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SUMMARY OF ISSUES IN THE EASTERN PACIFIC OCEAN BIGEYE TUNA ASSESSMENT

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CONTENTS

1. STOCK STRUCTURE

Understanding stock structure is an important part of developing a fisheries stock assessment. It is important to identify fish stock units for both management and assessment purposes. Specification of management units may drive the stock structure used in stock assessments to facilitate the evaluation of management actions. With respect to stock assessment, stock structure may relate to how the fisheries are defined in the assessment or how spatial structure in population dynamics is modeled.

There are three main implementations of stock structure in stock assessment models: 1) separate populations, 2) interacting sub-populations, and 3) spatially-defined fisheries. If there is little or no exchange among areas, then modeling the areas as separate populations (*i.e.* separate assessments for each area) would be appropriate. If there is substantial exchange among areas, but there are differences in the exploitation or other fishery or biological characteristics among areas, then modeling interacting sub-populations might be appropriate. If there is a large amount of exchange among areas, but some characteristics, such as size or age of fish, differ among areas, it may be appropriate to model each area as a separate fishery so that the fisheries can be assigned different selectivity and catchability. Modeling different selectivity in each area may adequately model size or age-specific movement without the need for a spatially-structured population dynamics model.

The current bigeye tuna assessment model (Aires-da-Silva and Maunder 2010) treats the bigeye of the eastern Pacific Ocean (EPO) as a single stock, but separates the data into fisheries based to some extent on spatial differences in the sizes of fish caught, but also on management considerations and spatial distribution of effort. The purse-seine fishery on floating objects post-1992 is separated into four fisheries and the longline fishery is split into two fisheries, north and south of 15°N (Figure 1). Historically, several versions of a Pacific-wide assessment have also been conducted (Hampton and Maunder 2005), but they have not been used for management advice. Differences in growth rates, maturity schedules, and other life history information between the eastern and western Pacific Ocean make Pacific-wide assessments problematic. Results of the Pacific-wide assessments are generally similar to those for the EPO region as obtained from the EPO assessment model if the same growth rates are used in both models (Hampton and Maunder 2006).

Schaefer (2009) reviewed the information about stock structure of bigeye tuna in the Pacific Ocean. Based on apparent maturation, size-composition, and catch-per-unit-of-effort (CPUE) data, spawning occurs widely across the equatorial Pacific during most months of the year, with no indication of stock structure. A genetic study did not provide evidence of genetic differentiation of bigeye in the Pacific. There have apparently been no investigations of geographical differences in morphometric or meristic characters, or in naturally-occurring biological markers of bigeye in the EPO. Tagging data in the EPO (Schaefer and Fuller 2009) indicate, however, that bigeye exhibit regional fidelity to the main area of tag releases, which has very high biological productivity, and suggests a very low level of mixing of bigeye between the eastern and western Pacific Ocean. Of the 6,562 bigeye recaptured after periods at liberty of more than 30 days, 95% were recaptured within 1,017 miles of their release positions. Movements of bigeye inferred from tagged fish in the western Pacific and Hawaii also strongly suggest relatively restricted horizontal movements and regional fidelity to geographically-confined areas. In the EPO, there appears to be a discontinuity at about 10°N in the distribution of longline catches. The bigeye tagging studies recently undertaken in the equatorial EPO demonstrate that movements are restricted primarily to the equatorial region, and no movement from the southern to the northern region of the longline catch distribution was observed. Bigeye within those two regions of the EPO, separated at about 10°N, may potentially represent spatially-segregated northern and southern sub-stocks, with little mixing between them.

Multivariate regression tree methods have been applied to longline and purse-seine CPUE trends and length-composition data. The results suggest that spatial structure exists in the EPO bigeye population. There was some similarity between the spatial structure identified from the longline length-composition distributions and that from the longline CPUE effort trends. Separate analyses of the two data types indicated a partition at around 150°W, consistent with the current western boundary definition of the EPO fishery area. In addition, latitudinal partitions of the EPO were indicated at around 10-15°N, at the equator, and at 15°S, and an inshore longitudinal partition at around 95°-100°W. The latitudinal partition around 15°N is also consistent with the current stock assessment stratification for the longline fishery. Results of the analysis of purse-seine length-composition data indicate an inshore/offshore partition of the EPO at 110°W. In addition, there was some evidence that the inshore region should be further divided into an equatorial area between 10°S-5°N, and an additional nearshore partition along 90°W. This stratification of the EPO shows some similarity to that currently used for the purse-seine stock assessment (Figure 1). The CPUE data from the purse-seine fishery did not provide any information on spatial structure.

Differences in length-composition data suggest that, at a minimum, separate fisheries with different selectivities should be modeled. This is the approach currently taken in the bigeye assessment. However, this may also indicate that modeling sub-stocks is required. Differences in CPUE among areas may indicate local depletion, and also suggest that separate stocks or interacting sub-stocks should be modeled. However, spatial differences in age structure may also cause different CPUE trends.

A preliminary evaluation of spatial structure in the stock assessment of bigeye in the EPO was made. The EPO was divided into four major geographical regions - inshore, central, northern, and southern – with no mixing of fish assumed between regions. An independent stock assessment was conducted for each region. The preliminary analyses show differences in the depletion levels of bigeye among geographical regions in the EPO. These results indicate that smaller spatial scales should be considered. However, similar trends in recruitment indicate that bigeye sub-stocks may be connected through recruitment or similar recruitment processes. Detailed results from the bigeye spatially-structured assessments are reported in Document BET-01-02b.

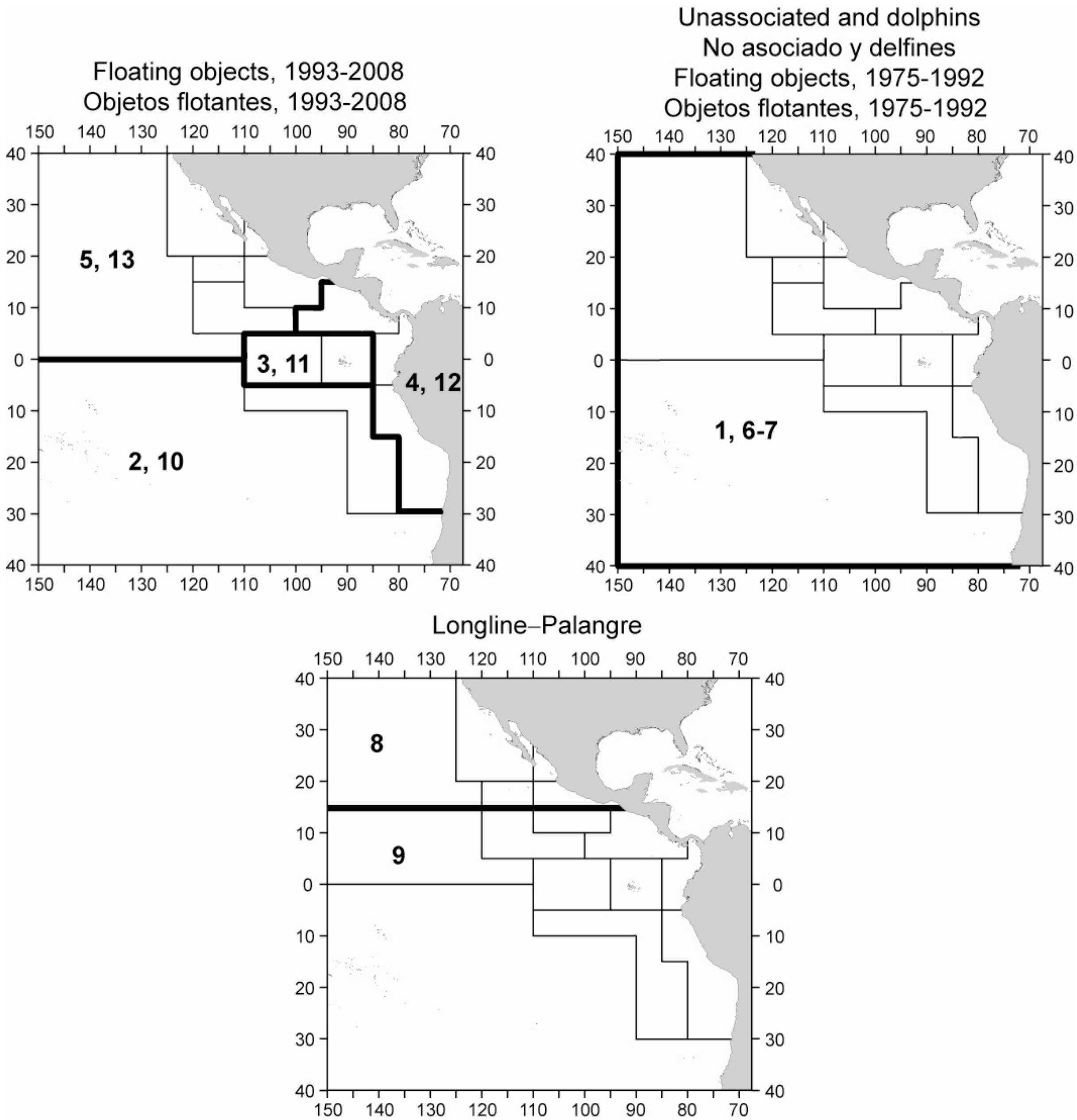

FIGURE 1. Spatial extents of the fisheries defined for the stock assessment of bigeye tuna in the EPO. The thin lines indicate the boundaries of 13 length-frequency sampling areas, the bold lines the boundaries of each fishery defined for the stock assessment, and the bold numbers the fisheries to which the latter boundaries apply.

2. GROWTH

Growth is one of the main population processes modeled in fishery stock assessments and it can have a large influence on the estimates of management quantities. Estimates of growth are problematic for bigeye tuna because accurate age data is available only up to about age four, after which the daily rings that are used for aging become hard to identify (Schaefer and Fuller 2006). Tagging data can also be used to estimate growth, but unfortunately, it is difficult to capture large bigeye for tagging and very few data are available for large individuals.

A von Bertalanffy growth curve fit to otolith daily increment age-length data estimates growth that is nearly linear for the range of ages for which data are available (up to four years only, out of a longevity estimate of 15 years, at least). Given the data available for the younger fish, it is difficult to get the von Bertalanffy growth curve to bend over to a reasonable length for old individuals while still fitting the age-length data. This implies a very large and unrealistic size for the old individuals when the model is extrapolated beyond to the older ages. Therefore, the more flexible Richards growth curve is a better choice to appropriately represent the mean length at age for bigeye. The asymptotic length parameter is usually fixed to a value that represents the average size of the oldest bigeye observed in the size composition samples.

In the two previous stock assessments for bigeye (Aires-da-Silva and Maunder 2009; 2008), the length at age used in the assessment model was based on the von Bertalanffy growth curve. This was due mainly to a Richards function not being available yet in Stock Synthesis (Version 2). The parameters of the von Bertalanffy growth curve were estimated by obtaining the best correspondence of length at age used in previous assessments that used a Richards curve. The latest assessment (Aires-da-Silva and Maunder 2010) assumes the von Bertalanffy growth function as in the two previous assessments. However, a Richards growth curve is now available in Stock Synthesis (Version 3). Hence, a sensitivity analysis using the recently-implemented Richards growth function was made. This assumption improved the model fit to the data, particularly to the bigeye age at size (otolith readings) and the size composition data. As a result, the IATTC staff indicated that a Richards growth curve could potentially be assumed as the base case model in future assessments.

Sensitivity analyses were conducted to investigate the differences in results obtained when using the von Bertalanffy and the Richards growth curves and the values of the mean lengths of the plus group (see Document BET-01-03 for details). In short, the stock assessment model is very sensitive to the model assumptions about the average size of the older bigeye tuna because the model is fit to length-composition data. If the older individuals are assumed to be too small, then the model predicts that few live to the large sizes seen in the length-composition data and the exploitation rate is estimated to be low. If the older individuals are assumed to be exceedingly large, then the model predicts that too many live to sizes larger than the sizes seen in the length composition data and the exploitation rate is estimated to be high. A similar effect also occurs for the estimates of variation of length at age, which is also an important component of growth estimation. The management quantities were highly sensitive to the assumed value of the mean length of the plus group. In general, the results were more optimistic (less depleted and lower fishing mortality) when the mean length of the plus group was assumed to be lower.

In order to improve the growth estimates, an analysis was conducted to combine the age-length data with the tagging growth increment data by using the information on larger individuals from the tagging growth increment data. Due to the difference between stochastic age-length models and growth increment models, the ages at release in the tag increment component of the model were treated as random effects. The model also included a sub-model to model shrinkage in the tagging growth increment data. The new estimates of growth continue to be problematic, with the length of old individuals estimated to be unrealistically high. This is probably due to the lack of data for old individuals and the data for small individuals overpowering the functional form. A better way of weighting individual data points is needed to allow the older individuals to have more influence on the growth curve.

The variation of length at age can be just as influential as the mean length at age. The age-length data also provide information about the mean length at age. Unfortunately, the age-length data were not collected randomly. They were collected to cover a range of sizes to provide information on mean size at age. Therefore, these data do not provide a good measure of variation of length at age. In a previous assessment using A-SCALA, conditional probability was used to apply an appropriate likelihood to the data and estimate variation of length at age. This measure of variation of length at age is used in the current assessment. It is a linear function of mean length at age.

3. CATCH-PER-UNIT-OF-EFFORT

Catch per unit of effort (CPUE) are the only data available to create indices of abundance for bigeye tuna in the EPO. There are no surveys conducted on abundance of tuna in the EPO. CPUE data are available from both the longline and purse-seine fisheries. The longline CPUE data provides information on large bigeye while the purse seine CPUE data provides information on small bigeye. Therefore, it is informative to have CPUE data from both types of fisheries. The CPUE from the purse-seine fisheries are considered to provide less reliable indices of abundance due to the targeting of tuna aggregations. The weighting of the CPUE data is determined by estimating an additive constant on the standard deviation of the likelihood for each fishery. Some purse-seine fisheries CPUE are not used in the model (early floating object, inshore floating object, and early and late dolphin/unassociated fisheries), mainly because the effort is low or because the CPUE is too variable.

Purse-seine CPUE is calculated as catch divided by the number of days fished. Days fished are assumed to be a better measure of effort than the number of sets because it relates to search time. However, floating objects have locator technology and success is more related to the number of fish under a FAD that is checked than the ability to find FADs. Because vessels can make different types of sets (floating object, dolphin associated, free-swimming school) in a trip, the amount of time spent fishing using a particular fishing type is unknown. The number of days fished by set type is calculated by regressing total days fished versus number of sets for the three set types. The estimated coefficients are the number of days fished corresponding to a single set of each set type. These can then be multiplied by the number of sets by set type to estimate the number of days fished by set type.

The longline CPUE data are standardized, using a delta-lognormal general linear model in which the explanatory variables are latitude, longitude, and hooks per basket. Only Japanese longline data are used in these analyses because the detailed data from the Japanese fleet covers a greater number of years. The fishing depth of the longline gear has changed over time as the fishery has targeted bigeye tuna. The fishing depth of the gear is related to the number of hooks per basket. The more hooks the deeper the gear fishes. This change in depth has made bigeye more vulnerable to the longline fishery and therefore hooks per basket has been used in the general linear model standardization. Several other methods have also been used to standardize the longline CPUE including regression trees (Watters and Deriso 2000), neural networks (Maunder and Hinton 2006) and the statistical habitat-based standardization model (Langley et al. 2005; Maunder et al. 2006). These models link the depth fished with the environmental data at that depth and the environmental preference of bigeye tuna. In general, the different methods used to standardize the CPUE do not have a large influence on the estimated abundance indices. Analyses in the western central Pacific Ocean (WCPO) have shown that inclusion of latitude and longitude eliminate the need for a habitat effect in the satHBS, indicating that latitude and longitude could be a proxy for habitat and that the habitat is reasonably constant over time.

A sensitivity analysis was made in which the only CPUE data used in the stock assessment model was from the southern longline fishery (south of 15°N, Figure 1). The results differ moderately from the base case. In particular, the current spawning biomass is estimated to be above the level that supports MSY. A sensitivity analysis, using iterative reweighting, was conducted to investigate the weighting of the data sets. Specifically, the appropriate standard deviations and sample sizes for the likelihood functions were determined iteratively, based on the fit to the data. When iterative reweighting was applied, more weight was given to the length-composition data and the fit to the southern longline CPUE data was poor. The population was estimated to be much more depleted than the base case.

The bigeye tuna assessment assumes that catchability is constant over time. Any trends in catchability are somewhat absorbed in the estimate of the standard deviation of the likelihood function. Previous analyses have looked at trends in catchability of the purse-seine fisheries, while assuming that longline catchability has remained constant. Recent analyses by scientists at the Secretariat of the Pacific Community (SPC) (Hoyle 2009) indicate that the longline catchability has been increasing (the fishing vessels are getting more efficient) over time (about 0.4-1.0% per year). The increase in catchability was determined by looking at the increase in vessel effects of new vessels entering the fishery. We ran a sensitivity analysis where catchability increased by 1% per year. The fit to the data was worse than the base case. The results are similar to the base case except that the current biomass is more depleted.

The spatially-structured bigeye assessment in the WCPO assumes that catchability and selectivity is the same for each area. This provides information on the relative abundance among areas. Weighting factors that modify the catchability are calculated based on summation of the latitude-longitude interaction term for an area. In the EPO assessment, the catchability for the northern and southern longline fisheries are estimated as separate parameters.

4. RECRUITMENT

The average level of recruitment, the relationship between recruitment and spawners, and the temporal variability in recruitment are important determinants of yield and stock status. There are several notable characteristics of the time series of estimated recruitment for bigeye tuna. First, the estimates prior to 1995 are lower, more uncertain, and less variable. The high uncertainty and low variability are due to the lack of length-composition data for small individuals prior to 1995. This is because the floating-object fishery was relatively small and restricted to the inshore area, so only one floating object-fishery was modeled. As the floating-object fishery expanded, more data have become available and the estimates have become more precise and the variability in recruitment is no longer spread out over multiple years. The increase in average recruitment after 1995 may be an artifact of the modeling due to the expansion of the floating-object fishery.

There are at least two competing hypotheses for the change in average recruitment in 1995: 1) there was a regime shift in the factors influencing recruitment and 2) the change is a model artifact due to the increase in catch of small individuals by the purse-seine fishery. Another, somewhat less obvious, possibility is a model artifact due to the reduction in longline effort since the early 1990s. It is important to determine the cause of the change in recruitment levels because the underlying reason may influence the assumptions made when calculating management quantities. Since the estimated average recruitment changes over time, the time period used to define average recruitment influences the management quantities. Maximum sustainable yield (MSY), biomass in the absence of fishing (B_0), and biomass corresponding to MSY (B_{MSY}) are all dependent on the average recruitment. Currently, average recruitment used in calculating these quantities is defined over the whole modeling period (1975 to present) because the calculations are based on the Beverton-Holt stock-recruitment relationship with a steepness of one (*i.e.* average recruitment equals virgin recruitment). If data for the period after 1995 is used to estimate average recruitment, MSY, B_{MSY}, and B_0 will be higher. The current fishing mortality and the fishing mortality corresponding to MSY will not be affected. Recruitment used in projections will also be higher. This means that the possible yields will be higher, projections will be more optimistic for the same catch levels, but the current population will be estimated to be more depleted with respect to B_{MSY} and B_0.

Several sensitivity analyses have been conducted to investigate the possibility that the increased recruitment is an artifact of assumptions used in the assessment model (see details in Document BET-01-05). It has been suggested that the increased recruitment is an artifact of the natural mortality of small individuals being too low in the model, so that in the early years the individuals that reach the longline fisheries represent a greater number of recruits that died due to natural mortality. Sensitivity analysis of natural mortality for young individuals has little influence on the relative estimates of recruitment between the two time periods. However, assuming that natural mortality is greater for older individuals (mature individuals) raises the average recruitment for the early years relative to the later years. This may be a consequence of the reduction in catch in the longline fisheries. However, to make the average recruitment equal for the two periods requires an unrealistic increase in natural mortality.

The increase in recruitment may be due to the expansion in the area fished by the floating-object fishery or some other aspect of the spatial structure of the fishery or population. Sensitivity analyses that modeled sub-areas as independent populations reduced the change in recruitment in some areas, but not others. The change in recruitment was greater in the areas in which the increase in floating-object fishing was the greatest.

One possibility to avoid the potential bias indicated by the change in recruitment is to start the model in 1995 after the change in recruitment and the expansion of the floating-object fishery occurred. Starting the model at a later date causes loss of information, but this loss may be minimal compared to the bias. On one hand there are much fewer length-composition and CPUE data from the purse-seine fisheries before 1995, so the loss is not so great. On the other hand, the population is estimated to have declined starting in 1990, so that some contrast in the biomass level would be lost.

The steepness of the stock-recruitment relationship can have a large impact on the estimated management quantities (*e.g.* B/B_{MSY} and the fishing mortality relative to the fishing mortality that supports MSY (F/F_{MSY})), but the impacts on the absolute estimates or trends in recruitment and biomass are generally much less. The maximum likelihood estimate (MLE) of steepness is 1.0, indicating that recruitment is independent of stock size. However, simulation analysis of generic stocks and of actual stocks indicate that steepness is difficult to estimate, and frequently the estimate is 1.0 even when the true value is much less. Simulation analysis also shows that in terms of maximizing yield, it is better to underestimate steepness than to overestimate it. This is because the yield curve is flat when steepness is high, so underexploiting the stock will have only a small influence on yield, while the yield curve is more domed when steepness is low.

5. SIZE-COMPOSITION RESIDUALS

There is a distinct pattern in the longline length-composition residuals that indicates a miss-specification in the model. In the southern longline fishery the model predicts more small individuals than observed prior to 1990 and more large individuals post 1990. This change in residual pattern occurs a few years before the floating-object fishery fully expanded. However, it does relate to a period where the fishing depth of the hooks in the longline fishery (based on hooks between floats) changed more than in other time periods. The CPUE data are standardized for hooks between floats, but length-composition data are not.

The residual pattern could be a consequence of spatial structure in the longline fishery and a change in the distribution of effort among the different areas. A sensitivity analysis was conducted that separated the longline fishery into more fisheries based on spatial structure (see details in Document BET-01-06). This analysis found a reduced residual pattern in some areas, but it remained in others.

One way of dealing with the residual pattern is to assume that the selectivity and catchability changed for some unknown reason in 1990 and incorporate that into the model. A sensitivity analysis using this assumption eliminated the residual pattern. However, making this assumption breaks the link between the two periods in the CPUE (and length-composition) data and will cause a loss in information. Alternatively, a covariate (*e.g.* hooks between floats) could be used as a covariate for selectivity, which would essentially standardize the length-composition data in a manner similar to how the CPUE data are standardized for hooks between floats. Starting the model in the mid-1990s would also eliminate the residual problem, while avoiding the issues with the change in recruitment.

6. HOW TO USE THE TAGGING DATA IN THE STOCK ASSESSMENT

The IATTC has collected tagging data for bigeye tuna over the last decade, and information from these data could be used in or to provide information for the stock assessment model. Both conventional and archival tag data have been collected. Currently, the tagging data are analyzed outside the stock assessment model. The information is used to look at horizontal and vertical movements, behavior, habitat utilization, and growth, among other things. None of this has been used in the assessment yet. The tag growth increment data can be used to help estimate growth as discussed above. The behavior and habitat information can be used in the standardization of purse-seine and longline CPUE. The tagging data could be integrated into the stock assessment model to provide information on movement and mortality, as has been done for bigeye in the WCPO. However, the tag releases are mostly from the core area of the purse-seine fishery, and movement away from this area has been limited. Recent and future tagging covers a wider spatial range and as these data become available it can also be used in the assessments.

Use of the tagging data in the assessment model to estimate movement and/or mortality is problematic due to the limited spatial range of releases. Two possible methods to use the data despite this issue are 1) develop an assessment based on the area in which the tagged fish were released and 2) take the estimates of dispersion from the tagging data and use that to estimate the movement among areas. The former approach is similar to that used in the WCPO, except that only a single isolated population in the central area would be modeled. Recoveries outside the area could be included in the area with the assumption that fishing mortality outside the area is similar to fishing mortality inside the area. This approach would not be using information on movement. The latter approach would use only information on movement, and assumes that movement is only through diffusion and that the diffusion process is the same in each area. The movement across area boundaries would have to take into consideration the spatial distribution of individuals within an area (*e.g.* by using fine-scale CPUE) so that low density areas away from boundaries do not have more influence on the movement estimates than they should.

7. OTHER TOPICS

7.1. Reference points

The mandate of the IATTC is to keep the stock size at a level that will support MSY. This implies that the biomass will be at or above B_{MSY}. It also implies that the fishing mortality will generally need to be at or below F_{MSY}. Therefore, we report assessment results relative to B_{MSY}, spawning biomass that corresponds to MSY (S_{MSY}), and fishing mortality corresponding to F_{MSY}. Since there are multiple gears and there is no real fully-selected age, we do not report F_{MSY}, but the amount that current F (the average over the most recent three years) needs to be scaled to obtain F_{MSY}. The existence of multiple gears adds the complexity that the reference points depend on the age-specific F, and this changes as allocation of effort among the gears changes.

The reference point S_{MSY}/S_0 = 0.19 is low compared to what would be expected for a similar stock. This is partly due to the assumption that recruitment is independent of stock size and that a large proportion of the catch is young fish. The biological characteristics growth, natural mortality, and maturity may also play a role. If the steepness of the stock-recruitment relationship is fixed at 0.75, S_{MSY}/S_0 increases to 0.29. It is not clear if the 0.19 value should continue to be used or if some other proxy should be used (see the section above on the stock-recruitment relationship).

7.2. Age- and sex-specific natural mortality

Natural mortality is one of the most influential parameters in fisheries stock assessment models. Unfortunately, it is also one of the most uncertain. Typically, natural mortality is assumed to be a single constant, but in reality it can differ with age, time, sex, or other characteristics. In the bigeye tuna assessment an age- and sex-specific natural mortality schedule is used. The natural mortality schedule is based partly on assumptions and partly on data. It is assumed that there is a linear decline in natural mortality from a high level at age 0 to a lower level at the age of 5 quarters. Natural mortality is then constant until maturity. At maturity, female natural mortality increases. Because not all females are mature at a given age, the natural mortality is a weighted average of the natural mortality for mature females and the natural mortality of immature females. Natural mortality for males is assumed to not change when they become mature. These assumptions are used to build a model for natural mortality, which is then fit to sex ratio data and estimates of natural mortality from tagging data in the WCPO.

Maunder *et al.* (2010) applied a cohort analysis, using the above assumptions and data to tagging data in an attempt to improve the estimates of natural mortality. The estimates of natural mortality were consistent with those currently used in the assessment, but the estimates were very imprecise due to uncertainty in reporting rates, lack of large fish tagged, and low mixing between the floating-object fishery and the longline fishery.

The value of natural mortality for the size of fish caught in the fishery has a substantial affect on the estimates of absolute abundance and management quantities. Several sensitivity analyses have been conducted.

7.3. Selectivity

Selectivity is assumed to be asymptotic for the southern longline fishery and is allowed to be dome shaped for the other fisheries, except for the discard fisheries. The selectivities for the discard fisheries that catch small fish are fixed. The selectivities are assumed to remain constant over time, except as defined as separate fisheries that are broken up by time (the early floating-object fishery and the other purse-seine fisheries).

There is substantial amount of temporal and spatial variability in the length-composition data, especially for those of the purse-seine fisheries. This may indicate that the assessment model should allow for additional temporal variability in selectivity so that the correct-sized fish are removed from the fishery and that the purse-seine length composition data has less influence of the assessment results.

The double-normal selectivity function implemented in stock synthesis is used to implement the dome-shaped selectivity. The selectivities for the smallest bigeye are fixed at zero. The selectivities for the largest bigeye are set at zero for the floating object fisheries and estimated (using the -999 option) for the other fisheries.

7.4. Environmental covariates

Environmental covariates have been used to the bigeye stock assessment to help estimate and predict recruitment. In some years the covariates have been significant, and in other years they have not. Poor estimates of recruitment before 1995 and the shift in average recruitment may make correlations difficult to detect. Covariates could be used to model other processes, such as catchability, selectivity, and growth.

7.5. Methods used to create the length-composition data

Length-composition data are a major component of the bigeye tuna stock assessment. The data are aggregated by area into the fisheries defined for the assessment. The purse-seine catch is sampled by well. Each well could be assumed to be an independent sample of the length composition for the respective fishery. Alternatively, the samples could be weighted by the bigeye in a well, the catch in a trip, and/or the catch in a length-composition measurement area stratum. The sampling design is based on length-composition sampling areas developed for yellowfin tuna, which may not be reasonable for bigeye tuna. The sample size for the purse-seine length-composition data is the number of wells sampled. This tends to be lower than indicated by the model fit to the data. A bootstrap procedure could be used to investigate the (relative) variance that should be used in the likelihood functions.

7.6. Inclusion of age conditioned on length data

Limited age data are available for bigeye tuna in the EPO. These data were not collected randomly, and were collected to provide information on a wide range of ages. The data are used to calculate the growth parameters that are used in the stock assessment model. Stock synthesis has the capability to include age conditioned on length data. The age data could be included in the model to provide information on mean length at age and on the variation of length at age.

7.7. Catch data

The catch data for bigeye tuna in the EPO may be inaccurate due to unreported or misreported catch. Misidentifying or misreporting bigeye as yellowfin, or even skipjack, tuna does occur. The IATTC conducts species-composition sampling to determine species composition of the catch. The historical catch is adjusted, based on these ratios. It is unlikely that the early catches of bigeye tuna were large, given that the effort of purse seines associated with floating objects was low.

There are several longline fleets throughout Central and South America that may not report their catches of bigeye tuna. Even though these fleets consist of relatively small capacities in comparison to distant-water longline vessels, the number of vessels could be considerable and the catches large.

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OTHER RELEVANT INFORMATION

IATTC October Stock Assessment Methodology Workshops
http://www.fisheriesstockassessment.com/TikiWiki/tiki-index.php?page=IATTC+October+Stock+Assessment+Methodology+Workshops

A comprehensive list of references relevant to bigeye tuna
http://www.fisheriesstockassessment.com/TikiWiki/tiki-index.php?page=Bigeye+review+2010+papers

DRAFT

Appendix A: Sensitivity analyses carried out in previous EPO bigeye tuna stock assessments

Sensitivity analysis type	MSY	C_{recent}/MSY	B_{recent}/B_{MSY}	S_{recent}/S_{MSY}	$F_{multiplier}$
Watters and Maunder (2001) - SAR1 2001, assessment year 1999					
BC	73,177	1.07	2.11	2.29	1.6
M constant at 0.1	57,079	1.32	1.36	1.54	0.92
Watters and Maunder (2002) – SAR2 2002, assessment year 2000					
BC - env r, env q (F3), fixed growth	64,727	1.89	1.11	1.83	0.9
no env r, est growth	84,559	NA	NA	NA	1.65
env r, est growth	61,373	NA	NA	NA	1.01
env r, env q (all F), est growth	60,646	NA	NA	NA	0.98
env r, env q (F3), est growth	60,430	NA	NA	NA	0.95
alternative catch	66,135	NA	NA	NA	0.88
steepness increased	68,603	NA	NA	NA	1.15
Mdecreased	71,353	NA	NA	NA	0.39
Mincreased	91,598	NA	NA	NA	2.09
Maunder and Harley (2002) - SAR3 2002, assessment year 2001					
BC (h=0.1)	70,061	1.11	1.1	0.74	1.85
h=0.75	61,780	1.26	1.01	0.67	0.97
h=1, Korean catch species composition method	59,462[2]	1.31	1.23	0.93	0.99
Harley and Maunder (2004) - SAR4 2004, assessment year 2002					
BC (h=0.1)	67,948	1.40	0.75	1.49	0.79
h=0.75	65,882	1.45	0.56	0.86	0.53
PS catch cannery est	63,256	1.14	0.93	1.66	0.88
Korean LL catch SPC	78,895	1.32	1.21	2.45	1.08
Habitat std CPUE	68,246	1.41	1.04	2.11	0.94
Iterative reweight	65,393	1.46	0.45	0.66	0.54
Harley and Maunder (2005) - SAR5 2005, assessment year 2003					
BC (h=0.1)	77,747	1.26	0.57	0.68	0.62
h=0.75	62,849	1.56	0.42	0.43	0.38
PS catch unloadings data	76,113	1.16	0.77	0.80	0.80
M juveniles increased	69,910	1.41	0.69	0.80	0.65
Maunder and Hoyle (2006) - SAR6 2006, assessment year 2004					
BC (h=0.1)	95,572	1.05	0.76	0.59	0.57
h=0.75	91,270	1.13	0.54	0.41	0.41
Maunder and Hoyle (2007) - SAR7 2007, assessment year 2005					
BC (h=0.1)	106,722	1.00	1.10	0.88	0.68
h=0.75	102,263	1.06	0.78	0.61	0.51
Linf=171.5 cm	140,329	0.77	1.74	1.68	1.44
Linf=201.5 cm	107,812	0.99	0.78	0.53	0.41
TWN LF	107,973	1.00	1.09	0.87	0.65
Aires-da-Silva and Maunder (2007) - SAR8 2007, assessment year 2006					
BC (h=0.1)	92,758	1.10	1.08	0.90	0.77
h=0.75	88,391	1.16	0.76	0.61	0.55
CPUE9 only	92,059	1.14	0.61	0.50	0.61
Growth est	99,839	1.02	1.36	1.19	0.98
Linf=171.5 cm	117,348	0.87	1.71	1.58	1.34
Linf=201.5 cm	89,234	1.13	0.83	0.60	0.57

[2] Results not reported in report

Fit eq. C	93,557	1.10	1.19	1.03	0.85
Iterative reweight	83,795	1.16	0.53	0.26	0.42
Time blocks	97,992	0.76	1.00	0.82	1.11
Time blocks - iterative reweight	82,122	0.85	0.77	0.43	1.14
JPN new data	94,215	1.40	1.14	0.97	0.77
Aires-da-Silva and Maunder (2009) - SAR9 2009 assessment year 2007					
BC (h=0.1)	81,350	1.08	1.15	0.90	0.82
h=0.75	78,150	1.12	0.74	0.56	0.57
CPUE9 only	85,005	1.03	1.23	0.90	0.85
Time blocks OBJ	79,654	1.18	1.12	0.89	0.81
Aires-da-Silva and Maunder (2010) - SAR10 2010, assessment year 2008					
BC (h=0.1)	83,615	1.19	0.99	0.89	0.81
h=0.75	81,482	1.22	0.62	0.52	0.54
Growth Richards	79,122	1.26	0.91	0.80	0.73
add WCPO regions - fitted	119,638	1.38	0.73	0.53	0.59
add WCPO regions - not fitted, shared sel.	124,002	1.29	0.95	0.86	0.79