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ON THE GREAT SCIENTIFIC INTEREST TO SAMPLE THE SEX OF TUNA RECOVERIES

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Summary

This paper makes a review and a discussion of the results obtained from the Indian Ocean tagging programme on the sex of large yellowfin and large bigeye recoveries. These results are based on a small sample of 75 bigeye and 100 yellowfin recovered during 5 years in the entire western Indian Ocean. All these recoveries have been very well measured by scientists and their time at liberty is well known. These results are showing and for the 2 species marked differences in growth rates and in the asymptotic sizes of male and female: males showing higher growth rates and larger asymptotic sizes. They also indicate that natural mortality of female yellowfin would be moderately larger than for males, and nearly identical for the 2 sexes of bigeye. It is concluded that these results are probably valid ones in the Indian Ocean, and that there is a serious possibility that similar biological results could also be valid ones in other oceans. It is recommended that WCPFC and IATTC should start a similar sampling program of their recoveries of large bigeye and yellowfin, especially those caught by purse seiners that are easily identified and sampled by observers. Future work should also be developed to incorporate better the complexity of these results in future tuna stock assessment models.

1- Introduction:

There is a universal observation in the EPO, WPO, Atlantic and Indian oceans, that male yellowfin tend to be widely dominant at large sizes over 135 or 145 cm (figure 1). It has been often hypothesized (for instance by the IATTC and WCPFC) that this sex ratio at size was solely due to the higher natural mortality of adult female yellowfin, in relation with their active spawning activity and the large amount of energy invested by females in this spawning. However this hypothesis remains widely open to discussion and strong alternate hypothesis, primarily a smaller asymptotic sizes of females, have also been permanently envisaged in the Atlantic and Indian oceans (following Albaret 1977).

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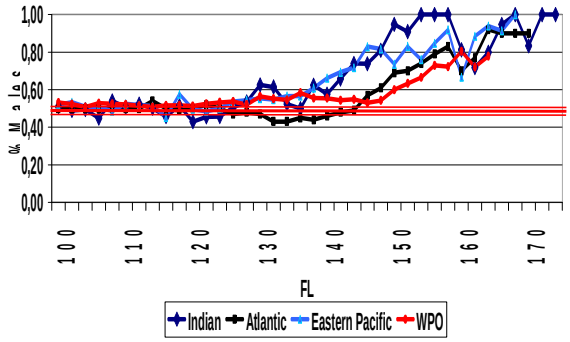

Figure 1: Sampled sex ratio at size of yellowfin in various oceans

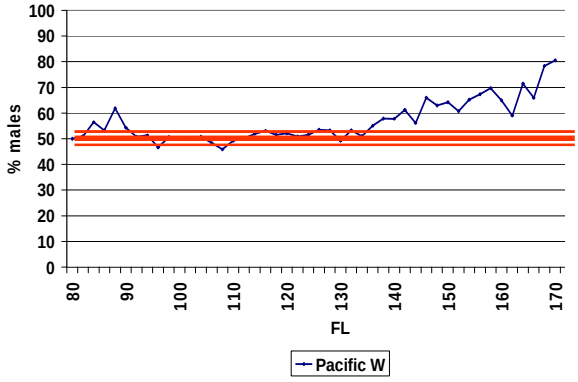

Figure 2: Sampled sex ratio at size of bigeye in the western Pacific

The same question may also be pending concerning some differential sex ratio at size that has been observed for bigeye tuna, also showing a dominance of males at larger sizes at least in the Western Pacific.

On the other side, age reading studies of adult yellowfin and bigeye have been most often showing similar or identical growth of males and females (as Wild 1986 for yellowfin), but these results may remain widely questionable because of the large uncertainties in age readings of old tunas. In general and as John Gulland repeatedly said during various ICCAT meetings, good recoveries of tagged tuna are much more convincing than age reading to study tuna growth, because of their direct and stronger weight of evidence (when the dates and sizes at recovery are perfectly well known). Following this John Gulland's recommendation, growth studies by sex should preferably be based on sexed recoveries, and results from tuna age readings of old individuals should be permanently questioned (as in the Fonteneau and Chassot 2012 paper). Furthermore, this knowledge of sexed recoveries is simultaneously providing various results of high value:

(1) Growth rates and asymptotic sizes of ♂ and ♀

(2) Estimates of the relative levels of natural mortality of adult ♂ and ♀, shown by the frequency of the recoveries of each sex at old ages.

For instance, following the natural mortality assumed in the EPO (figure 3), very few females are surviving after 2 years of such a high M, even without fishing mortality (figure 4).

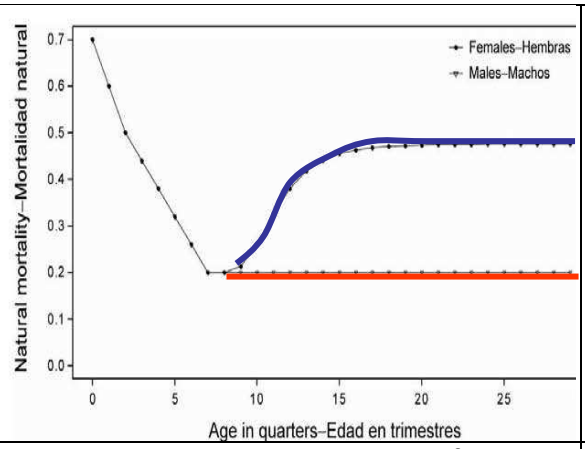

Figure 3: Natural Mortality at age of male (lower curve) et female (upper curve) yellowfin presently assumed by the IATTC in its stock assessments

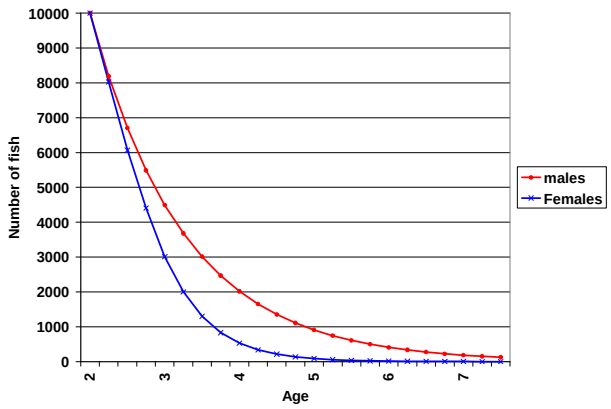

Figure 4: Decline of a population of adult yellowfin (combining males and females) in this hypothesis of Mi.

These 2 working hypothesis concerning L infinity and Natural mortality are of course very important in the functioning and results of the stock assessment models (as it will be discussed in chapter 4), and they should be permanently questioned by scientists. Large scale tagging programs and their recoveries of adult tunas offer a strong opportunity to validate them (or the opposite), as it has been recently shown in the Indian Ocean. The goal of this paper will be to examine these results and to discuss their potential impact on stock assessment.

2- The IOTTC tagging program: its recoveries by sex of adults yellowfin and bigeye

Following the large scale tagging program successfully conducted by the IOTC in 2005-2007, Fonteneau and Dewals 2009 made to the IOTC the proposal that future recoveries of adult yellowfin and bigeye should be perfectly well sampled by scientists and their sex well identified. This recommendation was accepted by the IOTC scientific committee and the following sample has been obtained: many of the purse seine recoveries of large yellowfin and bigeye being well measured and sexed by scientists since mid 2009 (then during a long period of nearly 5 years).

Table 1: Numbers by sex of large yellowfin and bigeye recovered in the Indian Ocean between July 2009 and March 2014.

Species	female	male	Total
Yellowfin	40	60	100
Bigeye	32	43	75
Total	72	103	175

It can also be noticed that these recoveries have been observed scattered in the entire fishing zones were large yellowfin and large bigeye have been caught by purse seiners during this period (figure 5 a yellowfin and 5 b bigeye).

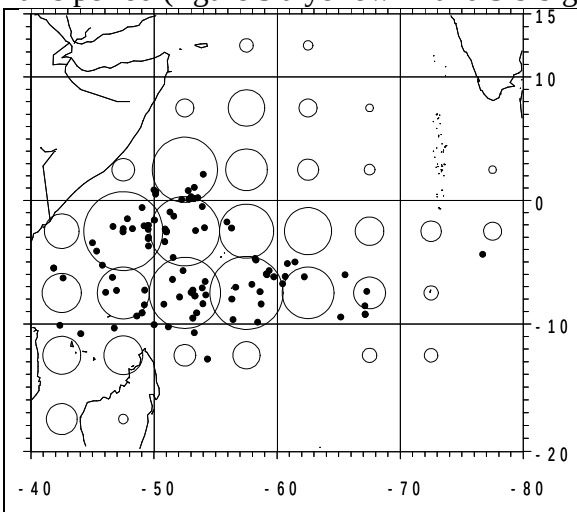

Figure 5a: Average catches of large yellowfin by purse seiners (2009-2012, black empty circles, by 5° areas) and location of the 75 sexed recoveries of yellowfin (black dots, exact positions of recovery)

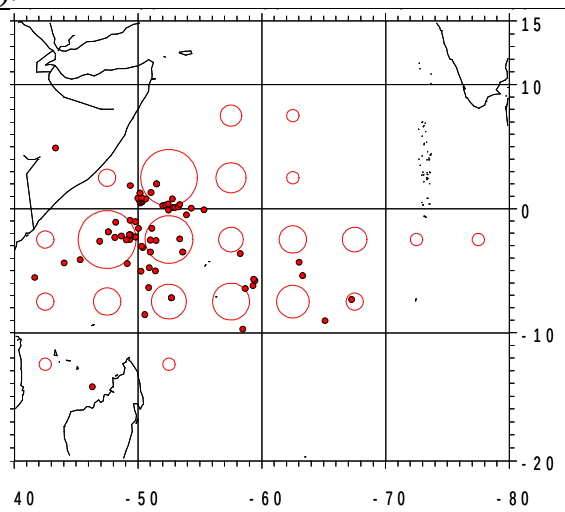

Figure 5b: Average catches of large bigeye by purse seiners (2009-2012, red empty circles) and location of the 50 sexed recoveries of bigeye (red dots)

The fact that the sampled recoveries have been observed during a long period of nearly 5 years and were caught well scattered in the entire fished zone gives additional strength to this sample of recoveries.

The final important point is that all these recoveries have been very well measured by scientists at the Seychelles Fishing Authority (SFA) laboratory in Seychelles, and that there were very small uncertainties in the durations at sea of these long duration's recoveries. The average uncertainty of duration at sea can be estimated for yellowfin at a level of only 0.12 % of these durations (for an average duration at sea of 4.2 years) and only at 0.10% of uncertainty for the bigeye durations at sea (for an average duration at sea of 4.9 years).

The absolute age at recovery has been estimated for each recovery:

(1) simply assuming that each tagged tuna had an average size at the theoretical age of its tagging; the 2 growth curves proposed by Fonteneau 2008 (for yellowfin and by Fonteneau 2013 for Bigeye, were used as a working hypothesis (see figure 6)

Figure 6: Growth curves assumed in the aging of the recoveries by sex.

(2) that their age at recovery of each tuna was the sum of its age at tagging, and adding its time at liberty

The observed growth of male and female yellowfin between tagging and recovery are shown on figure 7 and 8, in comparison with the average growth model used by the IOTC in its stock assessment (green curve) (Eveson and Million 2008)

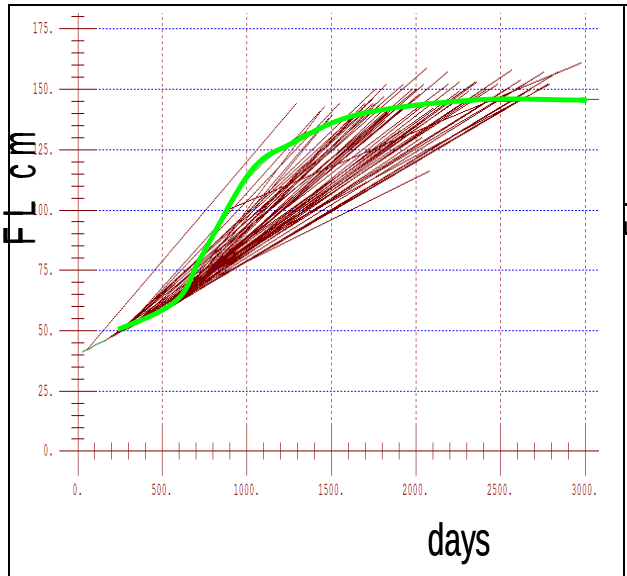

Figure 7: Theoretical and observed growth of male yellowfin

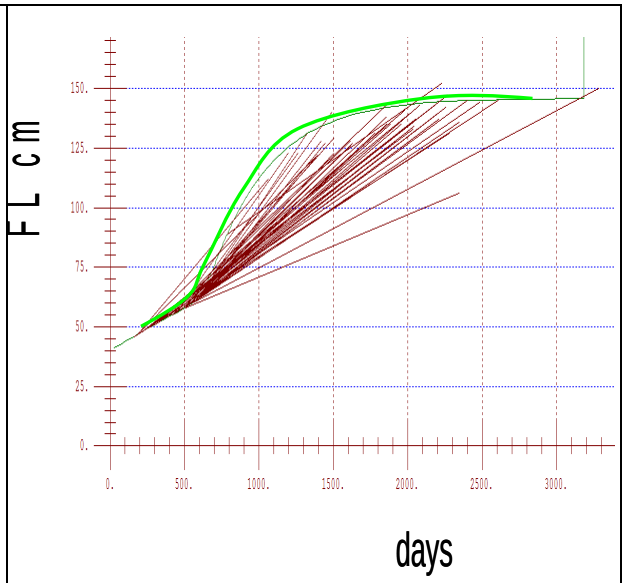

Figure 8: Theoretical and observed growth of female yellowfin

Figure 9 shows the observed residuals between the observed and theoretical growth of yellowfin: a majority of male yellowfin showing larger sizes than in the growth model, the opposite for female yellowfin.

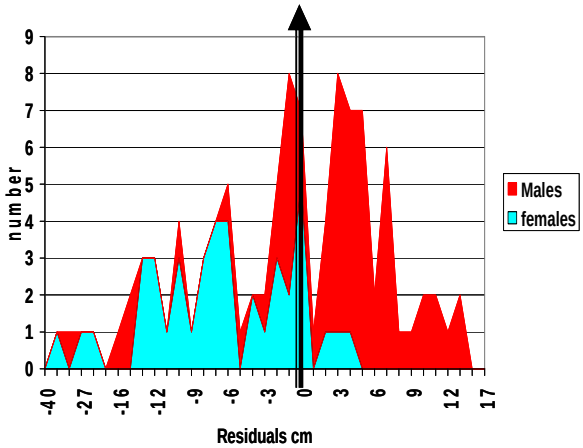

Figure 9: Residuals of yellowfin growth / sex at recovery between the IOTC growth model and the observed growth by sex

The observed growth of male and female bigeye between tagging and recovery are shown on figure 8 and 9, in comparison with the average growth model used by the IOTC in its stock assessment (green curve)

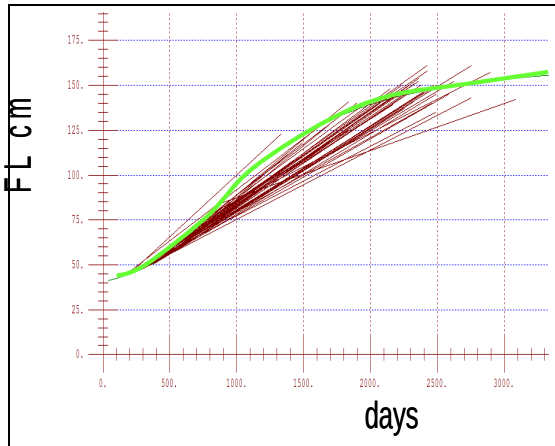

Figure 10: Theoretical and observed growth of male bigeye

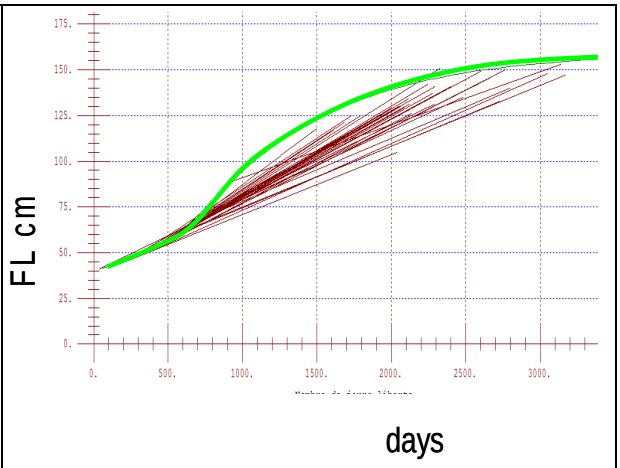

Figure 11: Theoretical and observed growth of female bigeye

Figure 12 shows the observed residuals between the observed and theoretical growth of bigeye: majority of male bigeye showing larger sizes than in the growth model, the opposite for female bigeye

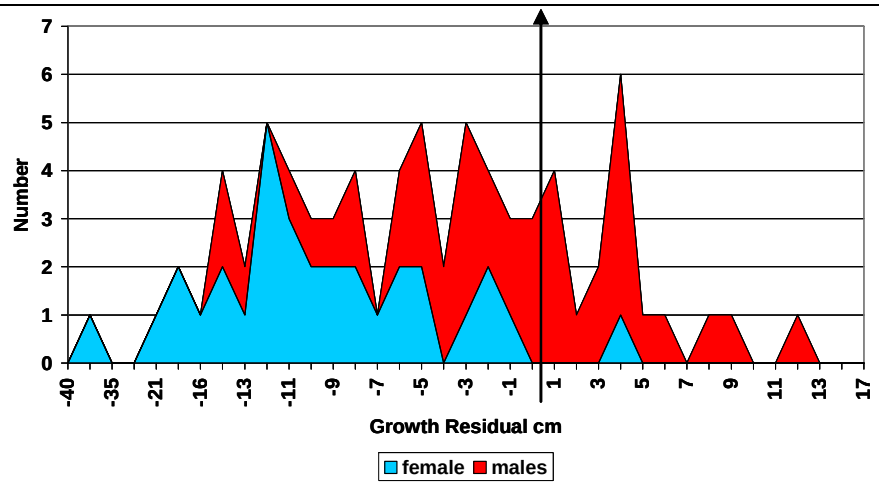

Figure 12: Residuals of bigeye growth / sex at recovery between the IOTC growth model and the observed growth by sex

These recoveries should also be examined based on the observed sex ratio of the recoveries as a function of their ages (figure 13 for yellowfin and figure 14 for bigeye).

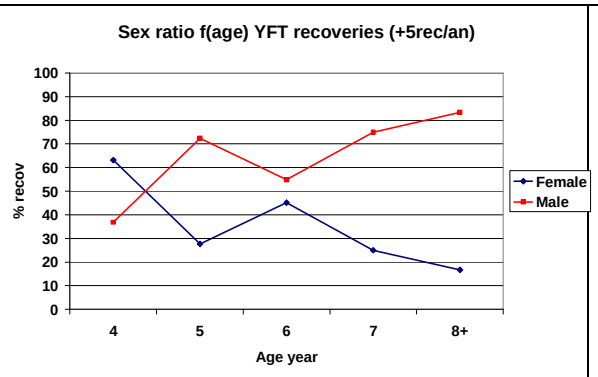

Figure 13 Observed sex ratio at age of the yellowfin recoveries (for all years with + than 5 recoveries)

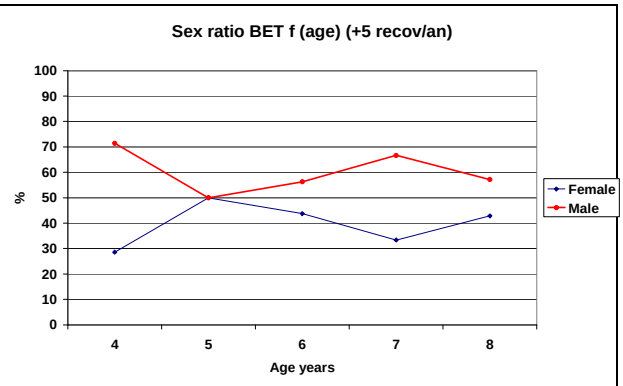

Figure 14: Observed sex ratio at age of the bigeye recoveries (for all years with + than 5 recoveries)

Figure 13 shows that yellowfin sex ratio at age were similar at ages 4-6 years, but vanishing females at age 7+, after more than 4 years in the adult fishery (age 3+). Based on these results, it could be hypothesized that the adult yellowfin population between age 4 and 6 had similar levels of M for male and female, but larger M at ages 7+ (assuming that the selectivities of the 2 sexes were similar in the yellowfin purse seine fishery).

Figure 14 shows that bigeye sex ratio at age were similar at ages 4-8 years, but with a lower percentage of females (43 %). Based on these results, it could be hypothesized that the adult population of bigeye between age 4 and 8 had similar M of male and female (assuming that the selectivities of the 2 sexes were similar in the bigeye purse seine fishery, when females may also show a constantly lower level of catchability/selectivity in the purse seine fishery?)

3- Discussion of the Indian Ocean results

One of the pending questions is that the Indian Ocean results are based on too small numbers of recoveries: only 100 yellowfin and 75 bigeye. Our belief, based on the analysis of these results is that these results are already fully indicative of growth and natural mortality of adult male and female yellowfin and bigeye

- Concerning growth: there should be little doubt that this small sample of fishes that have been very well measured at tagging and recovery, and fished after very well known and long durations at sea, is already highly informative upon the growth rates and differences in asymptotic sizes of each species following their sex.
- Concerning sex ratio at size: when 10 tagged tunas are recovered at age 5+ with sex ratio close to 50/50 (♂ and ♀), this result is already a strong statistical proof that the sex ratio of the population was not widely dominated by males (as in the today IATTC stock assessment models, figure 4). As an example, in a sample of only 10 recoveries caught on a population with 10% of ♀ (and then 90% of ♂), there is a probability of less than 1% to obtain a sex ratio of 40% of females (or more) in this small random sample of 10 recoveries. Furthermore, the confidence in this small sample is also widely increased when similar percentages can be observed independently during several successive years in the recoveries of the 2 sexes. As a consequence, it can be concluded that such *small numbers of sexed recoveries are probably sufficient to be strongly indicative of the sex ratio at age*

and of the relative Mi suffered by each sex, at least allowing to identify if there is/or not, a major difference in the Natural mortality of the 2 sexes

As a conclusion, the differential growth curves of bigeye and yellowfin ♂ and ♀ and the levels of sex ratio at age that have been observed in the Indian Ocean would appear to be already realistic results, even when they were based on a quite small sample (keeping in mind that there is no doubt that larger samples would of course be more significant).

2 major and new results are apparent in these Indian Ocean results:

- the asymptotic sizes of yellowfin and of bigeye appear to be significantly different for ♂ and ♀ : males being approximately 10 cm larger than females
- Natural mortality of the 2 sexes showing similar levels, but slightly larger for female yellowfin after 6 years of age.

However, it remains widely questionable if these results can be extrapolated to yellowfin and bigeye caught in other oceans, keeping in mind that the great similarities in the yellowfin sex ratio at size permanently observed world wide would at least suggest this possibility. The best or only way to solve this fundamental biological uncertainty would be to carefully sample the sex of future recoveries in the Pacific and Atlantic oceans, as there are today very good prospects to recover many large tagged yellowfin and bigeye in the Pacific Ocean, following the active tagging programs conducted in this ocean.

4- On the dynamics of tuna stocks in the hypothesis of (1) combined sex studies as today, or (2) separate sexes

It is very easy to simulate population sex ratio at size expected from an hypothetical level of natural mortality at age of the 2 sexes, for instance assuming the level of Mi by sex assumed for yellowfin in the EPO. An example of results from such simulation are given by figure 15.

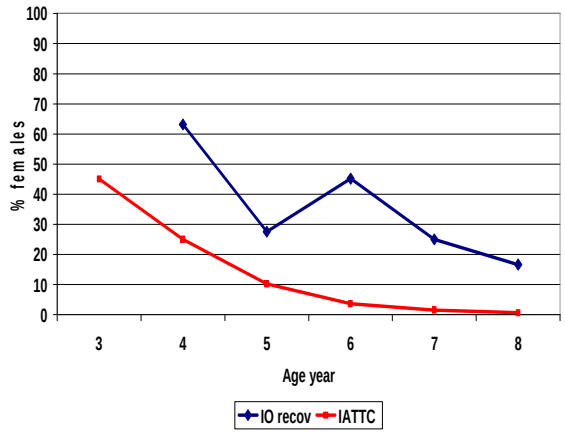

Figure 15: Red curve showing a yellowfin simulated sex ratio at age in the hypothesis of the IATTC Mi/sex, and sex ratio of yellowfin recoveries

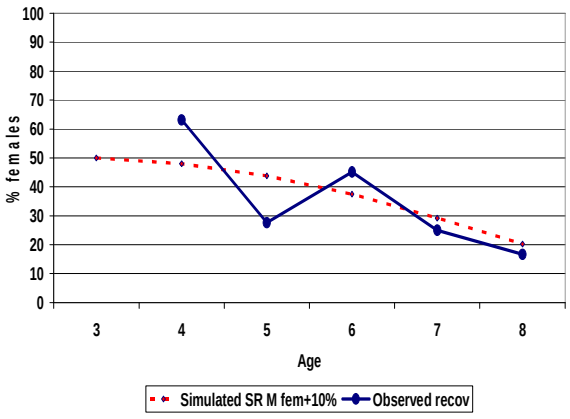

Figure 16: Red curve showing a simulated sex ratio at age in the hypothesis of male Mi 10% higher than Mi of females , and sex ratio of yellowfin recoveries

This type of simulation would indicate that, in the IATTC hypothesis of very high Mi of female yellowfin, females would be vanishing much more quickly than it was observed in the IO recoveries (figure 15). Simulations also indicate that the yellowfin sex ratio at age observed in the IO recoveries would approximately correspond to a level of M approximately 10% higher for females (age 3 to 8) (figure 16). If these Indian Ocean results are also valid in other oceans, their present stock assessments models combining the 2 sexes may tend to be widely unrealistic: when in reality, females caught at smaller sizes would have ages similar to larger males, population sizes of ♂ and ♀ being similar in numbers at age. Consequently, spawning biomass of mature females may tend to be widely underestimated in the today models: they are still alive, getting old, but much smaller than males and as a consequence fishing mortalities cannot be estimated well when the 2 sexes are combined (as today).

It can be estimated (based on average CAS and average sex ratio at size in the EPO) that the significant catches of large yellowfin > 140 cm in the EPO are widely dominated by males (figure 17), probably because of the larger asymptotic sizes of males?

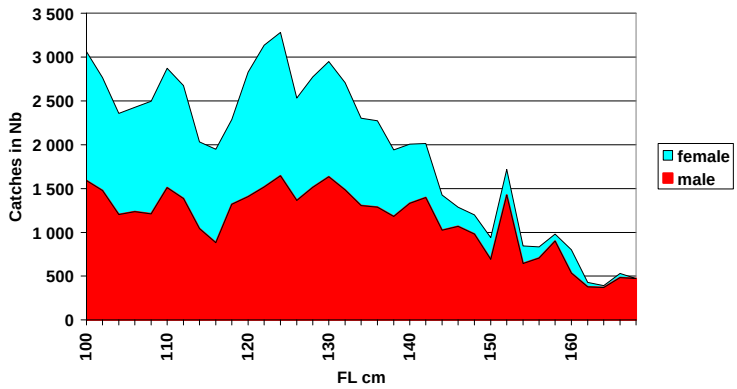

Figure 17: Estimated catch by sex of yellowfin in the EPO, based on average CAS period 1990-2006 and sampled sex ratio at size

There is no doubt that in this context, the real catch at size of adult BET & YFT should be permanently estimated by sex, for instance sampling them in the canneries!

This is at least a serious pending question that would need more investigations. In a first step, a MSE approach should help to explore the nature and importance of these biological uncertainties. In a second step this question would probably a need for alternate stock assessment models that would allow to handle biological heterogeneity between sexes.

5- Recommendation:

Two strong recommendations are proposed f*ollowing our tagging 0results presently obtained in the Indian Ocean:*

1) Scientific sampling of sexes of adult recoveries:

Our first recommendation is that all tagged tunas recovered in the Pacific and Atlantic oceans after long periods at liberty (yellowfin and bigeye), should be very well sampled by scientists: obtaining for a high percentage of these recoveries, and with a full confidence, their exact fishing date, their exact size and their carefully validated sex. It should also be recommended that large SKJ recovered should also be sampled, as in the Indian Ocean it

appears that growth of adult SKJ was too fast compared to the basic model, and that this anomaly may also be linked to a sexual growth. This recommendation should be put into action (1) for the recoveries of the tagging programs recently conducted in the Pacific Ocean by SPC/WCPFC and by the IATTC and (2) for the ICCAT large scale tagging programme planned in the Atlantic. These recoveries of adult tagged tunas should be widely facilitated in the Pacific Ocean by the very high rate of observers on board of purse seiners in the entire Pacific Ocean. These observers should also be in charge of (1) perfectly measuring the sizes of these recoveries and (2) to carefully identify their sexes (following a formal agreement with the tuna boats owners).

2) Improve stock assessment models in order to incorporate better the biological heterogeneities between male and female

A 2nd (and probably more complex?) recommendation would target the need to improve stock assessment models **in order to incorporate better** the biological heterogeneities between male and females. Stock assessment scientists should already start working upon new and improved stock assessment models that, when necessary, will be able to incorporate this biological heterogeneity in growth. These stock assessment models should be working by sex, based on an underlying population stratified by sex, ♂ and ♀ showing independent Mi and growth. This future improved modelling by sex should be based on the real Catch at size of adult BET & YFT that should be permanently **sampled and estimated by sex**, for instance sampling them in the canneries!

This research work should preferably be a join effort of the various tuna RFO, and conducted at a world wide scale, in the hypothesis that the Indian Ocean results would also be obtained soon in other oceans (based on the world wide similarities in the observed sex ratio at size).

Acknowledgments

This sampling of large yellowfin and bigeye recoveries was not planned nor budgeted in the original IOTC tagging program. It was made possible by a full and active cooperation of many skippers and owners of the EU purse seiners and most of them made available free of charge to scientists their valuable recoveries of large tunas. They should be fully acknowledged by science! Additional acknowledgments should also be given to the SFA staff of field technicians who have been doing the difficult task to identify and to obtain these tagged tunas, and to sample them with great care.

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