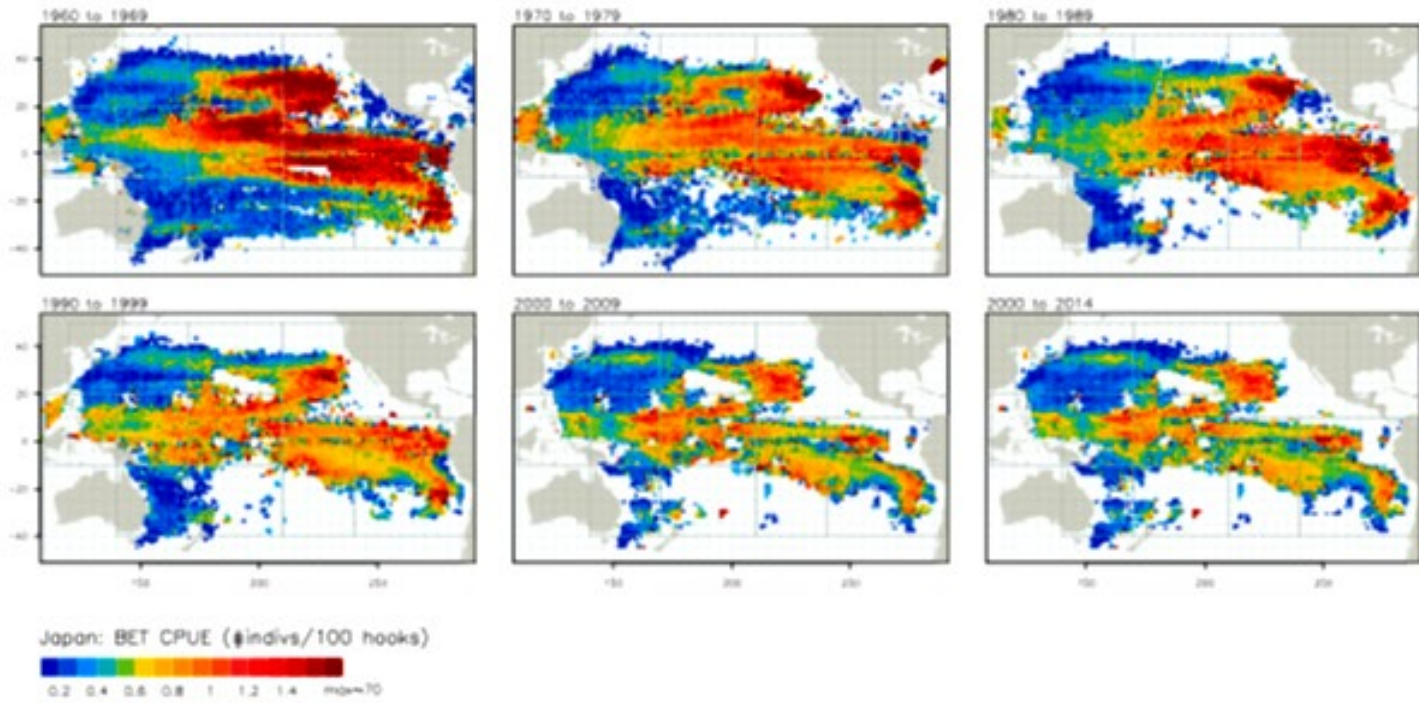


Figure 2.8. Japan longline nominal CPUE over time. From McKechnie et al. (2015).

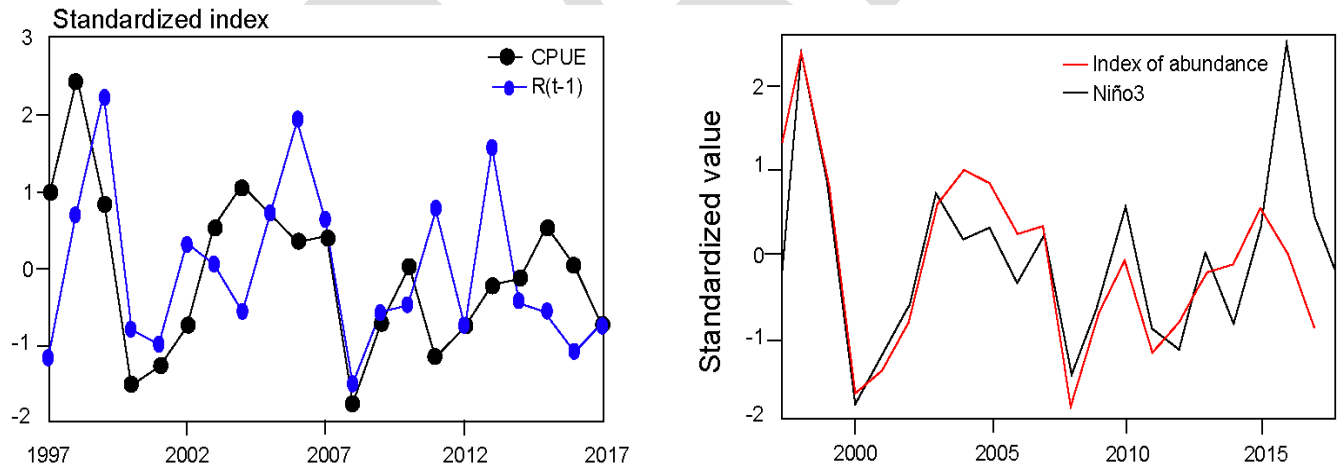
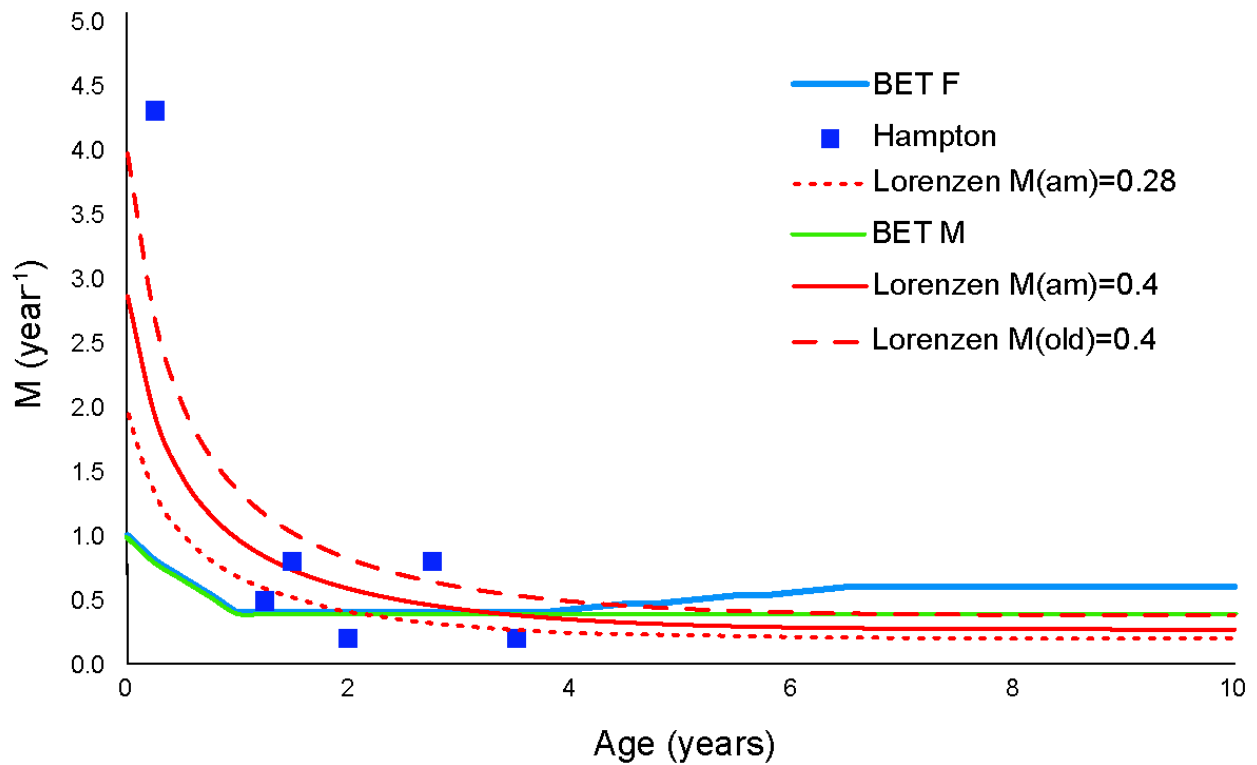
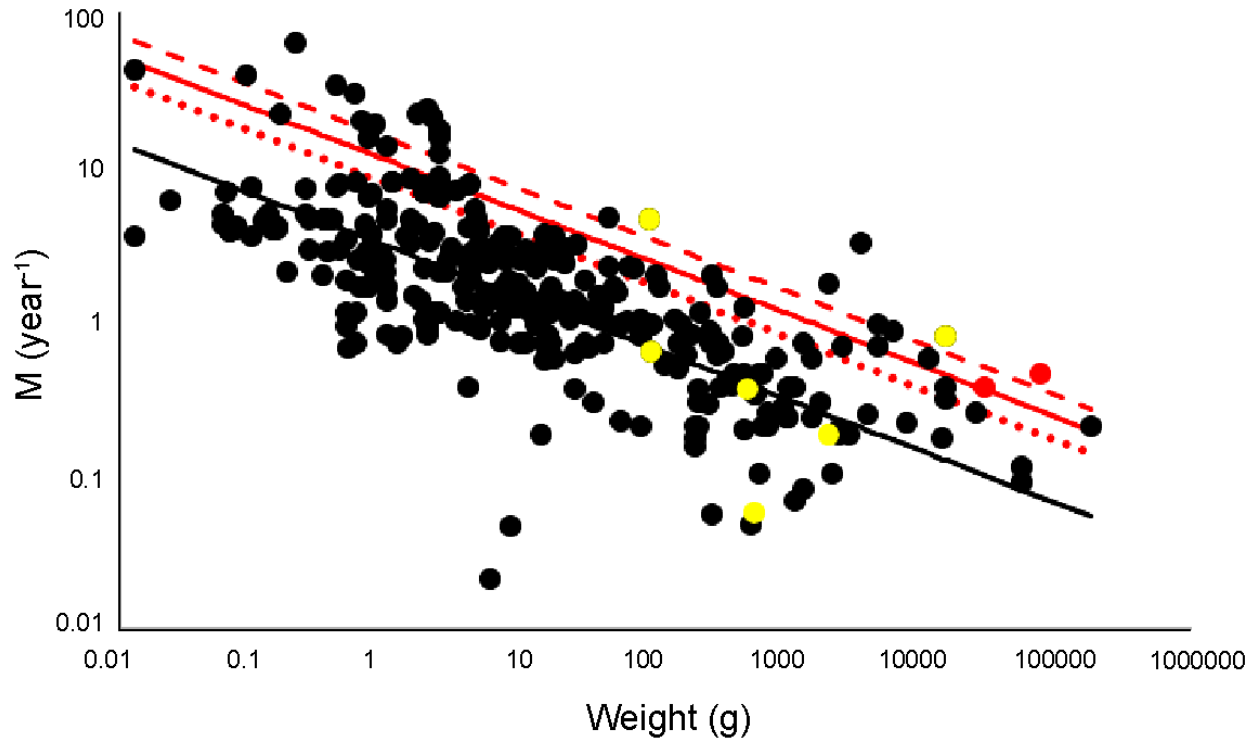


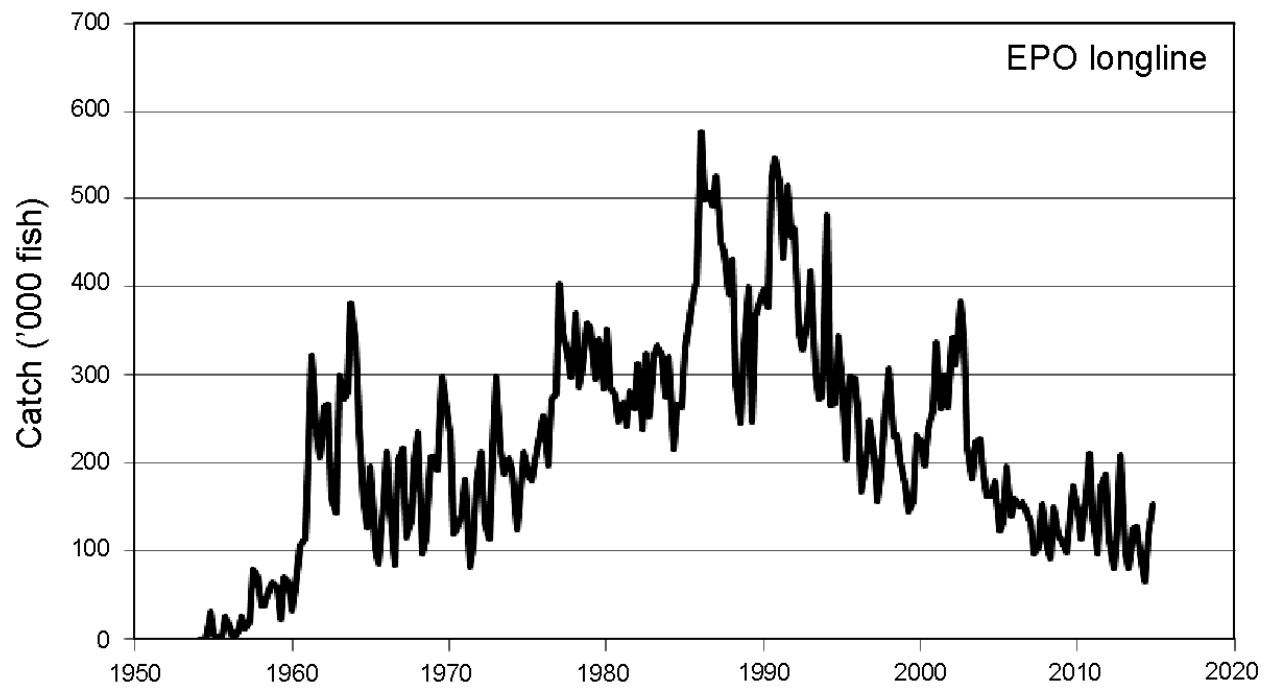
Figure 2.9. A. Comparison of purse seine index and lagged recruitment estimated by the model and B. Comparison of purse seine index with el Niño/La Niña index.



**Figure 4.1.** M-at-age pattern in bigeye tuna: M patterns assumed in the current assessment model for females (BET F) and males (BET M); estimates from Hampton's (2000) tagging study; and Lorenzen mortality curves scaled to values of M at age at maturity of  $M(am)=0.4\text{yr}^{-1}$  (the BET M value for fish age 1 and older) or  $M(am)=0.28\text{yr}^{-1}$  (the Hoenig M estimate), or to approach the BET M value for fish age 1 and older it in the oldest fish ( $M(old)=0.4\text{ yr}^{-1}$ ).



**Figure 4.2.** M-at-weight data for marine and freshwater fish used in Lorenzen (1996). The data included M estimates for bigeye tuna (red) and other scombrids (yellow). The black solid line shows the relationship estimated using Theil regression ( $M(w)=3.0 w^{-0.33}$ ). The red lines show the Lorenzen M curves hypothesized for bigeye tuna, scaled to intersect the bigeye M pattern at age at maturity (red solid line), to equal the Hoenig M estimate ( $0.28 \text{ year}^{-1}$ ) at age at maturity (red dotted line), or to approach the bigeye M pattern in the oldest fish (solid red line) (see also Figure 4.1. for the corresponding M-at-age patterns).



**Figure 4.3.** Time series of Japanese longline catch in numbers.



## **APPENDIX A – TERMS OF REFERENCE**

### **1. GOALS AND OBJECTIVES**

The purpose of the review of the IATTC staff's assessment of the bigeye stock is not to determine whether the current or proposed assessment is adequate for providing management advice; the intention is to provide information to the assessment team to improve the assessment. The goals and objectives of the review are to:

- a. identify the best available science for use in the assessment;
- b. provide an independent review of the assessment; and
- c. provide advice on future research and data collection that will improve the assessment and the provision of management advice.

### **2. REVIEW PANEL RESPONSIBILITIES**

The main responsibility of the Review Panel is to perform an adequate technical review of the assessment. The members of the Panel should disclose any conflicts of interest that could significantly impair their objectivity. Conflicts of interest include, but are not limited to, personal financial interests and investments, employer affiliations, and consulting arrangements, grants, or contracts.

The specific responsibilities of the Panel are to:

- a. be familiar with the Terms of Reference;
- b. review background documents, data inputs, and analytical models, along with other pertinent information (*e.g.*, previous assessments and Review Panel reports);
- c. discuss the technical merits and deficiencies of the input data and analytical methods, work with the IATTC staff to correct deficiencies, and, when possible, suggest new tools, analyses, and data collection methods to improve future assessments; and
- d. draft a report of the meeting, to document the discussions and recommendations.

It is the Panel chair's responsibility to coordinate the discussions so that the review is completed in the time available.

### **3. PUBLIC COMMENT**

Time will be allocated during the meeting for public comment. The Panel will take these comments into consideration when developing its report, as appropriate.

### **4. REQUESTS FOR ADDITIONAL ANALYSES**

The meeting is intended as a technical review of the assessment methodology, and additional analyses during the meeting may be beneficial. In the course of the meeting, the Panel may request a reasonable number of sensitivity runs, additional details on the models presented, or further analyses of alternative runs. However, any such requests must be clear, explicit, and be presented in writing, and be practical in terms of the time available. They should be listed individually in the Panel's report, along with their rationale and the response. To the extent possible, analyses requested by the Panel should be completed during the meeting by the assessment team.

### **5. PANEL REPORT**

The Panel's report should be drafted and approved shortly after the meeting. The report writing process will follow these steps:

- a. Panel outlines report at meeting;
- b. Panel writes and agrees draft report;
- c. Panel provides draft report to IATTC staff for comment on technical accuracy; and
- d. Panel reviews staff comments, and modifies report as necessary.

The report will include:

- a. Names and affiliations of Panel members;
- b. Brief overview of the meeting (location, agenda, main recommendations by Panel, *etc.*);
- c. Brief summary of current assessment model, data used, analyses presented, and proposed assessment model;
- d. List of analyses requested by the Panel, rationale for each request, and brief summary of the response;
- e. Comments on technical merits and/or deficiencies in the assessment, and recommendations for remedies;
- f. Unresolved problems and major uncertainties, *e.g.*, any special issues that complicate the assessment and/or interpretation of results;
- g. Data, fishery or assessment related issues raised by the public; and
- h. Prioritized recommendations for research and data collection for the subsequent assessment.

The Panel and the IATTC staff will strive to resolve any differences of opinion that may arise regarding the contents of the report. Any unresolved differences of opinion must be documented and reflected in the report, which will be published as an IATTC Special Report.

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## APPENDIX B – PANEL BIOGRAPHIES

**André E. Punt** (*Chair*) is a Professor in the School of Aquatic and Fishery Sciences at the University of Washington, Seattle, USA and the currently the Director of the School. He received his B.Sc, M.Sc and Ph.D. in Applied Mathematics at the University of Cape Town, South Africa. Before joining the University of Washington, Dr Punt was a Principal Research Scientist with the CSIRO Division of Marine and Atmospheric Research in Australia. Dr. Punt has been involved in stock assessment and fisheries management for over 30 years and has been recognized for his contributions in this area with awards from CSIRO, the University of Washington, the Australian Society for Fish Biology, and the American Fisheries Society. The research undertaken by Dr. Punt and the MPAM (Marine Population and Management) group at the University of Washington relates broadly to the development and application of fisheries stock assessment techniques, bioeconomic modelling, and the evaluation of the performance of stock assessment methods and harvest control rules using the Management Strategy Evaluation approach. Dr. Punt has published over 350 papers in the peer-reviewed literature, along with over 400 technical reports. Dr Punt is currently a member of the Scientific and Statistical Committee of the Pacific Fishery Management Council, the Crab Plan Team of the North Pacific Fishery Management Council, and the Scientific Committee of the International Whaling Commission.

**Steven X. Cadrin** is a Professor at the University of Massachusetts School for Marine Science and Technology. He is the chair of the Department of Fisheries Oceanography the Educational Director of the Massachusetts Marine Fisheries Institute. Steve has a PhD in Fisheries Science from University of Rhode Island, a MS in Marine Biology from University of Massachusetts and a BS in Marine Science from Long Island University. He has been a stock assessment scientist for over 30 years, previously with the National Marine Fisheries Service's Northeast Fisheries Science Center in Woods Hole, Massachusetts Marine Fisheries, and New York Department of Environmental Conservation. His accomplishments include the advancement of stock assessment methods for a wide range of invertebrate and finfish species, fishery management advice for regional, national and international fisheries, and global leadership in evaluating geographic stock structure and modelling spatially complex populations. He has chaired several regional, national and international working groups and committees and has convened workshops, symposia, and conferences for the International Council for the Exploration of the Seas, National Marine Fisheries Service, New England Fishery Management Council, American Fisheries Society and the Northeast Fish and Wildlife Conference. Steve was the inaugural recipient of the Excellence in Mentoring Award from the Joint Ocean Commission Initiative, and is Past President of the American Institute of Fisheries Research Biologists. His teaching and research agendas focus on population modelling, stock identification, fisheries management, collaborative research with fishermen, and application of advanced technologies for fishery science.

**Dan Fu** is the Stock Assessment Officer at the Indian Ocean Tuna Commission, FAO. He is responsible for coordinating and implementing research activities for evaluating stock status and providing management advice for regional tuna and billfish stocks. He is currently leading stock assessments for several tropical tuna and billfish species in the Indian Ocean including yellowfin, bigeye tuna, and swordfish, and is also extensively involved in CPUE standardizations and management strategy evaluation process for IOTC species. Before joining the IOTC, Mr. Fu was a statistical modeler at the National Institute of Water and Atmospheric Research of New Zealand (NIWA) where he was responsible for a number of finfish and shellfish stock assessments in New Zealand EEZ, as well as population modelling of marine mammals and seabirds. He has developed NIWA's population modelling and estimation package SEABIRD which has been used to assess population viability of a number of seabird populations in relation to fishery risks and in the quantitative risk assessment of New Zealand sea lion. He received his M.Sc. in Statistics at the University of Auckland.

**Kai Lorenzen** is Professor of Integrative Fisheries Science and Associate Director for Fisheries and Aquatic Sciences in the School of Forest Resources and Conservation, University of Florida. He holds a PhD in Applied Population Biology from the University of London (UK) and a Master's degree in Fisheries Biology with Mathematics from Kiel University (Germany). Dr. Lorenzen has over 25 years' experience in fisheries research and management, having worked as a fisheries consultant for MRAG Ltd. and served on the faculty of Imperial College London before taking up his current position. His core research interests are in fish population dynamics and the development of integrative trans-disciplinary approaches for addressing complex fisheries management problems. Among his notable contributions are empirical generalizations about size- and density-dependent population processes that are widely used in fisheries stock assessments; population dynamics models, assessment tools and planning frameworks for aquaculture-based fisheries enhancements (hatchery programs); and extensive field studies on the ecological and human dimensions of tropical inland fisheries. His work has been recognized with multiple honors and awards including the Mote Eminent Scholar Chair in Fisheries Ecology at Florida State University (2007-08). He has served on regional, national and international Panels for many organizations including FAO, the WorldFish Center and SEDAR and is currently the vice chair of the Scientific and Statistical Committee of the Gulf of Mexico Fishery Management Council.

**Richard D. Methot Jr.** is a research scientist at the United States National Marine Fisheries Service, Northwest Fisheries Science Center and NOAA's Senior Stock Assessment Scientist. He is the President of the American Fishery Society's Marine Fisheries Section and an affiliate professor at the University of Washington, Seattle, WA. He serves on the NMFS Science Board to guide science policy and operations. In that role, he has been the senior advisor to efforts to use advanced technology to improve fishery-independent surveys. His notable, career-spanning accomplishment is creation of the Stock Synthesis system for assessment of harvested fish stocks, for which he was awarded the U.S. Dept. Commerce Gold Medal in 2008. He actively supports the global user community for Stock Synthesis who conduct over 100 assessments using SS. The great flexibility of SS has also been instrumental in spurring active research on stock assessment methods and good practices. Dr. Methot is also actively engaged in protocols for scientifically-based fishery management. He has been instrumental in development of the U.S. National Guidelines for prevention of overfishing, attaining optimum yield, and using the best scientific information available.

**Kevin Piner** is a Research Fishery Biologist for NOAA Fisheries, Southwest Fisheries Science Center. He is responsible for evaluating stock status and providing management advice for Pacific Ocean temperate tuna and billfish stocks. He is currently a member of several species working groups of the International Scientific Committee for Tuna and Tuna-like species, including Pacific Bluefin tuna, albacore tuna, pelagic sharks and billfishes. Before joining the SWFSC he conducted population assessment for the Northwest Fisheries Science Center, and the Pacific Islands Fisheries Science Center. Prior to joining NOAA, he received his Ph.D. in Ecology at the Old Dominion University.

**John F. Walter, III** is a research fisheries biologist at the United States National Marine Fisheries Service, Southeast Fisheries Science Center and acting Chief of the Gulf and Caribbean Branch. He is also the Chair of the Western Bluefin tuna committee of the ICCAT SCRS, the scientific coordinator of the NMFS Bluefin Tuna Research Program and co-chair of the NMFS National Management Strategy Evaluation working group. In addition, he is an adjunct faculty member at the University of Miami, Rosenstiel School of Marine and Atmospheric Sciences. In his capacity as a fisheries biologist for NMFS, he serves as the lead assessment biologist on stock assessments of many high profile domestic and international species. His most recent assignments have been to lead a multi-national research team tasked with assessing Atlantic bigeye and yellowfin tuna. He supervises stock assessments of Gulf of Mexico red and grey snapper, gag and red grouper, triggerfish, Caribbean spiny lobster and numerous other species. Beyond his position as

a research fisheries biologist, he maintains an active research program focusing on incorporating environmental factors into stock assessments and in genomic approaches to fisheries assessments. His most notable areas of research are in evaluating the impacts of episodic red tide events in fisheries and in applying genomic close-kin mark recapture approaches for estimating Atlantic bluefin tuna abundance.

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## APPENDIX C – LIST OF PARTICIPANTS

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## **APPENDIX D – DOCUMENTS AVAILABLE TO THE PANEL**

### *MAIN DOCUMENTS*

#### **Primary assessment documents**

- Aires-da-Silva, A. Minte-Vera, C.V. and M.N. Maunder. 2018a. Status of bigeye tuna in the eastern Pacific Ocean in 2015 and outlook for the future. Pages 32-96 In Status of tuna and billfish stocks in 2015. IATTC Stock Assessment Report 17.
- Maunder, M.N., Lennert-Cody, C.E. and M. Román. 2018b. Stock Status indicators for bigeye tuna. Pages 18-24 In Status of tuna and billfish stocks in 2015. IATTC Stock Assessment Report 19.
- Xu, H., Minte-Vera, C., Maunder, M.N. and A. Aires-da-Silva. 2018. Status of bigeye tuna in the Eastern Pacific Ocean in 2017 and outlook for the future. IATTC Document SAC-09-05.

#### **Documents related to the 2010 review**

- Maunder, M.N., Aires-da-Silva, A. and C.E. Lennert-Cody. 2010. Summary of issues in the Eastern Pacific Ocean Bigeye Tuna Assessments. IATTC Document BET-01-01.
- Sibert, J.R., Harley, S.J., Ianelli, J.N. and A.E. Punt. 2012. External review of IATTC bigeye tuna assessment. IATTC Special Report 19.
- Valero, J. L. 2019. Conversion of BET 2017 base case assessment from Stock Synthesis version 3.23b to 3.3. Review of the stock assessment of bigeye tuna in the eastern Pacific Ocean. La Jolla, California (USA), 11-15 March 2019.

#### **Documents prepared for the March 2019 review meeting**

- IATTC. 2019. Modeling recruitment in the EPO bigeye tuna assessment. IATTC Document WSBET-02-01.
- Minte-Vera, C., Lennert-Cody, C., Xu, H., Valero, J., Maunder, M., Schaefer, K. Fuller, D., Lopez, J., Oliveros-Ramos, R. and A. Aires-da-Silva. 2019. A stock structure for bigeye tuna in the Eastern Pacific Ocean. IATTC Document WSBET-02-02.
- Minte-Vera, C., Xu, H., Vogel, N.W. Boster, J.E., Lennert-Cody, C., Maunder, M.N. and A. Aires-da-Silva. 2019. Data from longline fisheries. IATTC Document WSBET-02-03.
- IATTC. 2019. Responses by the IATTC staff to the recommendation of the first external review of the bigeye stock assessment (2012). IATTC Document WSBET-02-04.
- IATTC. 2019. Summary of purse seine data available for bigeye tuna in the eastern Pacific Ocean. IATTC Document WSBET-02-05.
- IATTC. 2019. Natural mortality used in the EPO bigeye assessment. IATTC Document WSBET-02-05.
- IATTC. 2019. Growth used in the EPO bigeye tuna assessment. IATTC Document WSBET-02-07.
- Valero, J.L., Maunder, M.N., Xu, H., Minte-Vera, C., Lennert-Cody, C. and A. Aires-da-Silva. 2019. Investigated potential causes of the misspecification-induced regime shift in recruitment in the EPS bigeye tuna assessment. IATTC Document WSBET-02-08
- Valero, J.L., Maunder, M.N., Xu, H., Minte-Vera, C., Lennert-Cody, C. and A. Aires-da-Silva. 2019. Spatial stock assessment model options for BET in the EPO and beyond. IATTC Document WSBET-02-09.

### *FOR INFORMATION*

#### **Previous bigeye review**

- Sibert, J.R., Harley, S.J., Ianelli, J.N. and A.E. Punt. 2012. External review of IATTC bigeye tuna assessment. IATTC Special Report 19.
- Maunder, M.N., Aires-da-Silva, A. and C.E. Lennert-Cody. 2010. Summary of issues in the Eastern Pacific Ocean Bigeye Tuna Assessment. IATTC Document BET-01-01.
- Lennert-Cody, C.E., Maunder, M.N. and A. Aires-da-Silva. 2010. Preliminary analysis of spatial-temporal pattern in bigeye tuna length-frequency distributions and catch-per-unit-effort trends. IATTC Document BET-01-02a.
- Aires-da-Silva, A. and M.N. Maunder. 2010. An evaluation of spatial structure in the stock assessment of bigeye tuna in the Eastern Pacific Ocean. IATTC Document BET-01-02b.
- Aires-da-Silva, A. and M.N. Maunder. 2010. Sensitivity analysis of bigeye stock assessment to alternative growth assumptions. IATTC Document BET-01-03.
- Maunder, M.N. and A. Aires-da-Silva. 2010. Investigation of catch-per-unit-of-effort data used in the Eastern Pacific Ocean bigeye assessment model. IATTC Document BET-01-04.
- Aires-da-Silva, A., Maunder, M.N. and C.E. Lennert-Cody. 2010. An investigation of the longline fishery length-frequency residual pattern in the stock assessment of bigeye tuna in the Eastern Pacific Ocean. IATTC Document BET-01-05.
- Aires-da-Silva, A., Maunder, M.N. and P.K. Tomlinson. 2010. An investigation of the trend in the estimated recruitment for bigeye tuna in the Eastern Pacific Ocean. IATTC Document BET-01-06.
- Maunder, M.N., Lennert-Cody, C.E., Aires-da-Silva, A., Bayliff, W.H., Tomlinson, P.K. and K.M. Schaefer. 2010.

Summary of data available for bigeye tuna in the Eastern Pacific Ocean and its use in stock assessment. IATTC Document BET-01-07.

### **Yellowfin review**

- Martell, S.J.D., de Bruyn, P., Davies, N.M. and B. Ernst. 2013. Recommendations of the review panel on the IATTC assessment of yellowfin tuna. IATTC Special Report 20.
- IATTC. 2012. Introduction to the review of the assessment of yellowfin tuna in the Eastern Pacific Ocean, 2012. IATTC Document YFT-01-01.
- Lennert-Cody, C.E., Maunder, M.N. and A. Aires-da-Silva. 2012. Exploring large-scale patterns in yellowfin tuna data from dolphin sets in the Eastern Pacific Ocean purse seine fishery. IATTC Document YFT-01-02.
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- Maunder, M.N. and A. Aires-da-Silva. 2012. A review and evaluation of recruitment and the stock-recruitment relationship for the assessment and management of yellowfin tuna in the Eastern Pacific Ocean. IATTC Document. IATTC Document YFT-01-05.
- Aires-da-Silva, A. and M.N. Maunder. 2012. An exploration of alternative methods to deal with time-varying selectivity in the stock assessment of yellowfin tuna in the Eastern Pacific Ocean. IATTC Document YFT-01-06.
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- Maunder, M.N. and A. Aires-da-Silva. 2012. A review of historical EPO YFT stock assessment sensitivity analyses. IATTC Document YFT-01-08.

### **Other documents**

- Aires-da-Silva, A. and M.N. Maunder. 2011. Additional sensitivity analyses in the stock assessment of bigeye tuna in the eastern Pacific Ocean. Pages 191-254 In Status of the tuna and billfish stocks in 2009. IATTC Stock Assessment Report 11.
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- Lennert-Cody, C.E., Maunder, M.N., Tomlinson, P.K., Aires-da-Silva, A., Pérez, A. and M. McCracken. 2012b. Post-stratified estimators of total catch for the purse seine fishery port-sampling data. Pages 178-190 In Status of the tuna and billfish stocks in 2010. IATTC Stock Assessment Report 12.
- Lennert-Cody, C.E., Okamoto, H. and M.N. Maunder. 2014. Analysis of Japanese longline operational-level catch and effort data for bigeye tuna in the eastern Pacific Ocean. Pages 186-216 In Status of the tuna and billfish stocks in 2012. IATTC Stock Assessment Report 14.
- Lennert-Cody, C.E., Maunder, M.N., Aires-da-Silva, A., Román, M.H., and V.M. Tsontos. 2018a. Pages 334-350 In Status of the tuna and billfish stocks in 2015. IATTC Stock Assessment Report 17.
- Lennert-Cody, C.E. Moreno, G., Restrepo, V., Román, M.H. and M.N. Maunder. 2018b. Recent purse seine FAD fishing strategies in the eastern Pacific Ocean: what is the appropriate number of FADs at sea? *ICES Journal of Marine Science* 75: 1748–1757.
- Matsumoto, T. and W.H. Bayliff. 2008. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1998-2003. *IATTC Bulletin* Vol 24 No. 1.
- Maunder, M.N. 2012. Reference points, decision rules, and management strategy evaluation for tunas and associated species in the eastern Pacific Ocean. Pages 107-120 In Status of the tuna and billfish stocks in 2011. IATTC Stock Assessment Report 13.
- Maunder, M.N. and A. Aires-da-Silva. 2012. Evaluation of the Kobe plot and Strategy matrix and their application to tuna in the eastern Pacific Ocean. Pages 191-211 In Status of the tuna and billfish stocks in 2010. IATTC Stock Assessment Report 12.
- Maunder, M.N. and A. Aires-da-Silva. 2018. Evaluation of the declining catch per set in the purse seine fishery on floating objects in the eastern Pacific Ocean. Pages 351-372 In Status of the tuna and billfish stocks in 2015. IATTC Stock Assessment Report 17.
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## APPENDIX E – REQUESTS AND RESPONSES

### Day 1 Requests

**A. Request:** Provide the time-series of catches for the years prior to 1975.

**Rationale:** The Panel wished to obtain an understanding of whether the pre-1975 catches are such that they could have led to the estimated initial depletion.

**Outcome:** The catches were provided to the Panel (**Figure 4.3**). Alternative model runs started in 1954 led to similar trends in spawning biomass, but the absolute magnitude of biomass was higher (Fig. 27 of WSBET-02-08)

**B. Request:** Conduct likelihood profiles for initial depletion. This could be achieved by pre-specifying all but one of the parameters that determines the initial age-structure and profiling on that parameter.

**Rationale:** The Panel wished to understand what sources of data are informing the initial depletion.

**Outcome:** The Panel agreed that this request should not be completed until a model is identified that resolves some of the other concerns.

**C. Request:** Remove the JRT vessel data from the 2018 assessment to see if these data have any influence on the estimates of recruitment / initial depletion.

**Rationale:** The length-composition data for the training fleets are centered on much smaller fish than the commercial length-composition data, and appear to be highly variable from one year to the next.

**Outcome:** The trend in spawning biomass in absolute and relative terms was insensitive to the use of the JRT training data.

**D. Request:** Remove the purse seine fleet discards from the model.

**Rationale:** The Panel speculated that these discards (for which selectivity is pre-specified) might be driving the Rshift to some extent.

**Outcome:** Removing the purse seine fleet discards had negligible effects on the estimates of recruitment and spawning biomass.

**E. Request:** Add in additional purse seine fleet discards based on extrapolating the discard rate for the post-1993 period back in time.

**Rationale:** There are no purse seine fleet discards in the assessment before 1993.

**Outcome:** The Panel decided that Request F provided a better examination of pre-1993 discards than this proposed analysis

**F Request:** Add alternative time-series of discards pre-1993 to evaluate the magnitude of the early discards that would be needed to remove the Rshift.

**Rationale:** The Panel wished to explore how influential the purse seine fleet catches were on the magnitude of the Rshift.

**Outcome:** Two analyses were provided, both of which eliminated the Rshift. The first involved creating pre-1993 discards that are 10 times the discards for 1993-97. Alternatively, multiplying the post-1993 catches by 0.25 removed the Rshift. These analyses provided confirmation that the key feature that leads to the Rshift is the need for additional recruitment to “balance” the increased purse seine catches given that the population did not crash even given a substantial increase in the catch-in-numbers.

**G. Request:** Show plots of longline effort (either sets or hooks) over space and time.

**Rationale:** The Panel were provided with plots of catch over space and time but not effort.

**Outcome:** **Figure 2.5** provides effort maps for Japan during the 1970s and 2000s, illustrating the change in distribution and intensity of fishing over time.

**H. Request:** Provide maps of predicted CPUE from the VAST model.

**Rationale:** The Panel wished to see whether there are changes in CPUE spatially.

**Outcome:** The plots were provided and formed the basis for further requests.

**I. Request:** Start the model in 2000.

**Rationale:** The Panel wished to understand whether a model that starts in 2000 would line up with a model that started in 1975.

**Outcome:** This request could not be completed during the meeting.

**J. Request:** Compare the VAST-based indices using Japanese data and Korean data separately with that based on the combined fleets data; show these trends with the GLM-based trend.

**Rationale:** The VAST model should better account for spatial structure.

**Outcome:** The trends from the VAST and the GLM were very similar. There was some evidence that the Korean CPUE is higher than the Japanese CPUE, particularly in recent years, but this may be a scaling issue. Comparisons between the VAST- and GLM-based indices are explored further in Requests K and V.

**K. Request:** Compare the VAST- and GLM-based indices for common areas.

**Rationale:** The Panel wished to understand whether moving to a VAST-based approach will change trends qualitatively.

**Outcome:** Qualitatively, the trends in standardized CPUE were very similar between the VAST- and GLM-based approaches.

**L. Request:** Show influence plots for the GLMs for the longline indices.

**Rationale:** The Panel wished to understand how the various covariates influenced the final standardized index.

**Outcome:** The plots were not scaled equally for the four areas (Areas A1, A2, A3 and A4) making interpretation difficult, but the effects of hooks-between-baskets and vessel were identified as drivers of the difference between the nominal and standardized indices, with a noticeable effect of hooks-between-baskets around 1995 (except for Area A4).

**M. Request:** Run ASPMs based on 2018 specifications (estimating recruitment devs) with each longline index in turn.

**Rationale:** The Panel wished to better explore the possibility of localized depletion.

**Outcome:** This request could not be completed during the meeting.

**N. Request:** Does the recruitment index based on purse seine CPUE correlate with age-0 abundance (lagged by 1 year)?

**Rationale:** There is a strong correlation between the index of recruitment and an El Niño index.

**Outcome:** The correlation between the recruitment index and age-0 abundance was weaker than that between the index of recruitment and the El Niño index, but this may reflect that the estimates of recruitment from the model are themselves not accurate.

**O. Request:** Provide a table of fleets, the areas and times they apply to, the selectivity patterns assumed, and which parameters are estimated.

**Rationale:** This information was needed to fully understand the structure of the model.

**Outcome:** The table was provided and as **Table 4.1** of this report.

## **Day 2 Requests**

**P. Request:** Provide  $R_0$  profiles splitting out the longline and purse seine size-composition data

**Rationale:** The Panel wished to understand which type of fleet are contributing most to the estimation of scale (and depletion)

**Outcome:** The plot (**Figure 2.3**) showed that two fleets (13 and 14) contributed the most to the likelihood profile for the composition data. These are the longline fleets for which (a) asymptotic selectivity is assumed and (b) correspond to the indices of abundance in the 2018 model.

**Q. Request:** Provide the split of the catches between purse seine and longline for the four-area model.

**Rationale:** The Panel wished to understand whether the change from longline to purse seine was restricted to a few areas.

**Outcome:** The figure was provided (**Figure 2.1**), which showed that the change from longline to purse seine occurred in all areas. It was noted that this may explain why recent attempts to remove the Rshift by moving to spatial assessments have not succeeded.

**R. Request:** Provide the rationale for starting the model in 1975.

**Rationale:** The model starts in 1975, but no documentation for this choice is provided.

**Outcome:** The IATTC staff **started** that:

- a. Port sampling for bigeye length composition started in 1975.
- b. Hooks per basket for longline CPUE standardization became available in 1997.
- c. Relies heavily on the stock recruitment relationship and accuracy of the catch.
- d. Many processes, particularly recruitment, may experience regime shifts and therefore the processes may be different in the earlier years before the data is available.
- e. The reason for starting when the first composition data is available rather than the index of abundance is because annual recruitment information is needed to interpret the index of abundance (Minte-Vera et al., 2017).

**S. Request:** Plot the standardized longline CPUE series by proposed areas to investigate whether there is local depletion

**Rationale:** There has been considerable discussion about localized depletion, and the Panel wished to see if the new areas show localized depletion.

**Outcome:** The plots were provided but were hard to interpret. This led to request V.

**T. Request:** Provide the formula used to set the “stage1” weights for the composition data.

**Rationale:** The stage 1 weights are adjusted by the lambda, but the weight assigned to the composition data depends on lambda and the stage 1 weights. The Panel also noticed that many of the stage 1 weights were very small (1 or less).

**Outcome:** The algorithm is to scale all longline length composition sample sizes by alpha where  $\alpha = \text{average}(PS\_SS) / \text{average}(LL\_SS)$ , PS\_SS is number of wells sampled for the purse seine fishery with highest SS (2) and LL\_SS is number of fish sampled for the longline fishery with highest SS (14). The data for 2015-2017 are not included in the average.

### **Day 3 Requests**

**U. Request:** Provide a table listing the hypotheses for the cause of the Rshift and then summarize whether model runs provide support for them. Use the results from WSBET-02-08 and earlier studies.

**Rationale:** The Panel wished for a summary of all of the evidence to assist it in its deliberations.

**Outcome:** The table was provided (given here as **Table 7.1**)

**V. Request:** Plot standardized longline CPUE series by the proposed areas (Areas A1, A2, A3, A4) to investigate whether there is local depletion (one plot by year; with loess smoother)

**Rationale:** This was a follow-up request to request S.

**Outcome:** The plot (**Figure 2.6**) shows that there are different trends by area when the indices are based on the GLM, but much less evidence for trends among areas using VAST. The latter result is likely a consequence of VAST analysing Areas A1 and A2 together and Areas A3 and A4 together. There is very little data for Area A2 in recent years and VAST will infer trends for area A2 from those in area A1.

**W. Request:** Take the model with  $L_{inf}$  estimated and  $\lambda=1$ , then conduct stage 2 tuning using the Francis approach, and then estimate steepness.

**Rationale:** The Panel wished to see the effects of Francis weights on a model with no Rshift and whether

steepness is estimated to be 1 when the Rshift is no longer present.

**Outcome:** The results were presented and showed little evidence for an Rshift.

**X. Request:** Develop age-specific M based on Lorenzen considerations.

**Rationale:** The scenarios regarding M included in Figure 3 of WSBET-02-06 are qualitatively appropriate, but not linked to prior theoretical work

**Outcome:** The value for M for age-0 animals was high but not as high as the estimate from Hampton (2000) (**Figure 4.1**). Including the natural mortality-at-age vector in the assessment removed the Rshift because the high natural mortality reduces the effects of the high purse seine catches since the mid-1990s.

**Y. Request:** Plot model-estimated sex-ratios and compare the results to the available data on sex-ratios.

**Rationale:** The Panel wished to understand whether the current M-vectors by sex lead to predicted sex-ratios that match available data.

**Outcome:** The plots were produced. The data for young animals were hard to explain but may be related to an inability to sex young animals or spatial variation in the sexes.

#### **Day 4 Requests**

**Z. Request:** Construct a model with density-dependent growth.

**Rationale:** This is one of the hypotheses in **Table 7.1**, but to date no alternative models have been developed to examine how large an effect this might be.

**Outcome:** There was insufficient computer memory to complete the request during the meeting.

**AA. Request:** Plot standard errors for CPUE over time (VAST and GLM)

**Rationale:** The Panel wished to understand whether the assumption that the CV of the CPUE indices is independent of area, quarter and year was valid.

**Outcome:** There is strong evidence that the CVs (particularly for Area A2 recently, and Area A4 generally) are not the same (**Figure 2.7**).

**AB. Request:** Report the Francis weights.

**Rationale:** The Panel wished to see how the stage 2 weights were adjusted.

**Outcome:** The stage-2 weights were presented.

**Appendix F – Comparison between 2018 base-model and four-area model**

	<b>2018 Base-Case<sup>1</sup></b>	<b>Spatial 4 areas no movement<sup>2</sup></b>	<b>Spatial 4 areas with movement<sup>3</sup></b>
<b>SS Version</b>	3.23b	3.30.12	3.30.12
<b>Years and timestep</b>			Years (1975-2018) as Quarters (1-172) approach
<b>Ages</b>			Max age 40 quarters (10 years)
<b>Sexes</b>			2-sex model
<b>Length bins</b>	2cm	10cm	10cm
<b>Areas</b>	1	4	4
<b>Fleets</b>	27	20	20
<b>Indices of abundance (LL)</b>	2	5	5
<b>Fleets with length compositions</b>	15	13	13
<b>Northern area (Hawaii) included?</b>	Yes	No	No
<b>Lambda Length comps</b>	0.05	1	1
<b>Includes discards?</b>	Yes	No	No
<b>Includes training LL vessel data?</b>	Yes	No	No
<b>Movement</b>	No	No	Juveniles 16%/quarter Eastwards, adults 5% E-W diffusion

<sup>1</sup>Xu et al. (2018); <sup>2</sup>WSBET-02-08; <sup>3</sup>WSBET-02-08 (their Figure 13). Other scenarios available in the report