INTER-AMERICAN TROPICAL TUNA COMMISSION

9TH STOCK ASSESSMENT REVIEW MEETING

LA JOLLA, CALIFORNIA (USA)
12-16 MAY 2008

DOCUMENT SARM-9-INF-B

COMMENTS BY THE IATTC STAFF ON DOCUMENT SARM-9-11d

1. INTRODUCTION

In a paper submitted for this meeting, *An overview of 10 years of IATTC bigeye stock assessments in the Eastern Pacific Ocean* (Document SARM-9-11d), Alain Fonteneau and Javier Ariz examined and discussed the bigeye stock assessment results obtained by the IATTC since 2000. Their conclusion was that there was a large variability, uncertainties and potential bias in these past results, and that these basic problems were seldom or never discussed in the yearly assessment reports. They tried to identify the potential causes that could explain these often wide uncertainties, and discussed a combination of statistical, biological and modelling uncertainties. In their conclusions, they made a series of research recommendations that, in their opinion, would improve the future quality of the bigeye stock assessment in the EPO.

The IATTC scientific staff disagrees with many of these conclusions and recommendations, and in this document explain the reasons for their disagreement, point by point. Text in *italics* is extracted from the paper by Fonteneau and Ariz.

2. RECOMMENDATIONS BY FONTENEAU AND ARIZ

2.1. Section 4-2-1: Natural mortality at age and longevity

a. "*Our feeling is that the constant M hypothesis used in the 2000 and 2007 assessments should never be used for bigeye, as it is totally unrealistic and against all biological laws (Beverton and Holt 1957, Ricker 1975, Peterson & Wrobleski 1984, McGurk 1986, Finch 1990), and against all the tagging results (Hampton 2000) to assume that natural mortality is the same for a 2.5 kg and for a 50 kg bigeye.*"

We agree with this point, but, as we pointed out at the meeting of the Working Group on Stock Assessment in 2007, the Stock Synthesis II (SS2) software package, which we used for the first time for the 2006 assessment, did not allow for a higher natural mortality (*M*) at the younger ages. The software has subsequently been improved, and now allows for a more realistic pattern of *M* for the younger ages, and we are using that in our current assessment. It should be noted that IATTC Stock Assessment Reports 2 through 7, presented at the annual stock assessment meetings held during 2001-2006, all use an age-specific natural mortality vector that incorporates a higher *M* for young bigeye.

b. "*It is possible that these biological uncertainties on natural mortality and longevity did produce significant errors in past/present bigeye stock assessments and further investigation should be developed in this field by the IATTC in order to reduce this uncertainty, for instance tagging large numbers of small yellowfin and bigeye in the central Pacific FAD areas.*"

We are currently analyzing our bigeye tagging data to see if it can improve our estimates of natural mortality rates. The SS2 software has been improved, and we plan to incorporate tagging data in next year's assessment.

c. "*These major uncertainties concerning the level and pattern of the natural mortality as a function of age should at least be fully explored in the basic IATTC stock assessment, and the ICCAT hypothesis should at least be envisaged having similar levels of juvenile M for yellowfin and bigeye for small* *sizes (i.e. at sizes <70 cm?)* ”

We will continue to analyze the first point mentioned in (c) above. In particular, we plan to analyze tagging data for bigeye tagged since 2000. There are now enough years of tag return data to begin a preliminary analysis, although we expect the results of that analysis to be revised as more returns are obtained from those tagged cohorts.

We disagree with the premise of the second point, as explained in Section 3.6. Previous IATTC assessments of bigeye have investigated the sensitivity of results to assumptions about age-specific *M*. IATTC Stock Assessment Report 1 (SAR-1) addressed age-specific *M* compared to a constant *M* for all ages, SAR-2 the overall level of *M*, and SAR-5 the *M* for young bigeye; additional sensitivity analyses are presented in Appendix B.

2.2. Section 4-2-3: Relative fecundity at size

a. Regarding maturity estimates from longline-caught bigeye: *“a major biological sampling effort, especially on longliners, should necessarily be conducted as soon as possible in order to reduce these uncertainties (this would be easy and inexpensive to do).”*

We believe our estimates of the maturity schedule are accurate, as discussed in Section 3.7. However, the sample sizes obtained from the longline fishery were small, and could be improved.

b. “*further biological research should be developed on the potential parental effect of bigeye tunas.*”

We have established a good understanding of the reproductive biology of bigeye tunas in the EPO, as discussed in Section 3.7. Further research is a low-priority item at present.

The IATTC staff is collaborating with the Secretariat of the Pacific Community (SPC) on a proposal requested by the Western and Central Pacific Fisheries Commission (WCPFC) for a regional, or possibly Pacific-wide, investigation of age-specific reproductive parameters for bigeye tuna, such as was recently completed for the EPO.

2.3. Section 4-2-5: Size of the spawning stock

a. Regarding the IATTC index of spawning biomass: *“This structural uncertainty should be at least better discussed and explained. Our recommendation is also that these results should always be given at the same scale, and preferably as absolute biomasses.”*

Presentation of an index does not alter any of our conclusions on stock status, because we follow standard practice for stock assessments and present conclusions based on a ratio of stock sizes, such as S_{MSY}/S_0. ‘Spawning biomass’ is a term that is sometimes used to refer, in general, to the reproductive capability of the stock. In some cases, the strict definition of spawning biomass, the weight of reproductively mature females, is not an appropriate measure of reproductive capability (*e.g.* the EPO yellowfin tuna assessment). We have used the term ‘spawning biomass’ to refer to the relative reproductive capability of the stock, but recently have used the term ‘index of spawning biomass’. In hindsight, a better term is needed to represent the relative reproductive capability of the stock, to avoid confusion and facilitate comparisons among assessments. For the bigeye assessment, our estimates of spawning biomass are the weighted sum of age-specific abundance with the weights equal to the product of age-specific average body weight and age-specific proportion of sexually mature females.

We agree that uncertainties need to be discussed and explained, and will endeavor to improve our presentation.

“Further biological research on bigeye spawning should be conducted, and especially on the size/age at 50% spawning.”

We believe that our estimates of size/age of 50% maturity are accurate (Section 3.7). Further research on bigeye spawning is currently a low-priority item.

2.4. Section 6: Conclusion

a. Regarding uncertainties and potential biases in IATTC stock assessment results: "*these major problems should be better identified, they should be fully recognized, and they should lead to large scale international research programs coordinated by the IATTC.*"

We have consistently evaluated the assessments for sources of uncertainty and bias, and will continue these evaluations.

b. *"The only way to solve these uncertainties would be to conduct a fully realistic large scale tagging programme, targeting a wide range of bigeye sizes, in the Northern and Equatorial areas, and especially in the areas West and East of the 150°W frontier, for instance between 120°W and 180°W, an emphasis being for instance be given to French Polynesia tagging), in order to evaluate the age specific transfer rates of bigeye as a function of age, around this administrative frontier. This large tagging program should be carried in parallel with an intensive biological research conducted on bigeye, and especially on adults, and preferably in conjunction with the same research conducted in the Central and Western Pacific."*

We have recommended a largescale tagging project in the past, and we continue to recommend it. We plan to continue biological research on bigeye.

RECOMMENDATIONS WITH WHICH THE IATTC STAFF AGREES

1. Higher natural mortality for young bigeye in our assessments; this is being done in our current assessment, and has been done in previous assessments except those completed in 2000 and 2007.
2. Improve estimates of age-specific natural mortality of bigeye by analyzing our tagging data and other information, and incorporate tagging data in future assessments.
3. Encourage scientists involved with longline fisheries to increase the sample sizes with regard to sex ratios and maturity.
4. Continue collaboration with the SPC on a proposal for a regional, or possibly Pacific-wide, investigation of age-specific reproductive parameters for bigeye tuna.
5. Recommend a large-scale tagging project, as proposed in the past.
6. Continue biological research on bigeye.
7. Continue to discuss uncertainties; we will endeavor to improve our presentation.

3. COMMENTS BY THE IATTC SCIENTIFIC STAFF

3.1. (Section 2.2.1: Increasing recruitments and increasing MSY?

"*The comparison between the main results of recent bigeye stock assessment analysis shows that the MSY has been widely and steadily increasing: from 60000 tons in 2000 to reach an average of 100000 t. tons during recent years (Figure 4a). The same observation can be done on the estimated biomass at MSY (Figure 4b)…*"

Since 2005 we have been using the bigeye growth curve based on the recent research in the EPO by Schaefer and Fuller (2006, IATTC Bulletin, Vol. 23, No. 2). As we showed in 2005, a consequence of this new growth curve was an increase in the estimated MSY and B_{MSY} (Figures 1 and 2, respectively). Another factor contributing to increases in the estimated MSY and B_{MSY} occurred when, beginning in 2004, several countries revised their recent longline catch reports to much higher levels, perhaps in response to IATTC Resolution C-04-09 on tuna conservation, which bases longline catch limits on 2001 catches).

MSY is a function of average recruitment. Historical recruitment is lower than recent recruitment; therefore, over time, the assessments include more years of higher recruitment in the average recruitment, and the MSY estimates increase correspondingly. MSY is now declining, as longline fishing effort continues to decrease while purse-seine effort on FADs continues to increase. As shown in all our assessments, MSY is a function of the mix of gear types, with the MSY for an all-longline fishery roughly twice that for an all-purse seine fishery.

If the low historical levels of recruitment are an artifact of the assessment, or the high recent recruitments are due to a regime shift, it may be appropriate to use only recent recruitments when estimating MSY. A sensitivity analysis of the management quantities derived from the current assessment to using only the recent recruitments when estimating MSY is presented in Appendix A. The results in Appendix A show that if we use only recent recruitments to calculate management benchmarks, then the estimates of MSY, B_{MSY}, S_{MSY}, S_0, and B_0 are increased relative to the base case. Also, the increase in S_0 causes the S_{recent}/S_0 ratio to decrease, implying a more depleted spawning biomass compared to the base case. The $F_{multiplier}$ is not affected.

Figure 3 shows that the exploitation rate (MSY/B_{MSY}) is less sensitive than either estimated MSY or B_{MSY} to the change in growth rate used for the assessment.

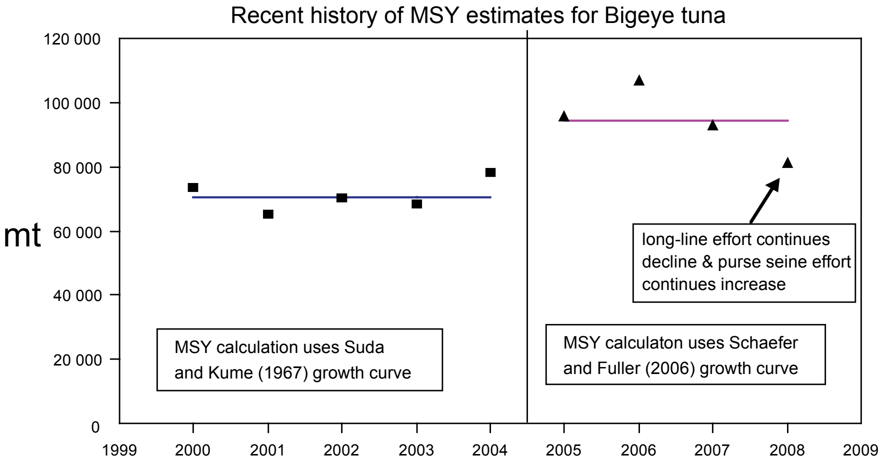


FIGURE 1. Recent history of MSY estimates for bigeye tuna.

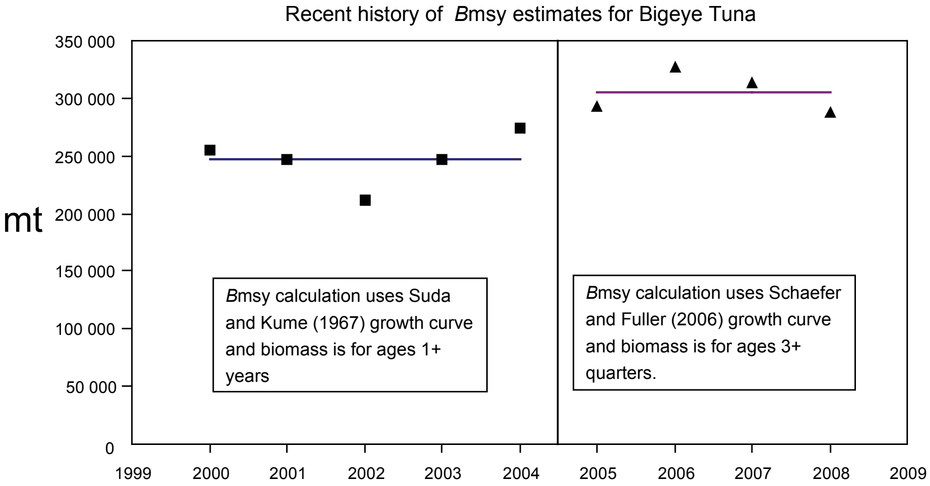


FIGURE 2. Recent history of B_{MSY} estimates for bigeye tuna.

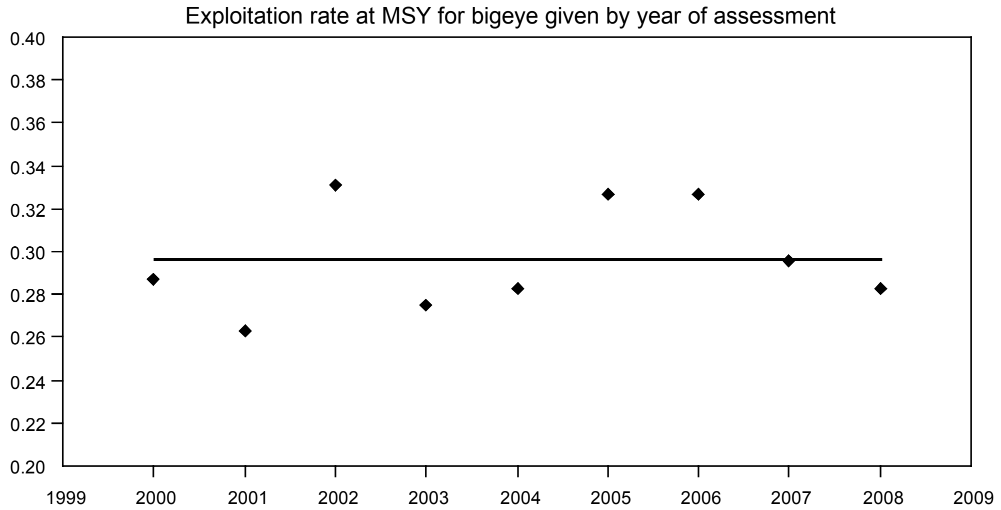


FIGURE 3. Exploitation rate of bigeye tuna at MSY, by year of assessment.

3.2. Section 2.2.1: Increasing recruitments and increasing MSY?

"the apparent trend of the estimated recruitments…"

The increase in estimates of recruitment appears to be a two-stage phenomenon, with generally lower estimates for 1975-1993, prior to the expansion of the FAD fishery into the region west of the Galapagos Islands (Figure 4).

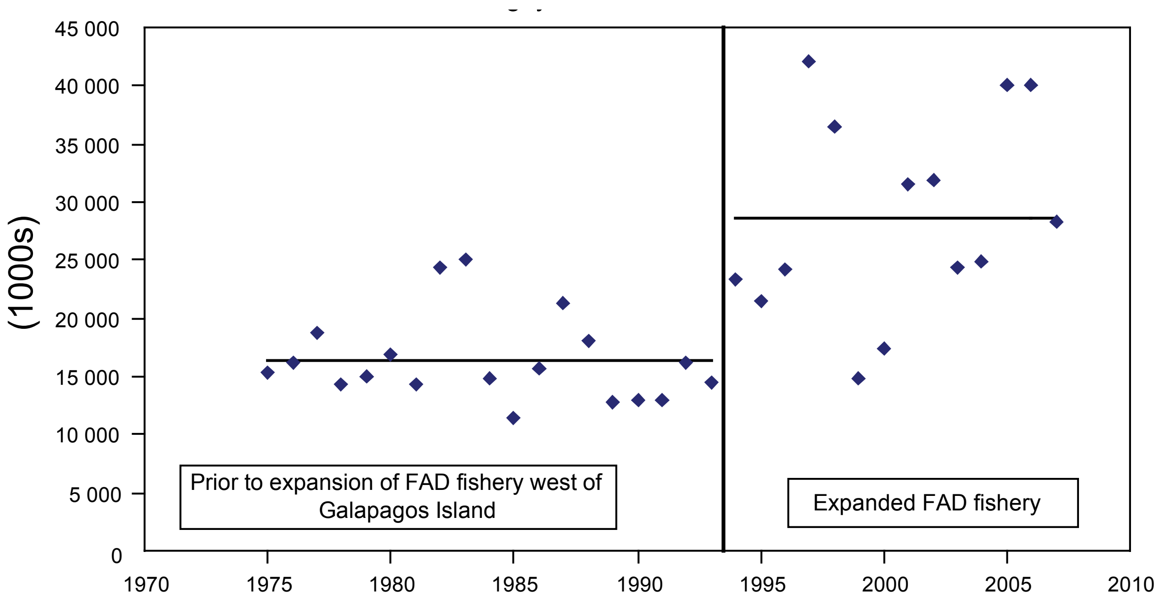
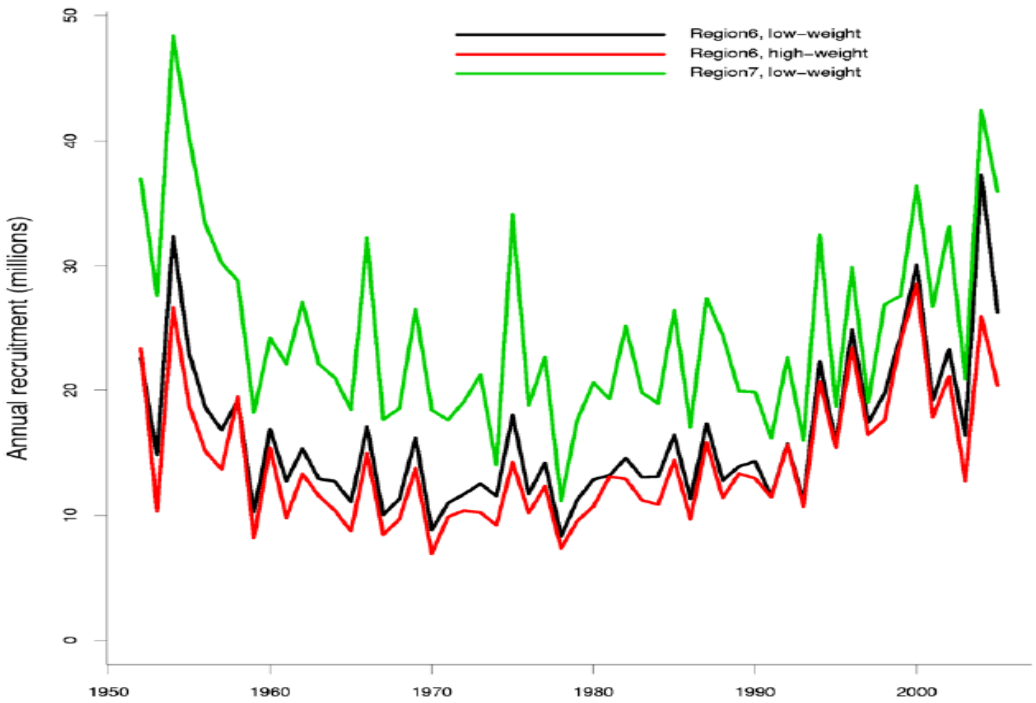


FIGURE 4. Recruitment of bigeye tuna in the EPO, 1975-2007

There are several hypotheses to account for the different levels of recruitment estimates, and many are touched upon by Fonteneau and Ariz. Some of these hypotheses are:

1. **Regime shift.** The increase in recent recruitment estimates was also seen in assessments by the SPC for the Western Pacific, in both of their six-region assessment models and, to a lesser extent, in the seven-region assessment model; the latter was considered preliminary and less reliable (Assessment Report WCPFC-SC2-2006/SA WP-2; figure below). The recruitment estimates for the 1950s were also higher. According to Adam Langley of the SPC (pers. comm.), "The high

recruitment in the early period is the model's attempt to explain the very sharp declines in longline CPUE in the early period while catches were low. So the model puts in really high recruitment early on and then recruitment declines to explain the reduction in CPUE. The whole debate [was] about whether these early CPUEs are really representative of changes in abundance at the regional level." Very high CPUEs during the first few years of a longline fishery are an almost universal phenomenon, and fishery scientists generally agree that these CPUEs are not realistic indicators of abundance of the fish. Accordingly, we think that those early recruitment estimates are too high.



Estimated annual recruitment (millions of fish) for the WCPO obtained from the three different model options (from SPC assessment report WCPFC-SC2-2006/SA WP-2)

2. **Underrepresentation of catch**. As discussed in (4) below, underestimation of purse-seine catches of bigeye is not a likely explanation. Longline catches could be both underestimated and overestimated, particularly in recent years when several countries revised their recent longline catch reports to much higher levels, but this is probably not sufficient to explain the change in recruitment estimates.

3. **Underestimation of natural mortality**. A possible explanation of the lower recruitment estimates is that M is grossly underestimated in our assessments of bigeye tuna less than 70 to 90 cm in length. However, as shown by Fonteneau *et al.* (2005, ICCAT Collected Volume of Scientific Papers, Vol. 57, No. 2) the age-specific natural mortality estimates used in our assessments are consistent with those used for bigeye both by ICCAT for the Atlantic and by SPC for the western Pacific. The more recent stock assessments of the IOTC, ICCAT, and SPC all use estimates of natural mortality at age that are similar to each other, but sufficiently different from ours to induce us to perform some sensitivity studies of the alternatives (Appendix B).

   Appendix B shows the results of the sensitivity analysis to different assumptions about natural mortality.

   The management quantities showed little sensitivity when higher levels of M were assumed for young fish 0-5 quarters of age (sensitivity 3, Figure B.1). Specifically, the $F_{multiplier}$ estimates are all below 1 (overfished status) for all reference points considered (Figure B.3a). In contrast, the management quantities showed higher sensitivity to the assumption made about the oldest of the young ages included in the early higher levels of M (sensitivities 1-2 and 4-5; Figure B.1).

The $F_{multiplier}$ was greater than 1 (stock underfished) for 9 out of 24 cases (37%) of the analyses of the sensitivity to the M assumptions made for the young fish. The more optimistic evaluations ($F_{multiplier} > 1$; sensitivities 1-2 and 4-5) all assumed high levels of M that are unrealistic for bigeye 5-12 quarters old (80-110 cm; Schaefer and Fuller 2006). Furthermore, they do not consider that a stock-recruitment relationship could exist. The exception is sensitivity 5 with an $F_{multiplier}$ of 1.0 for a S-R hypothesis. This M curve, however, is unrealistic.

In general, our stock evaluation results showed low sensitivity to assuming the M curves used in the most recent bigeye stock assessments by other RFMOs (Table B.1b). The exception is a curve used as a sensitivity analysis in the IOTC assessments (IOTC-2006-WPTT-R[EN], Report of the eighth session of the IOTC working party on tropical tunas). In this case, $F_{multiplier}$ is estimated to be at 1.2 and 1.0 for the MSY and 20% S_0 reference points, respectively. However, if we take the same IOTC reference points (S_{MSY}/S_0=0.31-0.47), $F_{multiplier}$ is at a much lower level (0.80).

A higher estimate of the $F_{multiplier}$ (0.96) was obtained when we assumed the ICCAT natural mortality curve (ICCAT 2007. Report of the 2007 ICCAT bigeye tuna stock assessment session). This is a result of the higher M values assumed for young fish up to 8 quarters of age (Figure B.2). However, the S_{MSY}/S_0 reference point for ICCAT ranges between 0.3 and 0.4. If a 0.3 reference point is assumed, $F_{multiplier}$ is at 0.6 for the ICCAT scenario.

Except for sensitivity 3, the recruitment estimates for the period prior to 1994 are increased for all sensitivity analyses in comparison to the recruitment estimates for the 1994-2007 period (Table B.1).

4. **Underexploitation of the bigeye stock in the EPO by the longline fishery.** This hypothesis postulates that the expansion of the purse-seine fishery on FADs exploits a component of the bigeye stock that historically was not fully exploited by the longline fishery. That hypothesis is supported by the incomplete spatial coverage of the longline fishery (Figure 5).
5. **Emigration.** Large emigrations of bigeye tuna from the FAD fishery area into the central or western Pacific could account for the lower historical recruitment estimates. Our tagging data does not support such a hypothesis, as elaborated in Section 3.5. Also, if large quantities of bigeye emigrated from the EPO prior to 1993, then we would expect to see large recruitments estimated for the western Pacific during those years; however, as discussed above, that was not the case.

3.3. Section 2-2-2: Variability in the status of the most recent years

"*In this context it is very simple and it should be of prime interest, to do a retrospective analyses of the validity of these "last years diagnosis", simply comparing their relative position in their initial position of "last years", and the position of the same year, but 1 year and 2 years after (these revised estimates being much more realistic, at least if the stock assessment is consistent).*"

To evaluate retrospective trends in recent abundance estimates, we choose years so as to avoid mixing estimates across years when a major revision of our assessment methods took place. The last major change occurred in 2005, when we began using the bigeye growth curves of Schaefer and Fuller (Section 3.1) in our assessments (Stock Assessment Report 6). That Report included a list of nine important changes, so we now restrict our comparisons to the four most recent years (2005-2008).

The point estimates from these four years were graphed to see how they compare to the results presented by Fonteneau and Ariz. In contrast to their results, they do not show any clear retrospective pattern (Figure 6). There is substantial uncertainty in our estimates of biomass of bigeye 3+quarters of age. The confidence intervals for the estimates of spawning biomass (Figure 7) illustrate the large uncertainty in these estimates, which extends all the way through the historical estimates, due to parameter uncertainty.

Standard retrospective analyses using the current assessment, which involve only eliminating data and do not include changes in assumptions, show what appears to be a minor retrospective pattern (Figure 8), but one in which the most recent estimates have decreased.

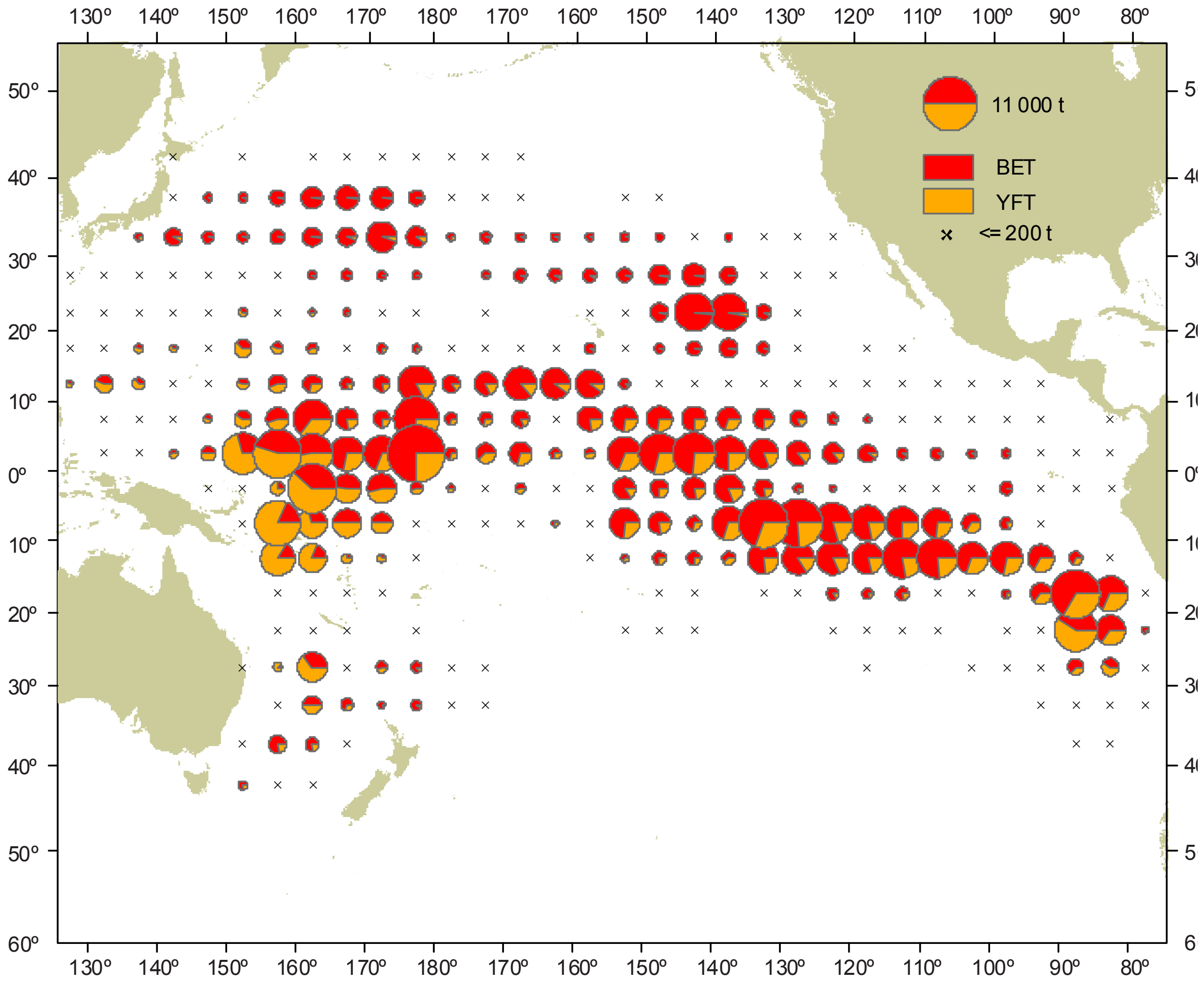


FIGURE 5. Distributions of the catches of bigeye and yellowfin tunas in the Pacific Ocean by Japanese and Korean longline vessels, 2002-2006. The sizes of the circles are proportional to the amounts of bigeye and yellowfin caught in those 5° by 5° areas

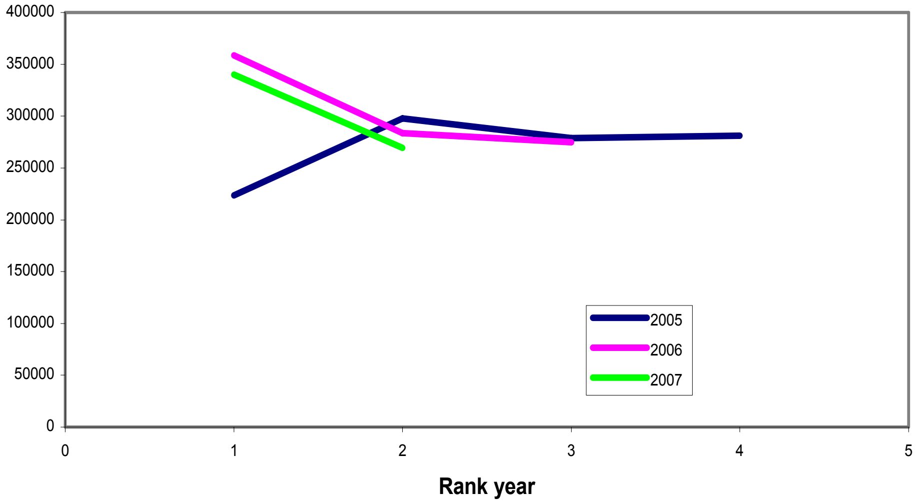


FIGURE 6. Biomass of bigeye aged 3+ quarters, 2005-2007.

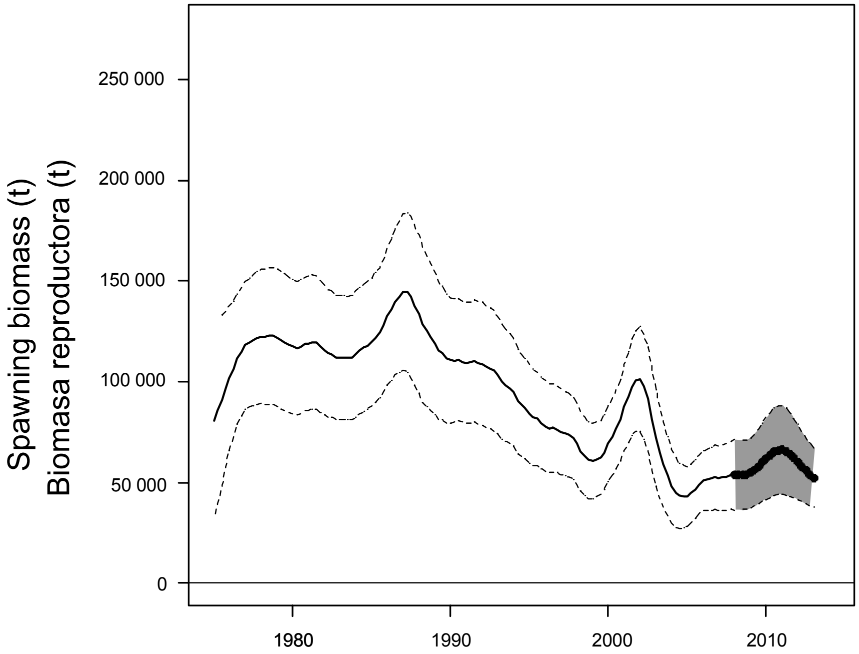


FIGURE 7. Spawning biomass of bigeye tuna, including projections for 2008-2012 with average fishing mortality rates for 2005-2007. These calculations include parameter estimation uncertainty and uncertainty about future recruitment. The areas between the dashed curves indicate the 95% confidence intervals. (From Document SARM-9-06b, 2008)

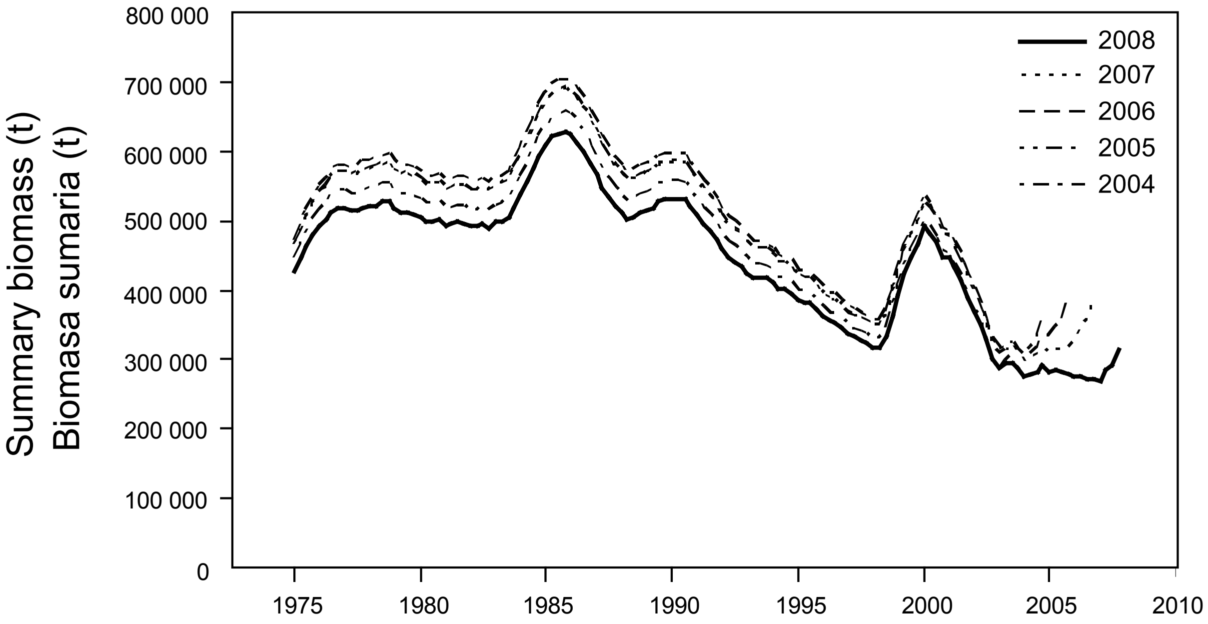


FIGURE 8. Retrospective estimates of summary biomass calculated by removing data from the current assessment.

3.4. Section 3: Errors and bias in catch and effort data

"*Ad hoc estimates of bigeye catches have been done by the IATTC for the 1994-1999 period, but during the earlier years, the bigeye catch series remain uncorrected, assuming that the species composition was OK before 1994 (before the FAD fisheries).*"

Species composition corrections have been applied to the catches before 1994. However, it is not the species composition sampling program that has caused the estimated catches of bigeye to increase since 1994, nor is this a phenomenon unique to the EPO. As Figure 4 in Fonteneau *et al.* (2005, ICCAT Collected Volume of Scientific Papers, Vol. 57, No. 2) shows, catches of bigeye in all the world's oceans increased steadily up to around 2000, and as their Figure 5 shows, purse-seine catches of bigeye increased rapidly worldwide (see below).

The species composition corrected and uncorrected estimates of the catches of bigeye in the EPO prior to the initiation of the species composition sampling program are shown in Figure 9. It is clear that corrections in the estimates are not responsible for the increase in the bigeye catch, as can also be seen in Figure 11 of Fonteneau and Ariz. The raw catch data, unadjusted for species composition errors, shows a marked increase in catches beginning in 1994.

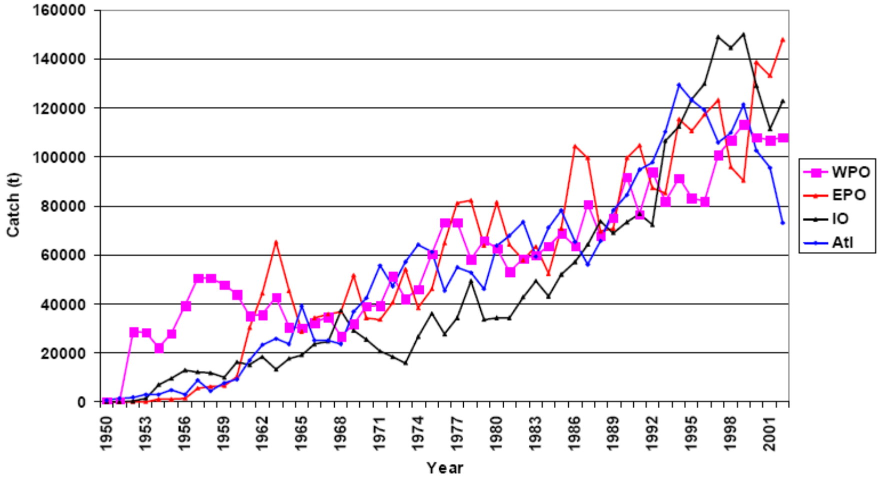


Figure 4. Yearly catches of bigeye tuna taken by ocean (Atl:Atlantic, IO: Indian Ocean, EPO: eastern Pacific Ocean and WPO: western Pacific Ocean).

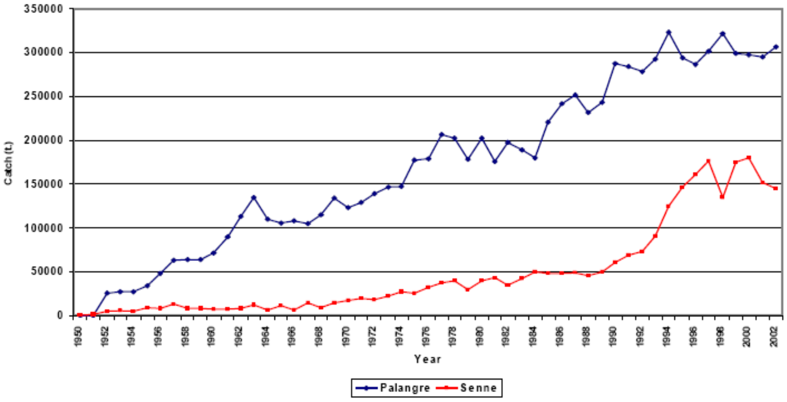


Figure 5. Yearly catches of bigeye tunas taken world wide by purse seiners and by longliners.

from Fonteneau *et al.* (2005, ICCAT Collected Volume of Scientific Papers, Vol. 57, No. 2)

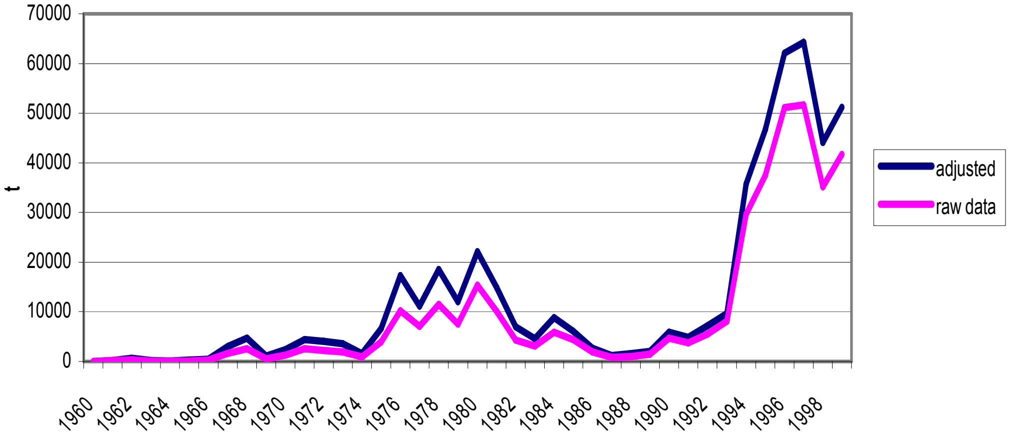


FIGURE 9. Estimated purse-seine catches of bigeye in the EPO, 1960-2000, with and without species composition error adjustment

The cause of the increase was the expansion of the purse-seine fishery on FADs to the equatorial region west of Galapagos Islands. Much of the area occupied by this fishery is contained in Areas 9, 10, and 11 in Figure 10, which shows the sampling area stratification used in our estimation of length frequencies.

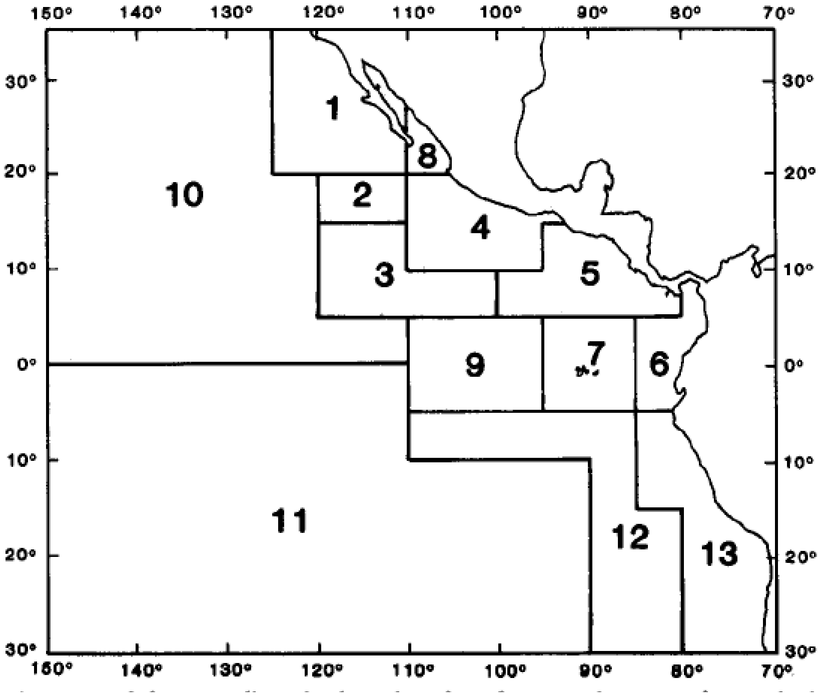


FIGURE 10. Areas used for sampling the lengths of surface-caught tunas.

Figure 11 shows estimates of bigeye catch in these three areas; as can be seen, most of the purse-seine catch is taken in those areas, and the rapid increase in these catches began in 1994. Figure 12 shows the spatial distribution of bigeye tuna catches in the purse-seine fishery on FADs during 1993-2007.

Historical purse-seine catches of bigeye in the EPO consisted primarily of fish taken in unassociated schools with sets in certain time-area strata, and the catches of bigeye associated with floating objects were minimal.

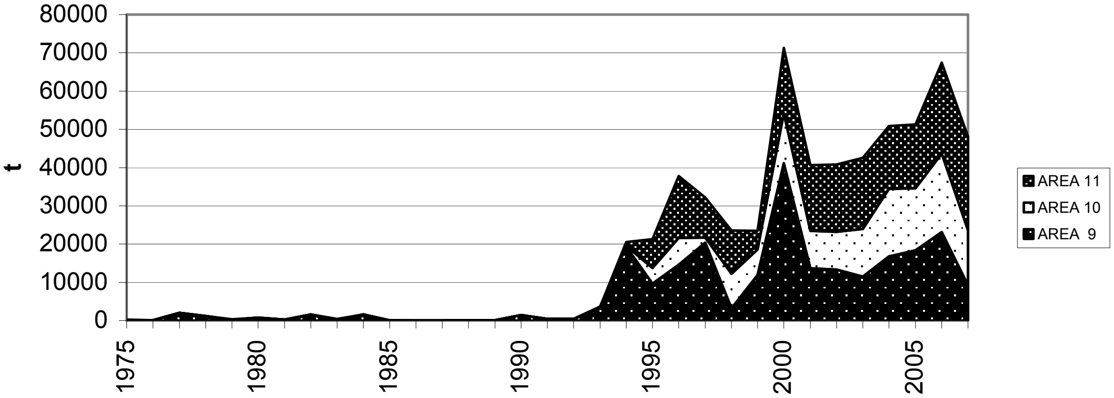


FIGURE 11. Catches of bigeye in the offshore equatorial region (Areas 9-11), 1975-2007 (unadjusted for species composition errors prior to 2000).

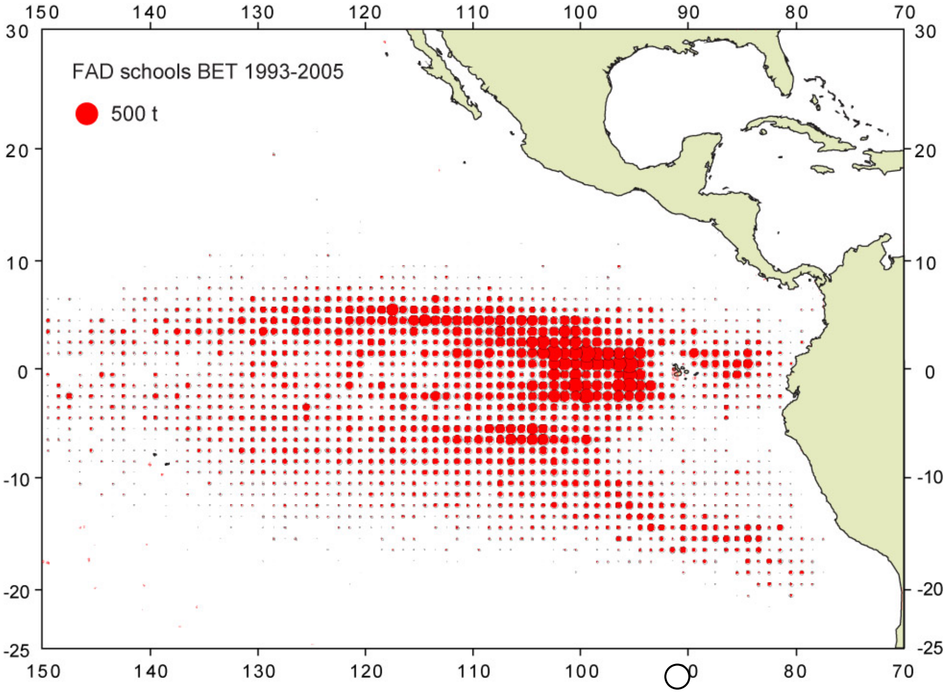


FIGURE 12. Spatial distribution of purse-seine catches of bigeye in sets on FADs, 1993-2005.

3.5. Section 4-1: A western frontier at 150°W?

"*Most bigeye stock assessments done by the IATTC have been conducted in the hypothesis of a strict W-E frontier at 150°W, such a frontier being primarily based on the low rate of transpacific bigeye recoveries."*; and

"In the same way, they do not prove that bigeye born in the Equatorial areas do no migrate to the Northern Pacific at age 3 towards their feeding zones North of 20°N, even if this "obvious" movement pattern has not yet been confirmed by the tagging results."

Extensive tagging of bigeye in the equatorial EPO during 2000-2005 with archival and conventional tags has demonstrated that fish, including those over 3 years of age and those at liberty more than one year, show restricted movements within the equatorial EPO. Recent bigeye tagging studies in the central Pacific around the Hawaiian Islands, and also in the Coral Sea, have also demonstrated that the movements of bigeye are restricted, with very few individuals moving more than about 1,000 nm. The horizontal movements and spawning patterns of bigeye in tropical and subtropical regions are similar to those of yellowfin and skipjack, and different to the migratory movements and spawning patterns of albacore and bluefin tunas. Bigeye feed primarily on organisms that inhabit the deep-scattering layer, such as squid and mesopelagic fishes. The concentrations of these organisms in the equatorial EPO is very high, as documented in numerous oceanographic surveys, including EASTROPAC. There is no evidence from tagging or any other source to indicate that there is movement of bigeye spawned in the equatorial EPO to feeding zones north of 20°N at any age.

3.6. Section 4-2-1: Natural mortality at age and longevity

"*These major uncertainties concerning the level and pattern of the natural mortality as a function of age should at least be fully explored in the basic IATTC stock assessment, and the ICCAT hypothesis should at least be envisaged having similar levels of juvenile M for yellowfin and bigeye for small sizes (i.e. at sizes <70 cm?)*"

The ICCAT hypothesis is, as far as we know, not used by the ICCAT bigeye stock assessment working group, whose assessment uses a natural mortality schedule similar to ours. It seems illogical to hypothesize that young yellowfin and bigeye tunas (less than 70 cm) have similar natural mortality rates. As shown in Document SAR-8-07, the spatial distributions of small yellowfin and of juvenile bigeye (<2.5 kg and 2.5-12.5 kg) are quite distinct (Figures 13 and 14). We think that the three reasons given by Fonteneau and Ariz are flawed, even for FAD areas, where the two species overlap. First, the behavior of juvenile bigeye is very different from that of yellowfin: during the day, when not associated with floating objects, they spend the majority of their time well below the thermocline, tracking the prey organisms of the deep-scattering layer, and making some upward forays for behavioral and physiological thermoregulation. Yellowfin, on the other hand, primarily inhabit the mixed-layer depths, with occasional short-duration dives to the deep-scattering layer for foraging. Second, bigeye do not live mostly in mixed schools in shallow waters, and the average time that they spend associated with floating objects was estimated from archival tag data to be about 20% of the days at liberty. Third, the feeding habits and foraging strategies of the two species are different, and due to the differences in their daytime depth distribution, so probably there are differences in the feeding habits and foraging strategies of predators of bigeye and yellowfin tunas.

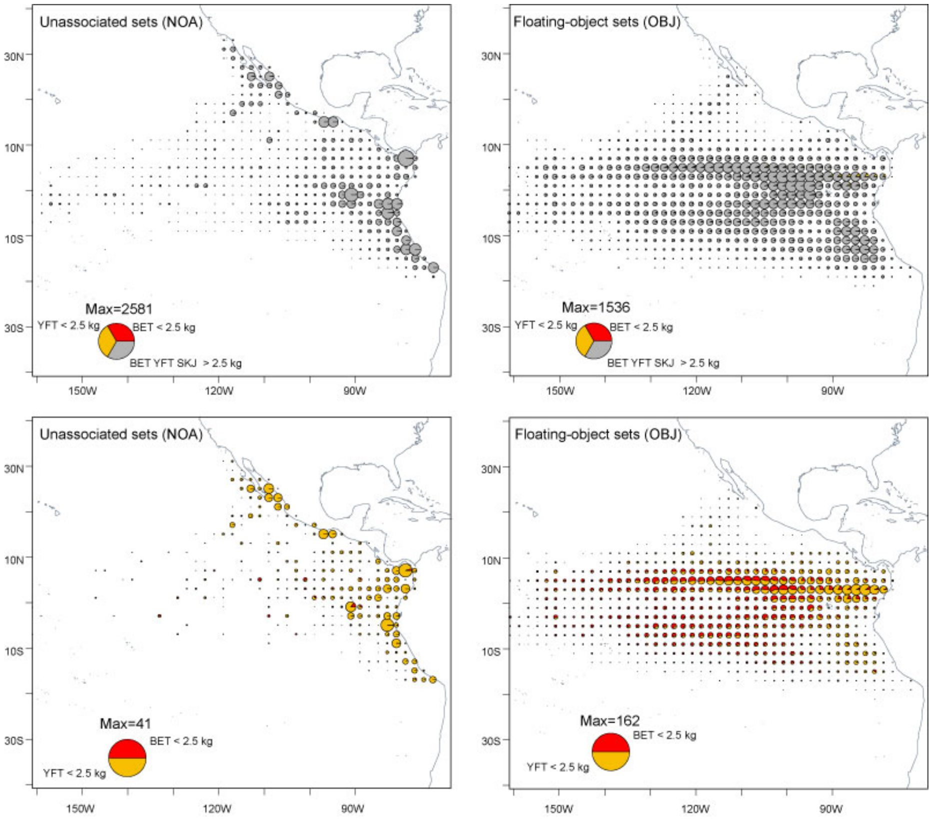


FIGURE 13. Average annual catches in the EPO, in metric tons, of skipjack, yellowfin, and bigeye tunas (top panels), and of yellowfin and bigeye < 2.5 kg (bottom panels), by set type, 1994-2006.

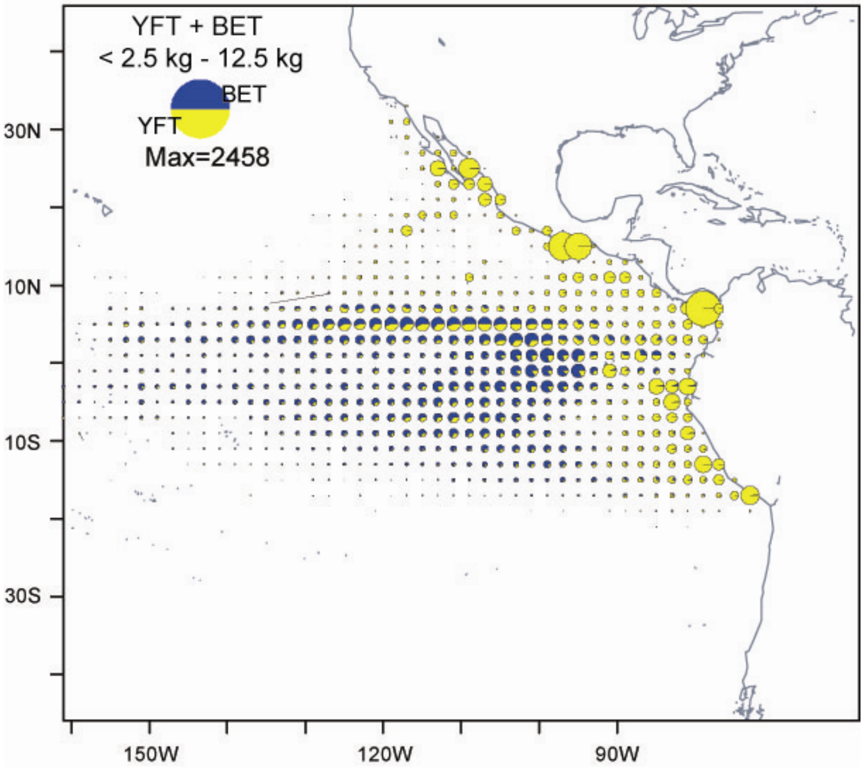


FIGURE 14. Average annual catches, in metric tons, of yellowfin and bigeye 2.5kg-12.5kg in the unassociated and floating object fisheries in the EPO combined, 1994-2006.

3.7. Section 4-2-3: Relative fecundity at size

"The age at first spawning remains widely uncertain in the EPO, and when the Schaefer et al 2005 study indicate a late size at maturity at 135 cm, various other studies or results indicate a much smaller size at 1st maturity at about 1 meter, as in other areas of the Pacific Ocean (Farley et al. 2006, Sun et al 2006, and Taiwanese EPO observer unpublished data). It should be kept in mind that the sample from longliners in this study was very limited: only 120 fishes, fishes that were possibly taken outside spawning strata."

Although there are some limitations to our knowledge about the reproductive biology of bigeye in the EPO, there is little uncertainty about the lengths and ages at maturity. Although, as Fonteneau and Ariz point out, only 124 bigeye samples were available from the longline fisheries, 1,986 bigeye caught by purse-seine vessels were sampled, with significant numbers within the 140-160 cm length interval (Schaefer *et al*., 2005, IATTC Bulletin, Vol. 23, No. 1). Histological evaluations of ovaries from 683 females provided the foundation for the estimates of length-specific reproductive characteristics. The minimum length at sexual maturity observed was 102 cm. The proportion of mature fish increases gradually until just before the predicted length at 50% maturity of 135 cm, at which point it increases rapidly relative to the increase in length. After that point, a decline in the rate of maturation is observed, with 90% of the females predicted to be mature at 151 cm. Contrary to Fonteneau and Ariz' claim, the age at first maturity and at various lengths along the maturity schedule are well known in the EPO (Schaefer and Fuller, 2006, IATTC Bulletin, Vol. 23, No 2).

Regardless of the methodology used, most previous studies in the Pacific have reported the minimum length at sexual maturity for female bigeye to be around 100 cm, which is similar to the finding in the most recent study conducted in the EPO. In contrast to other studies of maturity of bigeye, the smallest mature female reported for the northwestern Coral Sea (Farley *et al*., 2003, CSIRO Report No. 2000/100) was 80 cm, and the length at 50% maturity for females was estimated to be 102.4 cm. However, the classification of maturity was based simply on the macroscopic appearance of the ovaries, which potentially resulted in an underestimation of the length at 50% maturity, as discussed by Schaefer (2001, Reproductive biology of tunas. *In* Block, Barbara A., and E. Donald Stevens (editors), Tuna: Physiology, Ecology, and Evolution, Academic Press, San Diego: 225-270).

3.8. Section 4-2-4: Growth

"*Furthermore, one of the basic fact that has often been observed on bigeye tunas (as for yellowfin) is their clear 2 stanza growth curve, (as analyzed for yellowfin in the Atlantic by Gascuel et al 1992) that has been fairly well shown by the recoveries from various tagging programs (Figure 24 from the Indian Ocean tagging)*."

The age and growth of bigeye in the EPO has been well estimated from validated ageing, using otoliths of fish from 30 to 150 cm, and from tagging data for fish from 50 to 170 cm. The growth in length of bigeye in the EPO is well described, based on fitting the von Bertalanffy model and various Richards growth models to the length-at-age data. There is no evidence for the existence of a 2-stanza growth curve in these bigeye data. Furthermore, the estimation of bigeye growth from tagging programs in other ocean areascontains apparent biases associated with measuring frozen and curved fish and the failure to adjust the measurements for shrinkage. Also, serious biases are much less likely for growth than for parameters such as mortality, recruitment, and movement, so it would be better to concentrate on possible biases in parameters other than growth.

3.9. Section 6: Conclusion

" ... such highly migratory species ... show a combination of a viscous behaviour (Mac Call 1990) as it has been well shown by the results of recent IATTC tagging but also ***obviously*** *doing large scale movements (for instance towards their northern feeding zones: these bigetye are not born at 35°N!)."*

The statement that the bigeye distributed and captured in the northern EPO are not born at 35N does not justify the proposed conceptual movement model of migrations from the equatorial EPO to such latitudes. Bigeye distributed at higher latitudes in the EPO are probably the result of spawning in the vicinity of 20°N, where the sea-surface temperatures are greater than 24°C during the northern summer.

3.10 Section 6: Conclusion

"One of the more critical limiting factor is probably the weakness of tagging results in the area, recent tagging being very interesting ones, but too limited to peculiar sizes and areas components of the stock, possibly biased by the TOA anchored buoys (equivalent to anchored FADs)."

When tagging bigeye associated with the moored TAO buoys in the equatorial EPO, we were aware of the probable bias in movement patterns, and wanted to prevent large numbers of short-term recaptures. To this end, entire aggregations of tunas, including the tagged bigeye, yellowfin, and skipjack, were "drifted" away from the buoys to distances of about 50 nm by moving the vessel slowly away from the buoys, and then "abandoned" by increasing the vessel's speed to about 8 knots.

WEB LINKS

ICCAT bigeye assessment: http://www.iccat.int/Documents/SCRS/DetRep/DET_bet.pdf
WCPFC/SPC bigeye assessment: http://www.wcpfc.int/sc2/pdf/SC2_SA_WP2.pdf
IOTC bigeye assessment: http://www.iotc.org/files/proceedings/2006/wptt/IOTC-2006-WPTT-R[EN].pdf
Fonteneau *et al.* (2005) paper presented at second world bigeye tuna meeting:
http://www.iccat.int/Documents/CVSP/CV057_2005/no_2/CV057020041.pdf
Schaefer, Fuller, and Miyabe paper on reproductive biology of bigeye tunas in the EPO:
http://www.iattc.org/PDFFiles2/Bulletin-Vol.-23-No-1-ENG.pdf

APPENDIX A.

Adjustment of the SBR and management quantities for a potential bias in the early recruitment estimates or a regime shift in recruitment

If the estimates of recruitment prior to 1994 are biased low, it may be appropriate to use only the recent recruitments to estimate the historical spawning biomass ratios (SBRs). Similarly, if there has been a regime shift toward higher levels of recruitment, it may be appropriate to use only recent recruitments when calculating recent SBRs. The following equation was used to correct the SBRs:

$$SBRc_t = \frac{SB_t}{\frac{\overline{R}_{1994-2006}}{R_0} SB_0}$$

where

$SBRc_t$ is the corrected spawning biomass ratio at time *t*,

SBR is the spawning biomass at time *t*,

$\overline{R}_{1994-2007}$ is the average recruitment during 1994-2007,

R_0 is the virgin recruitment,

SB_0 is the virgin spawning biomass.

The estimated time series of the spawning biomass ratio derived after correction *(SBR_r)* and the base case model estimates (*SBR*) are shown in Figure A.1.

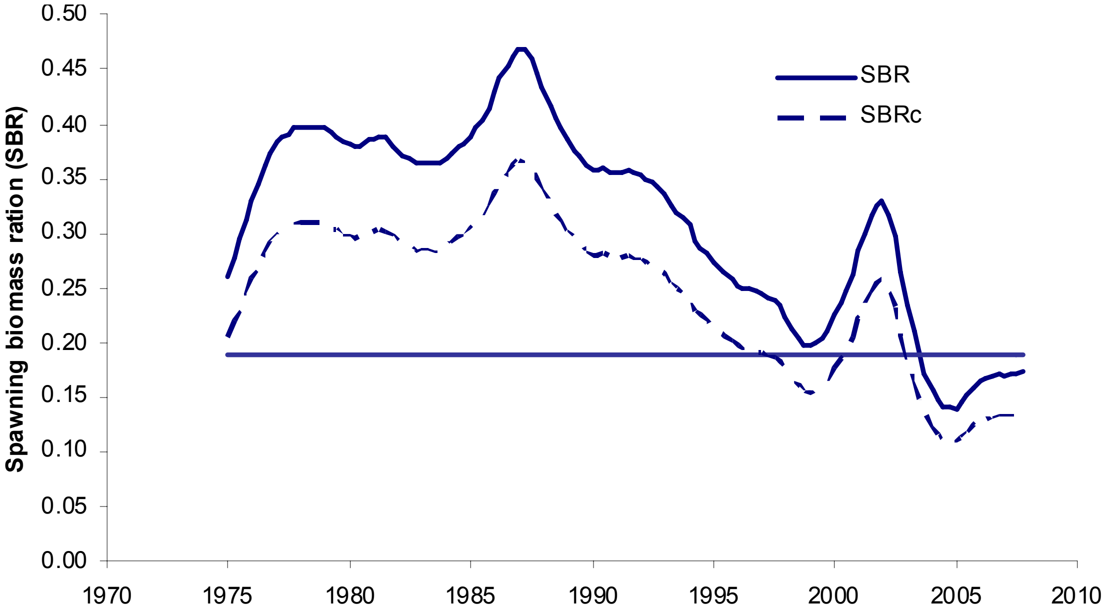


FIGURE A.1. Spawning biomass ratios correct for the potential recruitment change (*SBR_c*) and non-corrected estimates derived from the base case model (*SBR*).

The correction also needs to be applied for the management quantities. For this purpose, all MSY-related quantities were either multiplied (MSY, B_{MSY} and S_{MSY}) or divided (C_{recent}/MSY, $B_{\text{recent}}/B_{\text{MSY}}$, $S_{\text{recent}}/S_{\text{MSY}}$) by the correction factor $\overline{R}_{1994-2007} / R_0$.

The table below presents a comparison between the management quantities estimated by the base case and those with recent recruitments.

	Base case	**Recent recruitments**
MSY	81,350	104,128
B_{MSY}	287,912	368,527
S_{MSY}	59,626	76,322
B_{MSY}/B_0	0.26	0.26
S_{MSY}/S_0	0.19	0.19
C_{recent}/MSY	1.44	0.84
$B_{recent}/B_{\mathrm{MSY}}$	1.15	0.90
$S_{recent}/S_{\mathrm{MSY}}$	0.90	0.71
$F_{\mathrm{multiplier}}$	0.82	0.82

APPENDIX B.

Sensitivity analyses to alternative natural mortality (*M*) curves

One of the possible explanations for the lower recruitment estimates indicated by Fonteneau and Ariz is that *M* was grossly underestimated for the younger fish (Section 2.3). This could also introduce bias in the evaluation of the stock status.

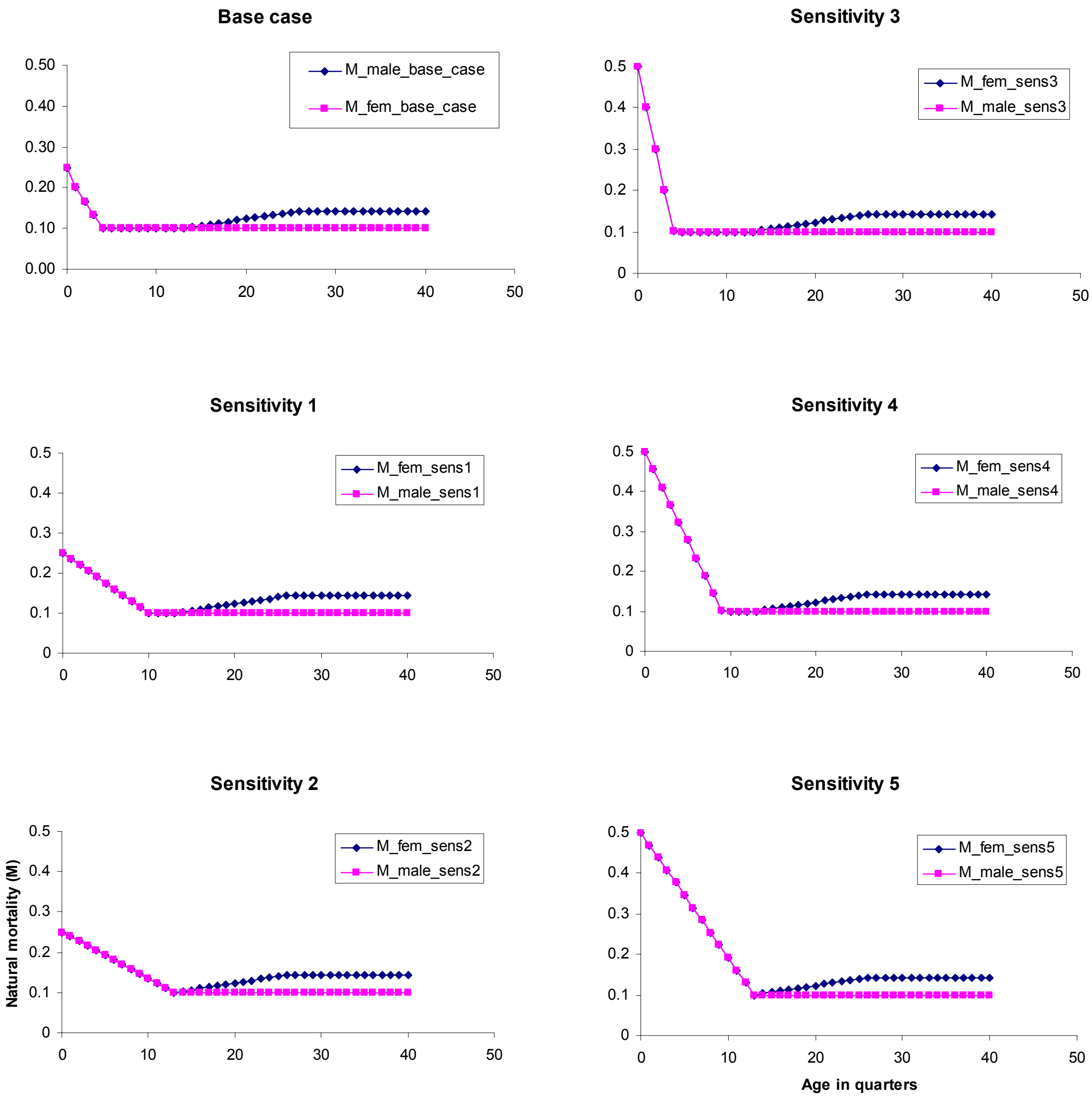
The sensitivity of the estimated management quantities to assuming different *M* curves in the current stock assessment was investigated. Two types of sensitivity analyses were conducted.

In the first analysis, the effect of variations in shape of the young segment of the *M* curves assumed for males and females (Figure B.1) was investigated. This was done by assuming one of two different levels of *M* for the age-0 fish (0.25 and 0.50 year^{-1}), and a linear decreasing trend of *M* between age-0 and one of three possible young ages (5, 10 and 13 quarters of age). In the second analysis, the *M* curve used in the most recent bigeye assessments by each one of the other RFMOs (Figure B.2) was applied to both sexes in the SS2 model.

The estimates of the management quantities obtained from the sensitivity analysis are shown in Tables A.2.1a and b. *The* $F_{multiplier}$ corresponding to the multiplicative factor needed to reduce ($F_{multiplier} <1$) or increase ($F_{multiplier} >1$) the current *F* in order to achieve the target reference point was computed for each sensitivity analysis. Four target reference points are considered: the spawning biomass (*S*) at MSY; *S* at an MSY proxy of (a) 20% of the virgin spawning biomass (S_0), and (b) 30% of $S_{0\mathrm{a}}$ and including a stock-recruitment relationship , with a steepness (*h*) of 0.75.

Figure B.3a shows the $F_{multiplier}$ estimates obtained from the analyses of sensitivity to the *M* assumptions for young fish. Figure B.3b shows the $F_{multiplier}$ estimates obtained when the *M* curves of other RFMOs were used.

Figure B.4a shows the estimates for the current spawning biomass (S_{cur}) divided by the spawning biomass corresponding to MSY (S_{MSY}) obtained from the analyses of sensitivity to the *M* assumptions for young fish. Figure B.4b presents the S_{cur}/S_{MSY} estimates obtained when the *M* curves of other RFMOs were used.


Base case

Sensitivity 3

Sensitivity 1

Sensitivity 4

Sensitivity 2

Sensitivity 5

FIGURE B.1. *M* curves for female and male bigeye tuna investigated in the sensitivity analyses.

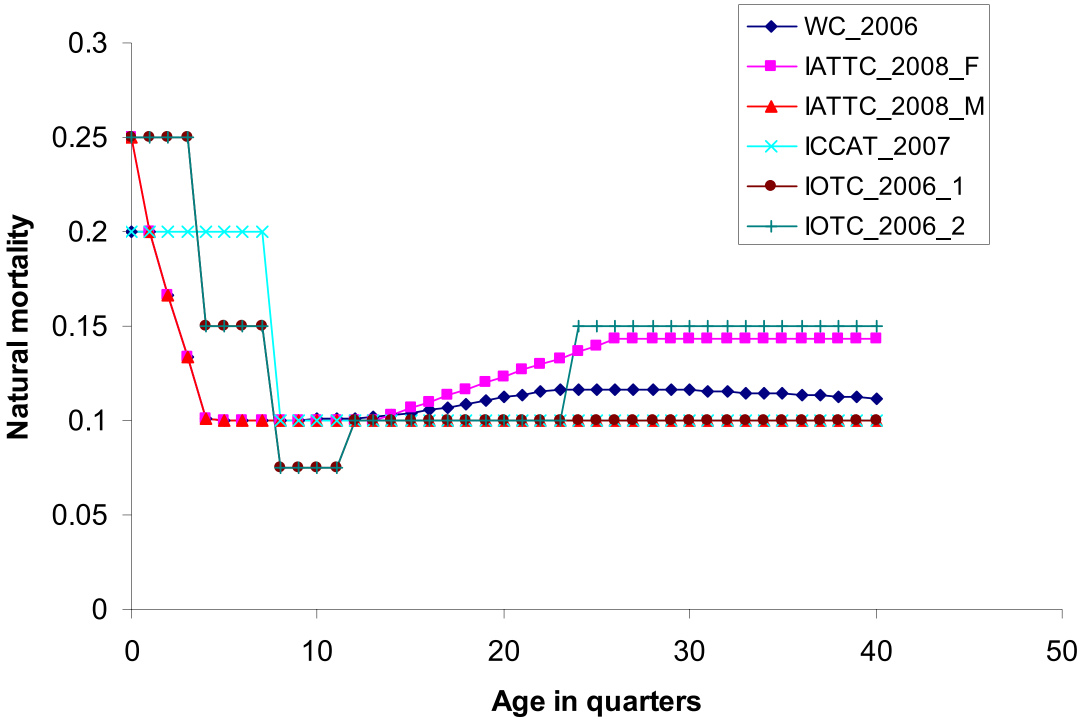


FIGURE B.2. Natural mortality curves used in the most recent bigeye tuna stock assessments by various RFMOs.

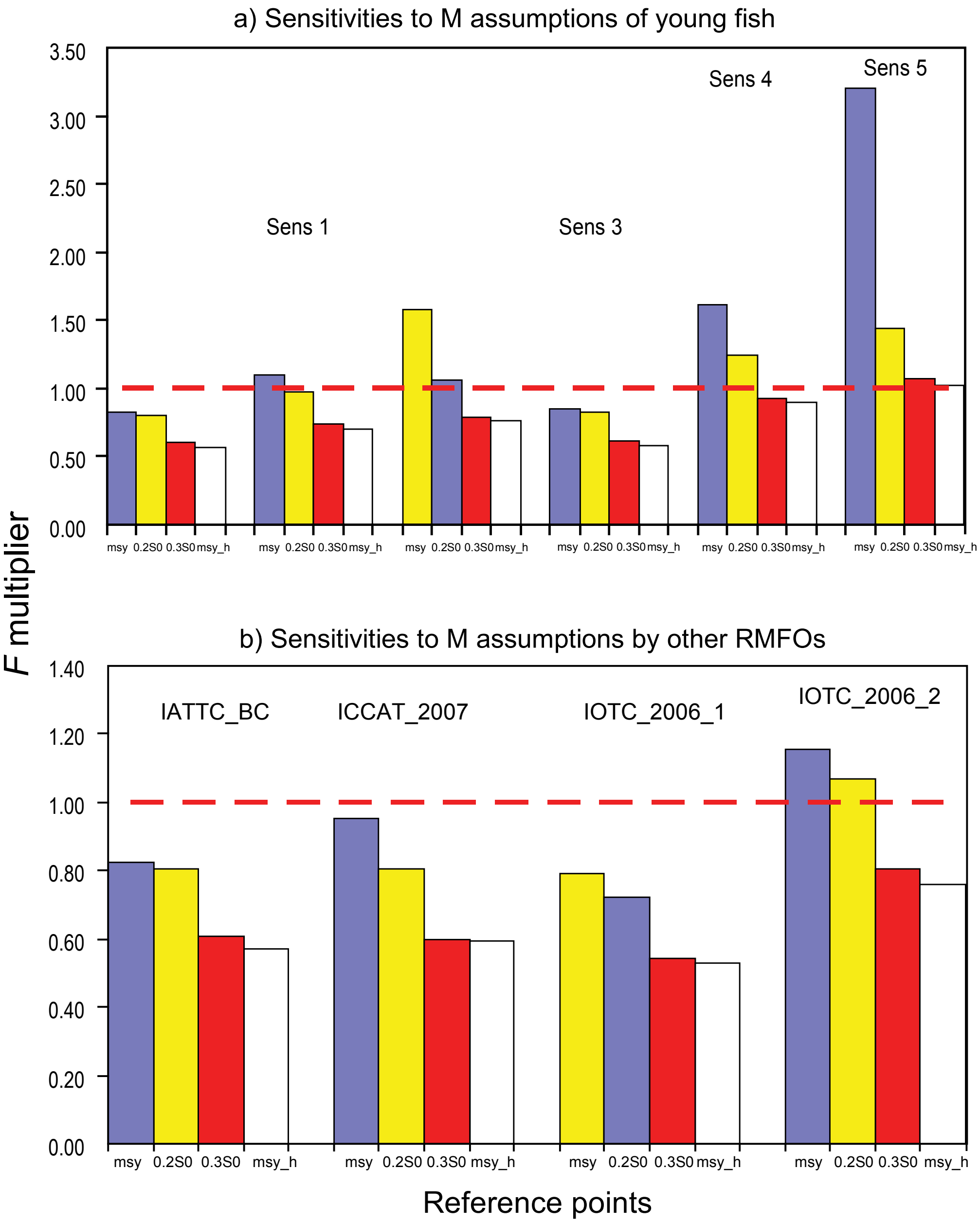


FIGURE B.3. Estimates for the $F_{multiplier}$ obtained from the sensitivity analyses to various assumptions on natural mortality: a) different scenarios about the *M* values of young fish (top); and b) *M* curves assumed in the most recent assessments by other RFMOs (bottom). The $F_{multiplier}$ is the multiplicative factor needed to reduce ($F_{multiplier}$ <1) or increase ($F_{multiplier}$ >1) the current *F* in order to achieve the reference point. The four reference points (vertical bars) considered for each sensitivity analysis are: the spawning biomass (*S*) at MSY; *S* at an MSY proxy of (a) 20% of the virgin spawning biomass (S_0), and (b) 30% of S_{0a} and including a stock-recruitment relationship, with a steepness (*h*) of 0.75.

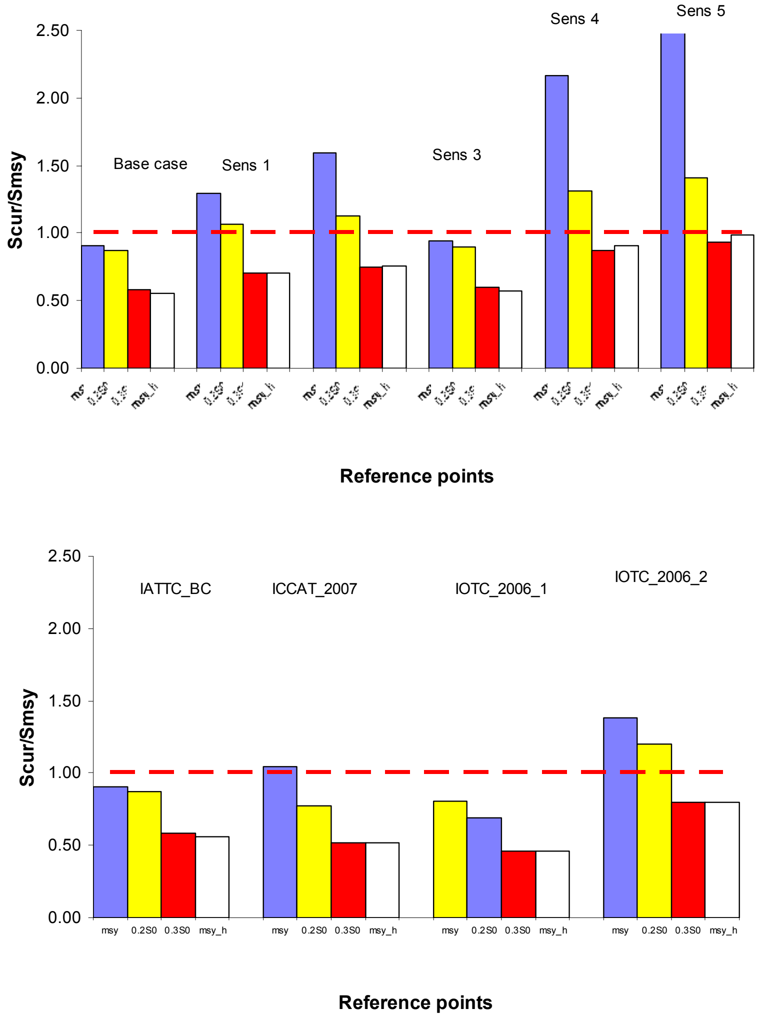


FIGURE B.4. Estimates for the current spawning biomass (S_{cur}) divided by the spawning biomass corresponding to MSY (S_{MSY}). The four reference points (vertical bars) considered for each sensitivity analysis are: the spawning biomass (S) at MSY; S at an MSY proxy of (a) 20% of the virgin spawning biomass (S_0), and (b) 30% of $S_{0\mathrm{a}}$ and including a stock-recruitment relationship , with a steepness (h) of 0.75.

TABLE B.1. Management quantities derived from the sensitivity analysis: a) different scenarios about the *M* values of young fish (Figure B.1); and, b) *M* curves assumed in the most recent assessments by other RFMOs (Figure B.2).[1]

a)

	Base case	**Sens1**	**Sens1_h**	**Sens2**	**Sens2_h**	**Sens3**	**Sens3_h**	**Sens4**	**Sens4_h**	**Sens5**	**Sens5_h**
MSY	81,350	91,822	83,898	99,071	88,188	82,284	78,563	109,984	93,393	144,941	106,040
B_{MSY}	287,912	268,673	480,842	249,988	466,366	283,816	494,924	247,095	477,101	172,554	453,321
S_{MSY}	59,626	49,983	108,158	40,821	98,824	58,222	116,437	37,832	100,697	7,906	72,412
B_{MSY}/B_0	0.26	0.24	0.34	0.23	0.34	0.25	0.34	0.21	0.34	0.16	0.36
S_{MSY}/S_0	0.19	0.16	0.28	0.14	0.28	0.19	0.29	0.12	0.27	0.03	0.25
C_{recent}/MSY	1.44	0.95	1.05	0.88	0.99	1.07	1.12	0.79	0.94	0.60	0.82
$B_{recent}/B_{\mathrm{MSY}}$	1.15	1.54	0.93	1.78	1.02	1.19	0.76	2.12	1.15	3.59	1.31
$S_{recent}/S_{\mathrm{MSY}}$	0.90	1.30	0.70	1.59	0.76	0.94	0.57	2.16	0.91	9.11	0.98
$F_{multiplier}$_MSY	0.82	1.10	0.70	1.57	0.76	0.85	0.58	1.62	0.90	3.21	1.03
$F_{multiplier}$_SBR02	0.81	0.98	-	1.05	-	0.83	-	1.24	-	1.44	-
$F_{multiplier}$_SBR03	0.61	0.74	-	0.79	-	0.62	-	0.93	-	1.07	-

b)

	Base case	**Base case h**	**ICCAT_2007**	**ICCAT_2007_h**	**IOTC_2006_1**	**IOTC_2006_1_h**	**IOTC_2006_2**	**IOTC_2006_2_h**
MSY	81,350	78,150	87,652	84,624	81,098	80,991	93,076	83,667
B_{MSY}	287,912	500,357	258,618	511,183	279,578	537,220	303,491	519,289
S_{MSY}	59,626	118,154	54,332	136,830	66,193	152,204	68,272	137,135
B_{MSY}/B_0	0.26	0.34	0.24	0.34	0.25	0.34	0.24	0.34
S_{MSY}/S_0	0.19	0.30	0.15	0.28	0.17	0.29	0.17	0.29
C_{recent}/MSY	1.44	1.12	1.00	1.04	1.08	1.08	0.94	1.05
$B_{recent}/B_{\mathrm{MSY}}$	1.15	0.74	1.33	0.74	1.08	0.64	1.60	1.02
$S_{recent}/S_{\mathrm{MSY}}$	0.90	0.56	1.05	0.52	0.81	0.46	1.38	0.80
$F_{multiplier}$_MSY	0.82	0.57	0.96	0.59	0.79	0.53	1.16	0.76
$F_{multiplier}$_SBR02	0.81		0.80		0.72		1.07	
$F_{multiplier}$_SBR03	0.61		0.60		0.54		0.80	
S_{MSY}/S_0_RFMO			0.311-0.40		0.31-0.47[1]		0.31-0.47[1]	

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[1] IOTC summary results do not specify which *M* curve was used for summary values.