Analysis of the recoveries by sex of adult yellowfin and bigeye in the Indian Ocean

by Alain Fonteneau and Jean Pierre Hallier

Summary

This paper analyzes the recoveries of 99 adult YFT and 104 BET recovered during the 2009-2016 period with an identification of their sex, sizes and exact time at liberty, following the IOTTP tagging program ran in the Indian Ocean by the IOTC in 2005-2009. These recoveries clearly show a distinct growth between the 2 sexes and a lower asymptotic size of the females for both species. They also show that natural mortality of adult male and female are very similar for BET, while the natural mortality of adult female YFT appears to be significantly higher. These two biological parameters are of key importance in all the analytical stock assessments analysis, and the paper recommends to study the feasibility to incorporate sexes in future SS3 stock assessment models and to evaluate the consequences of using these more realistic parameters in the models.

Key words: tagging, recovery, yellowfin, bigeye, sex, growth, natural mortality, Indian ocean

1-1- Goals and history and of these peculiar recoveries

It was decided during the IOTTP that it would be very interesting to identify the sexes of carefully measured recoveries of adult YFT and BET. These recoveries by sex were targeting two scientific goals: (1) to evaluate the growth rates and the asymptotic sizes of adult males and females YFT and BET and (2) to evaluate if the natural mortality of the adult males and females was at similar or at widely distinct levels (as it has been often assumed in various stock assessment analysis, for instance by the IATTC). This sampling program was targeting to measure the difference in the trend of Mi of adult YFT and BET, and not their absolute levels, following the conclusion of Aanes et al. (2007).

Natural mortality at age and by sex and growth by sex are probably the two most influential parameters in most tuna fisheries analytical stock assessment models and their subsequent management recommendations, because these two biological parameters directly condition the stock productivity and the reference points used for fisheries management advice.

This sampling project was also based on the personal strong view expressed by John Gulland in various ICCAT meetings, stating that tagging results are providing the best way to measure tuna growth when scientists have been carefully measuring the same individual twice during its life and after a well-known number of days. On the opposite, if the age readings of hard parts are also interesting, their results remain often quite uncertain, because they are

facing cascading but unknown uncertainties in the preparation of the hard parts, in the reading equipment, in the expertise of the readers, in the biological consistency of daily rings, etc.

A meeting was organized in 2008 in Spain, between various EU scientists involved in the IOTTP program and the managers of the three associations of EU tuna purse seiners (ORTHONGEL, ANABAC & OPAGAC). It was approved during this meeting by the managers that the recoveries of adult YFT and BET landed in Seychelles would be offered by the fishery sector, free of charge to science and to the Seychelles Fishing Authority (SFA).

The recommendations from this meeting have been quite successfully followed, and as a result, 203 adult tunas, corresponding to nearly 12 tons of tunas (corresponding to an average landing price close to 30000 Euros) have been offered to science and very well sampled by SFA scientists, each of these recoveries being carefully measured and weighted by well trained technicians in the SFA laboratory.

This scientific operation was unique in the history of tuna tagging, as these results have never been obtained in any of the other tuna commissions (ICCAT, IATTC and SPC/WCPFC)

2-IOTTP tagging of YFT & BET

Significant numbers of tunas were tagged by IOTC during its IOTTP program between 2005 and 2007: 56200 YFT and 35200 BET. These tunas have been most often tagged at small sizes: average size of 59 cm for YFT and 54 cm for BET (at average weights close to 4 kg, see figure 1). Following these large-scale tagging, large numbers of adult YFT and BET have been landed by PS during subsequent years, mainly in Seychelles, and an increasing proportion of these adult tunas have been very well sampled by SFA scientists during the period 2009-2015, reaching high percentage of sex sampling, since 2011 for BET and since 2012 for YFT (see table 1)

Table 1: Numbers of adult YFT & BET (>1m) recovered yearly on purse seiners in the Indian Ocean, total numbers and numbers recovered with known sexes.

	Sex recov PS		Nb Recov PS		Nb Recov Total			
Year	YFT	BET	YFT	BET	YFT	BET	%sexYFT	%SexBET
2009	12	9	445	77	470	106	2,7	11,7
2010	27	9	141	55	145	85	19,1	16,4
2011	25	35	64	43	69	62	39,1	81,4
2012	27	28	35	42	35	66	77,1	66,7
2013	1	4	3	4	4	6	33,3	100,0
2014	4	8	5	10	7	12	80,0	80,0
2015	3	11	4	11	4	15	75,0	100,0
2016	0	0	0		0	2		
Total	99	104		242	734	354		

A total of 99 YFT and 104 BET were identified at recovery with known sexes and sizes perfectly measured without errors. Sizes at tagging of the recovered tunas were very similar for male and female of YFT and of BET (figure 1) and it can easily be assumed that the sex ratio of the tagged tunas was close to 50/50.

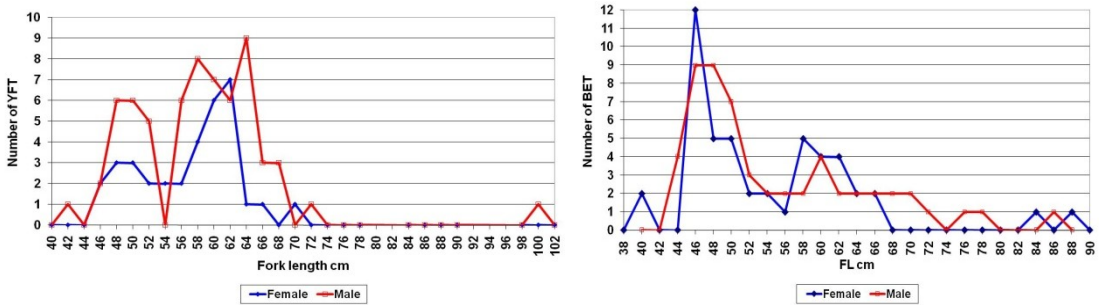

Figure 1: Tagging sizes of the adult YFT (Fig 1a, left) and of the adult BET (fig. 1b right) recovered with known sex

3- Growth and asymptotic sizes of YFT & BET

3-1- Growth of recovered YFT

Our view is that the following figures 2a & 2b are showing well the fit, good or bad, between the theoretical growth (Farley et al 2023) and the apparent growth of the observed YFT recoveries, knowing well the size of the tagged tuna and simply assuming that each fish was tagged at its theoretical age.

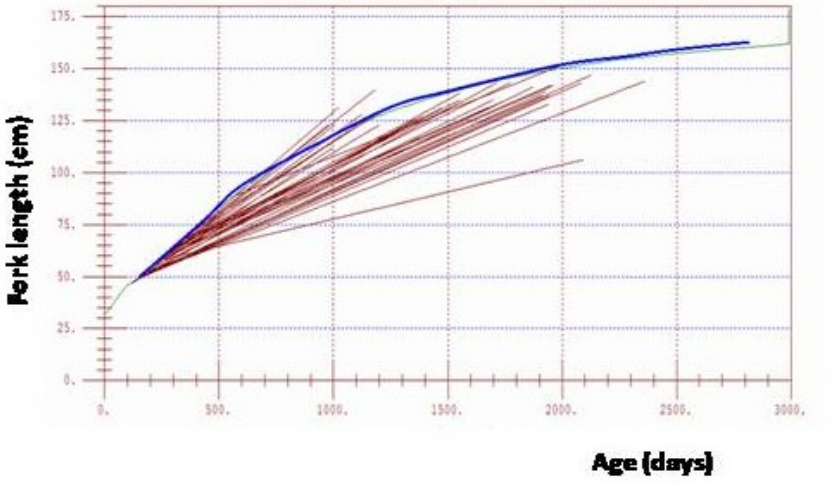

Figure 2a. Changes of size between tagging and recovery of female YFT and growth curve used in the most recent SS3 analysis.

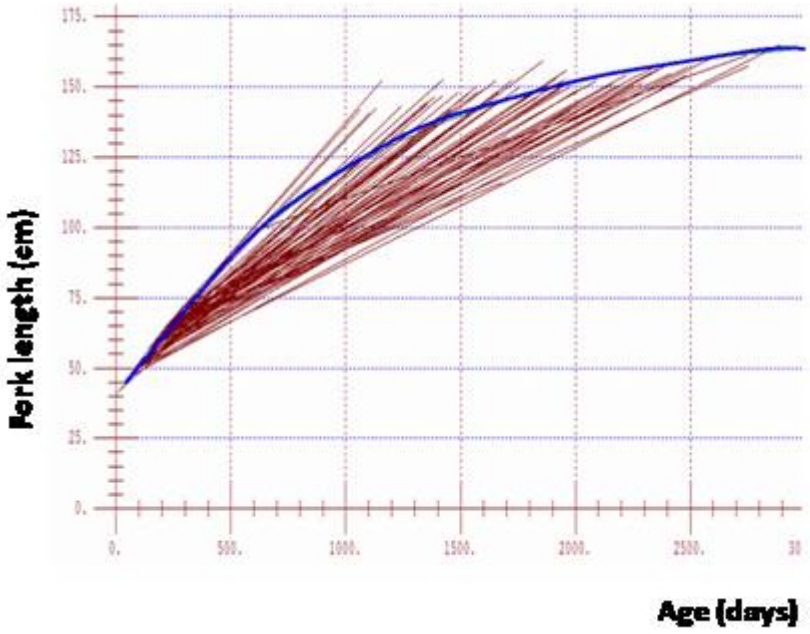

Figure 2b: Changes of size between tagging and recovery of male YFT and growth curve used in the most recent SS3 assessment.

These 2 figures are showing:

(1) that a majority of male YFT are growing faster and often at higher sizes that in the theoretical curve

(2) that most female YFT are growing at much lower levels that in the theoretical curve

Figure 3 is also showing the same differential growth pattern of the 99 sampled male and female YFT.

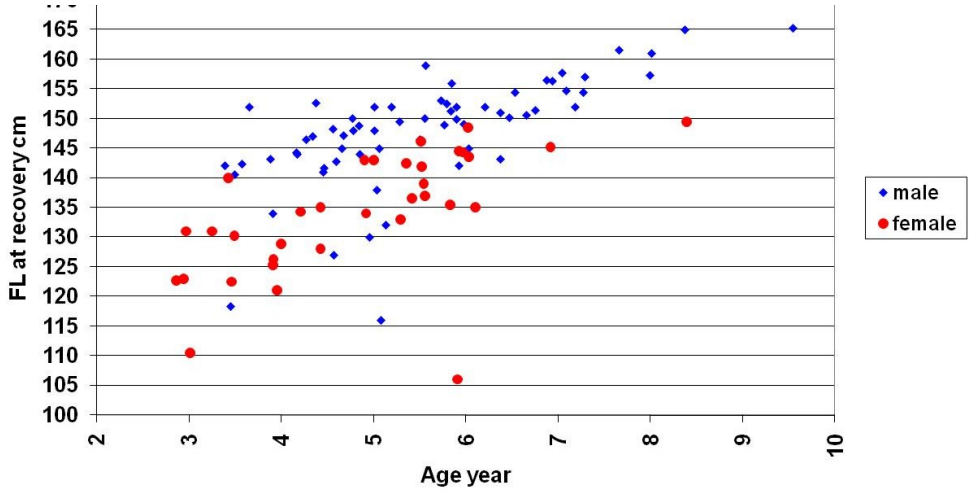

Figure 3: Sizes and ages at recovery of the 99 YFT recovered with known sex and age

The following table 3 summarizes the observed differences of the YFT growth of the 2 sexes, comparing the average sizes at recoveries by sex, of all the recoveries and of the 15 oldest recoveries.

Table 2: Sizes and age of the recovered adult YFT by sex.

selected age recoveries	sex	Average FL cm	Average age year
All recoveries	male	148	5,5
All recoveries	female	134	4,8
15 oldest recoveries	male	157	7,4
15 oldest recoveries	female	140	6,3

The observed difference of 17 cm between the sizes of the 15 oldest recoveries of male & female YFT, caught at similar average ages, are probably indicative of the difference between the asymptotic sizes of the 2 sexes (as the growth of the very old fishes appears to be very limited). This range of differences between the asymptotic sizes of male and female YFT was already well identified since the IOTTP symposium in 2011 by all the growth studies, but this result was not really used in the stock assessment models used by the IOTC.

3-2- Growth of recovered BET

Figures 4a & 4b are showing the fit, good or bad, between the theoretical growth (Farley et al 2021) and the apparent growth of the observed BET recoveries, knowing well the size of the tagged tuna and simply assuming that each fish was tagged at its theoretical age.

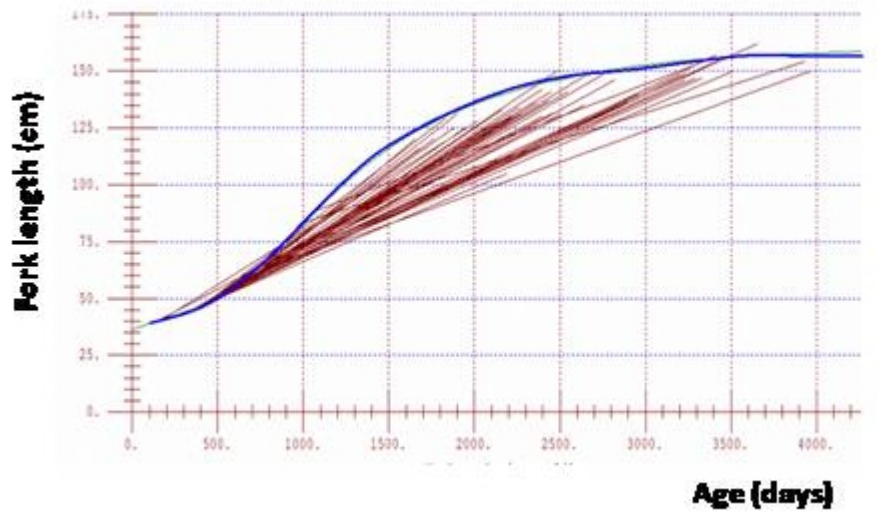

Figure 4 a. Changes of size between tagging and recovery of female BET and growth curve used in the SS3

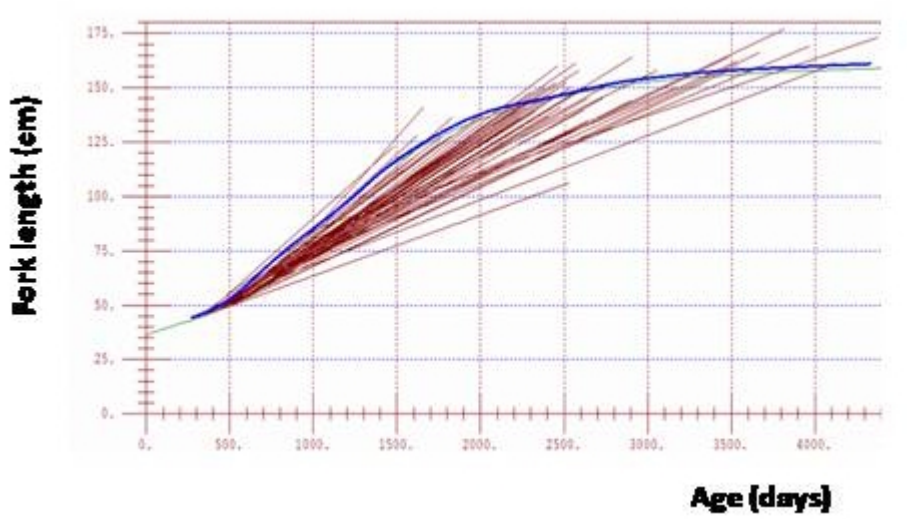

Figure 4b. Changes of size between tagging and recovery of male BET and growth curve used in the most recent SS3 analysis

Most male BET are showing faster growth than in the model, the opposite for female; in such a context, the use by SS3 of a single average growth curve will be questionable: the age of many old but small female being probably misclassified in the stock assessment model as being catches of younger individuals. This potential problem is probably worse for BET than for YFT, because of the large amount of female in the catches of adult BET, well shown by the numbers of BET recoveries by sex and by age (figure 5).

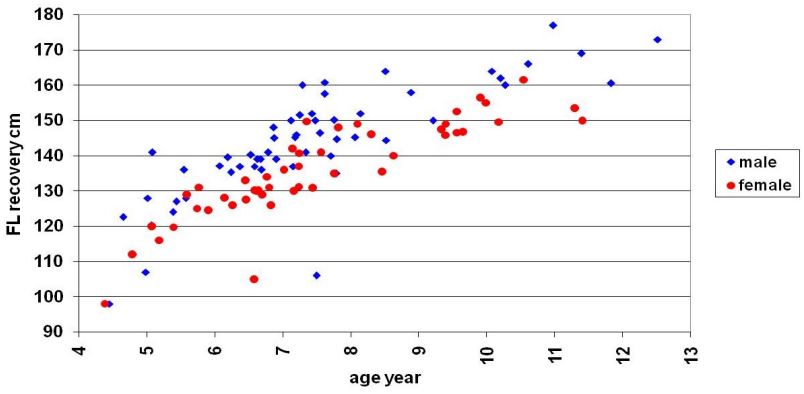

Figure 5: Sizes and ages at recovery of the 104 BET recovered with known sex and age

The following table 4 summarizes these observed differences of the 104 BET growth of the 2 sexes, comparing the average sizes at recovery and the average age of these recoveries by sex, for all the BET recoveries and for the 15 oldest recoveries.

Table 3: Sizes and age of the recovered adult BET by sex.

selected age recoveries	sex	Average FL cm	Average age
All recoveries	male	143	7,4
All recoveries	female	136	7,5
15 oldest recoveries	male	159	9,8
15 oldest recoveries	female	149	9,7

The observed difference of about 10 cm between the sizes of the 15 oldest recoveries of male & female BET, caught at the same average ages, are probably indicative of the difference between the asymptotic sizes of the 2 sexes (as the growth of the very old fishes appears to be very limited). This range of differences between the asymptotic sizes of male and female YFT was already well identified since the IOTTP symposium in 2011 by all the growth studies, but this result was not really used in the stock assessment models used by the IOTC.

Our conclusion is that the pattern of asymptotic sizes of adult male & female YFT & BET would be quite similar to the sizes of adult humans, as shown by figure 6.

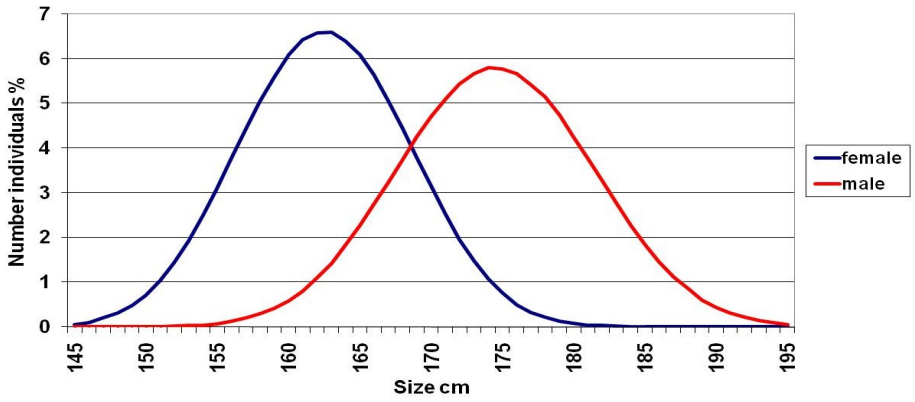

Figure 6: relative frequency of adult human sizes of European male and female in 1958 (from Stuart and Steveson 1959)

- Showing a significant difference in their asymptotic sizes: male showing higher average sizes than female

- Showing a variance of the maximal sizes of male and female that is quite similar to mankind: large males being widely dominant at sizes over their asymptotic sizes, small females being widely dominant at sizes lower than their asymptotic sizes. The human population also showing a mixture of the 2 sexes at sizes between the L infinity of females and males.

3-3- Estimates of potential Stock assessment errors assuming a single growth rate of the species (based *de facto* on the larger sizes and the L infinity of males)

It is difficult to estimate the potential causes of this type of errors in a statistical model such as SS3 (Methot and Wetzel 2013) commonly used by various tuna RFMOs or the MULTIFAN CL (Hampton and Fournier 2001) model built for the analysis of tuna stocks, used by SPC and WCPFC. However it is quite easy to evaluate qualitatively the potential bias due to a lower infinity of the females: many large females, for instance for large YFT at sizes between 130 and 150 cm (then at ages estimated by the recoveries between 4 and 8 years) being misclassified by SS3 as much younger adults. As a result, if our IOTTP recoveries by sex are showing the real growth of each sex, then most of the present stock assessment analysis of BET and YFT would be facing 2 potentially serious bias:

(1) The fishing mortality of the old adults (for instance over 5 years) will be (potentially widely) overestimated, while the fishing mortality on young adults will be correspondingly underestimated

(2) On the opposite : the spawning biomass of the old adults (for instance over 5 years) will be overestimated, while the biomass on young adults will be correspondingly underestimated

These serious potential problems are faced by YFT & BET, but probably at distinct levels as the difference between asymptotic sizes of male & female are more important for YFT than for BET. However, as the natural mortality of adult female YFT appears to be higher (see paragraph 4-1-2), the biomass of adult female YFT tend to be reduced; as a result, the adult stock tend to be dominated by the growth of males at the oldest ages.

On the opposite, while the difference between asymptotic sizes of male & female are less important for BET, the natural mortality appears to be similar for male and for female (see paragraph 4-1-3), and as a consequence the growth curve of males may introduce serious bias in the stock assessment of BET.

4- Relative Natural mortality of adult male and female YFT & BET

4-1- Numbers of recoveries by sex as a function of their estimated ages

4-1-1-Overall

Our view is that the knowledge of sexed recoveries is the best (and only?) way to estimate the difference in natural mortality between adult male and female YFT and BET as the age of each recovery is easily and well estimated, simply:

(1) Estimating the age at tagging: simply assuming that the fish was tagged at the age of the growth curve

(2) Adding to this estimating age the observed time at liberty between tagging and recovery

The knowledge of the age and sex of recovered tunas allows to estimate the numbers of tunas recovered as a function of their sex and ages: these tables allow to estimate if the natural

mortality of adult YFT and BET are identical, or if they are widely distinct (as it has been often assumed in some stock assessments analysis)

4-1-2- Recoveries of YFT by sex and by age

These numbers of YFT recoveries are given by table 4

Table 4: Number of YFT recovered with known sex and age as a function of the age of the recoveries

sex	3	4	5	6	7	8	9	10	total
Female	6	10	6	11	1	1	0	0	35
Male	3	11	18	17	10	4	0	1	64
Total	12	25	29	34	18	13	9	11	99

These numbers are also well summarized by figure 7 showing the percentage of adult females recovered as a function of their estimated ages at recovery.

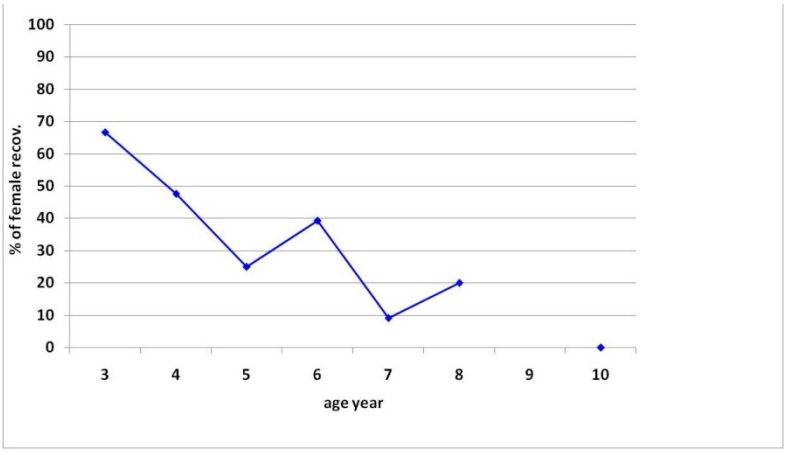

Figure 7 : Percentage of female YFT recoveries as a function of their ages at recovery

These table and figure are showing that the natural mortality that the Mi of adult YFT females appears to be higher than for male, at least at ages over 4 years: only 19 females vs 50 males have been recovered at ages over 4 years, and female recoveries showing a steadily declining amount after an age of 4 years. This decline of the adult female YFT was also shown by the pattern of sex ratio at size of adult YFT landed by purse seiners in the Indian Ocean (see figure 8) .

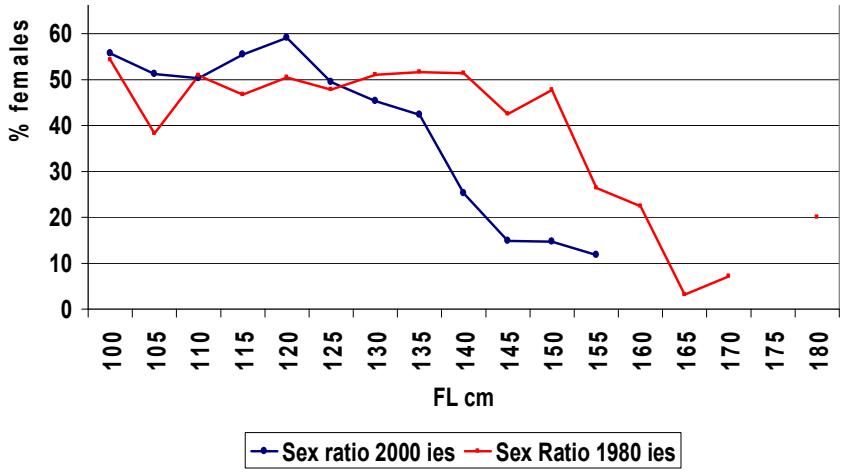

Figure 8: Percentage of female in the sampled catches of YFT in the Indian Ocean: historical samples (80ies) and recent samples (early years 2000)

This figure is showing during the 2 studied periods a marked decline of the percentage of adult female YFT in the sampled landings of PS, but this decline was observed at distinct sizes in our 2 periods: after 150 cm in the historical fishery and after 125 cm during the period 2003-2006 (taking note that the levels and profile of the PS catch at size of purse seiners was nearly identical between these 2 periods). It is not clear if this apparent change in the pattern of sex ratio at size would be artificial (for instance due to a quite unrealistic sampling bias) or a real one, due to major changes in the YFT stock (for instance due to its increasing exploitation rates). It would be very interesting to update and to reinforce this sampling of the sex ratio at size of YFT

Based on the study of recoveries by sex, this decline of the amount of large female YFT in the catches of adult YFT observed since 1980 would be primarily due to a combination of 2 factors: (1) the asymptotic sizes of females that are clearly well under the L infinity of males (about 17 cm lower) and (2) the higher natural mortality of spawning females, for instance 10 to 20 % higher than for males.

4-1-3- Recoveries of BET by sex and by age

These numbers of BET recoveries as a function of their sex and ages are given by table 5

Table 5: Number of BET recovered with known sex and age as a function of the age of the recoveries

year	4	5	6	7	8	9	10	11	12	13	Total
Female	1	4	8	16	6	4	6	3	0	0	48
Male	1	8	6	19	9	4	3	3	1	1	55
total	2	12	14	35	15	8	9	6	1	1	103

These numbers are also well summarized by figure 9 showing the percentage of adult females recovered as a function of their estimated ages at recovery.

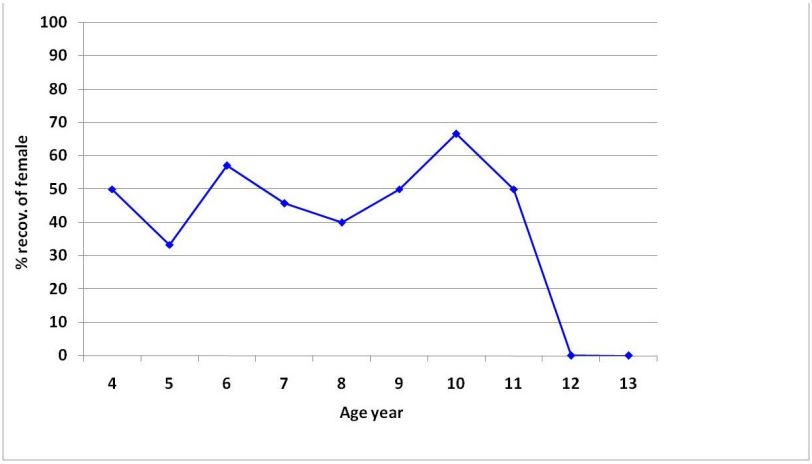

Figure 9: Percentage of female BET recoveries as a function of their ages at recovery

These table and figure are showing that the natural mortality of recovered adult male and female BET appears to be very similar or nearly identical, at least between ages 4 to 11 years. It should be noted that the natural mortality of adult females of YFT & BET assumed by the IATTC in the Eastern Pacific Ocean (EPO) are widely higher than for males, then widely distinct from the patterns observed for the Indian Ocean recoveries, see for instance figure 10 showing the levels of Mi of males and females presently assumed for YFT by the various tuna commission (keeping in mind that the fished population in the model is not stratified by sex)

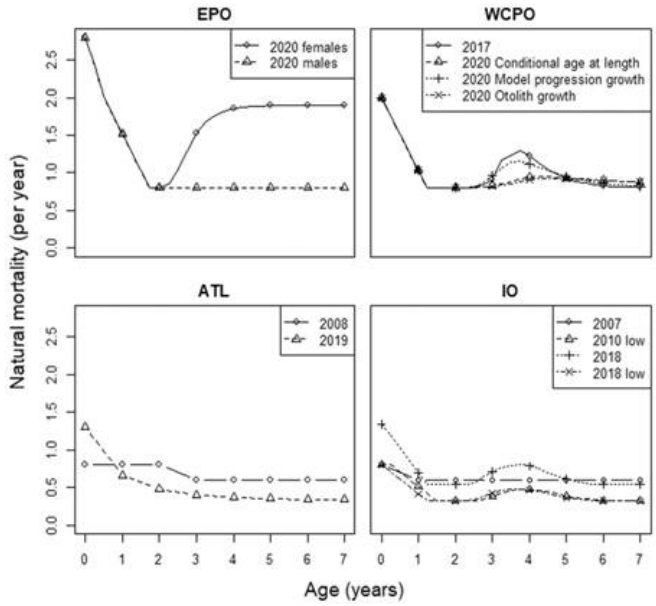

Figure 8: Natural mortality at age, total and/or for male and female YFT assumed in the recent stock assessments analysis of the 4 concerned tuna commission (taken from Hoyle et al 2023)

These assumed differences between the level of natural mortality at age used by the 4 tuna commissions in their stock assessment analysis are quite striking. In our view, they are also quite unrealistic, assuming that the Mi levels and trends by age and sex are probably quite similar in the 4 studied YFT stocks.

These assumed patterns of natural mortality at age are often in contradiction with the patterns observed in our recoveries:

- In the Indian ocean: the observed increase of female Natural mortality should produce a visible steady increase of Mi for the old YFT
- In the Eastern Pacific: the very high Mi of spawning females should produce a vanishing population of adult females at ages over 4 years (see figure 9), while these old females are declining but still quite abundant in our recoveries

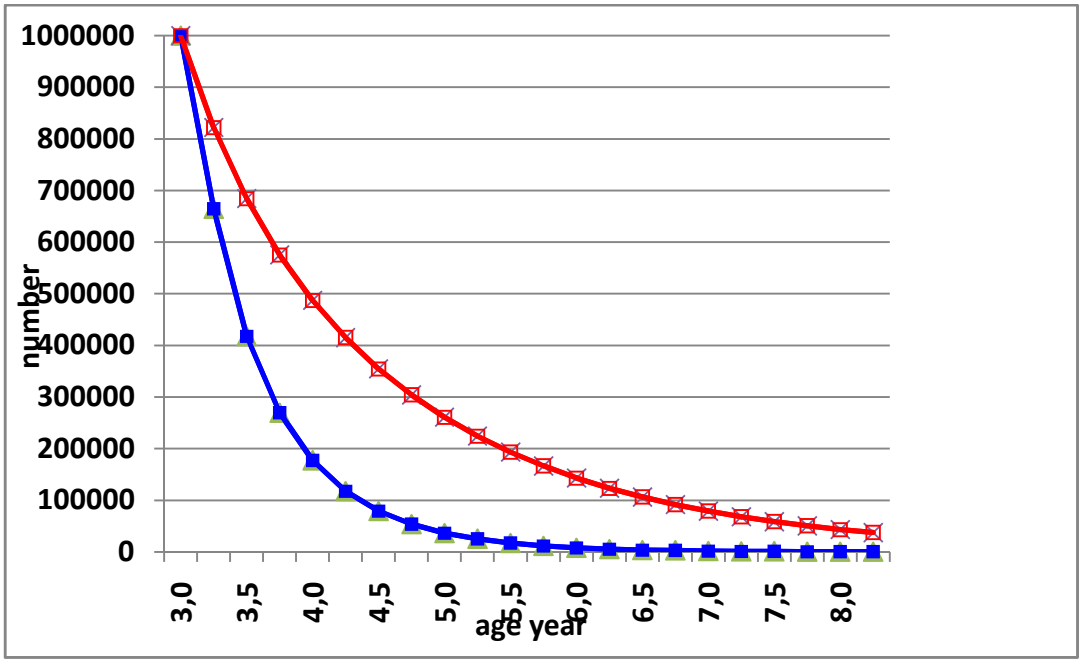

Figure 9: Decline of an initial population of 1000000 individuals suffering the natural mortality rates of adult male and female YFT assumed by the IATTC

If the real patterns of natural mortality of YFT by sex in the Eastern Pacific are similar to the pattern of Mi observed for the Indian Ocean recoveries, these differential levels of adult male and female Mi used by the IATTC would be widely wrong.

An ad hoc statistical analysis of the YFT recoveries by sex should be conducted in order to estimate better the relative levels of the female and male natural mortality.

4-2- Estimates of potential Stock assessment errors due to overestimated levels of natural mortality of spawning females

Based on the IOTC recoveries of adult YFT by sex, it would appear that Mi of adult spawning female YFT would be slightly higher than the Mi of adult male. This level of adult M of females is very important as it will condition the level of the biomass of the adult spawning females (this biomass of females being much more important than the biomass of male to condition the spawning potential of the stocks). If the Mi of females is overestimated, the levels of the spawning stock will potentially be underestimated by the assessment models. On the opposite, if the Mi of females is underestimated (IOTC?), the real potential level of the spawning stock will potentially be overestimated by the present assessment models. However these potential effects on the results of complex statistical models can only be estimated by ad

hoc alternative runs of the models, because of the multiple factors that are simultaneously handled by these statistical models. This potential risk of error would not be faced by the BET analysis, because our recoveries of BET are showing similar numbers of male and female even for the oldest ages.

5-Conclusion

Even if we have to keep in mind the limited numbers of sampled tunas used in this analysis:

- the observed sizes of recoveries of male & female BET & YFT are probably strong indicators of the differences between the asymptotic sizes of the 2 sexes in the Indian Ocean, and
- the numbers of adult male & female recovered as a function of their age, are strongly indicative of the relative natural mortality at age of adult male and female YFT & BET.

It was a pity to note that in the Atlantic the sex of the recoveries of adult BET and YFT was never identified during the AOTTP, the large scale tagging program ran by ICCAT in 2016-2017, while this research action was clearly recommended in the plan of the tagging program.

Based on these results, there is clearly a major interest , following any large scale tagging program of YFT, BET or BFT, to identify for as many recoveries as possible, the sex of the recovered adult. In the Indian Ocean, the potential cost of this action was a minor one, compared to the cost of any large scale tagging programs: its main potential cost of about 30000 Euros used to buy the adult YFT and BET recoveries was really a very minor cost compared to the IOTTP budget, close to 16 million Euros (keeping in mind that these tunas were offered by the Spanish and French owners of the EU PS).

This cost of buying the adult recovered tunas should easily be incorporated in the budget of all the future tagging programs targeting YFT, BET or BFT. Furthermore, this investment can be planned without any risk of failure (*just do it*), while most tagging operations are facing multiple uncertainties and risks! The scientific results obtained from this action are clearly of major scientific interest, for instance: (1) in order to improve the biological knowledge upon BET & YFT, and (2) more importantly in order to improve the stock assessment analysis. There is no doubt that Mi of adults and growth are 2 key stone parameters in all sequential population analysis, including in all the modern stock assessment models that are estimating the numbers of tunas at each age in the fished stocks and the fecundity of the stocks. The hypothesis that natural mortality and growth are nearly identical for both sexes and for all tuna species and stocks, is clearly questionable or inadequate. This hypothesis should be abandoned from future stock assessments analysis. The future incorporation of distinct growth and distinct natural mortality at age of male and female in the stock assessment models (SS3 or MFCL) would probably be quite complex, especially in

the absence of size sampling by sex of the landings, but it would be important to study and to test the feasibility to develop these improved methods.

Litterature

Aanes, S., Engen, S., Sather, B-E., Annes, R., 2007. Estimation of the parameters of fish stock dynamics from catch-at-age data and indices of abundance: can natural and fishing mortality be separated? Can. 1232 J. Fish. Aqut. Sci. 64, 1130–1142.

Aldrin, M., Aanes, F.L., Tvete, I.F., Aanes, S., Subbey, S., 2021. Caveats with estimating natural mortality rates in stock assessment models using age aggregated catch data and abundance indices. Fish. Res. 1242 243, 106071. 4

An. IATTC 2024. Stock Assessment Report 24. Status of the tuna and billfish stocks in 2022 (358p).

An. IOTC (2020). Report of the 22nd Session of the IOTC Working Party on Tropical Tunas, Stock Assessment Meeting. OTC–2020–WPTT22(AS)–R[E]_Rev1.

Dortel, E., Sardenne, F., Bousquet, N., Rivot, E., Million, J., Le Croizier, G., Chassot, E. (2015). An integrated Bayesian modeling approach for the growth of Indian Ocean yellowfin tuna. Fish. Res. 163, 69–84. https://doi.org/10.1016/j.fishres.2014.07.006.

Eveson, P., Farley, J. (2021). Investigating growth information for yellowfin and bigeye tuna from the IOTTP tag-recapture data. IOTC-2021-WPTT23-21.

Eveson, P., Million, J., Sardenne, F., Le Croizier, G. (2012). Updated growth estimates for skipjack, yellowfin and bigeye tuna in the Indian Ocean using the most recent tag recapture and otolith data. IOTC-2012-WPTT14-23.

Eveson, P., Million, J., Sardenne, F., Le Croizier, G. (2015). Estimating growth of tropical tunas in the Indian Ocean using tag-recapture data and otolith-based age estimates. Fisheries Research 163: 58–68.

Farley, J., Krusic-Golub, K., Eveson, P. Clear, N., Luque, P. et al. (2021c). Estimating the age and growth of bigeye tuna (*Thunnus obesus*) in the Indian Ocean from counts of daily and annual increments in otoliths. IOTC-2021-WPTT23-18.

Farley, J.H., KrusicGolub, K., Eveson, P., Luque, P., Fraile, I., Artetxe-Arrate, I., Zudaire, I., Romanov, E., Shahid, U., Razzaque, S., Parker, D., Clear, N., Murua, H., Marsac, F., Merino, G., 2023. Updating the estimation of age and growth of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean using otoliths (No. IOTC-2023-WPTT25-20). Indian Ocean Tuna Commission.

Hampton, J., and D.A. Fournier. (2001). A spatially disaggregated, length-based, age-structured population model of yellowfin tuna (*Thunnus albacares*) in the western and central Pacific Ocean. Marine and Freshwater Research 52, 937-963.

IOTC(2024). Stock assessment of yellowfin tuna in the Indian Ocean for 2024. by Agurtzane Urtizberea1, Giancarlo M. Correa, Adam Langley, Gorka Merino, Dan Fu, Emmanuel Chassot, Shiham Adam. 149p.

Laslett, G.M., Eveson, J.P., Polacheck, T. (2002). A flexible maximum likelihood approach for fitting growth curves to tag-recapture data. Can. J. Fish. Aquat. Sci. 59, 976–986.

Methot, R.D., Wetzel, C. (2013). Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fish. Res. 142: 86-99.

Richards, F.J. (1959). A flexible growth function for empirical use. J. Exp. Bot. 10(2): 290-301.29

Sardenne, F., Dortel, E., Le Croizier, G., Million, J., Labonne, M., Leroy, B., Bodin, N., Chassot,E. (2015) Determining the age of tropical tunas in the Indian Ocean from otolith microstructures. Fish. Res. 163:44–57. doi:10.1016/j.fishres.2014.03.008.

Williams, A.J., Leroy, B.M., Nicol, S.J., Farley, J.H., Clear, N.P., Krusic-Golub, K., Davies, C.R, (2013) Comparison of daily- and annual- increment counts in otoliths of bigeye (*Thunnus obesus*), yellowfin (*T. albacares*), southern bluefin (*T. maccoyii*) and albacore (*T. alalunga*) tuna. ICES J. Mar Sci 70(7): 1439–1450. doi:10.1093/icesjms/fst09

Zudaire, I., Artetxe-Arrate, I., Farley, J.H., Murua, H., Kukul, D., Vidot, A., Razzaque, S.,Ahusan, M., Romanov, E., Eveson, P., Clear, N., Luque, P., Fraile, I., Bodin, N., Chassot, E.,Govinden, R., Ebrahim, A., Shahid, U., Fily, T., Marsac, F., Merino, G., 2022. Preliminary estimates of sex ratio, spawning season, batch fecundity and length at maturity for Indian Ocean yellowfin tuna (No. IOTC-2022-WPTT24(DP)-09). Indian Ocean Tuna Commission