Growth rates and apparent growth curves, for yellowfin, skipjack and bigeye tagged and recovered in the Indian Ocean during the IOTTP

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Summary 1

This working paper analyzes the apparent growth rates of yellowfin, skipjack and bigeye tagged and recovered in the Indian Ocean as a function of their sizes. This study is based on the provisional recovery data released in June 2008 by the IOTC secretariat. The first step of the study describes the criteria used to eliminate various potential errors in this provisional recovery file. The analysis concentrates on the estimation of the apparent growth rates of the three species, as a function of their average sizes between tagging and recovery. This analysis does not directly target to fit a theoretical growth model to the recovery data. But apparent growth curves are deduced from growth rates, for the three species and provide size/age relationships which that may well be suitable as an input of assessment models. It was assumed that these observed results are often more realistic than a theoretical growth obtained through an inadequate growth model. These results are compared with the growth patterns previously estimated by scientists and used by the IOTC for its stock assessments. The comparison shows that yellowfin and bigeye growth are clearly following 2 stanza models and not Von Bertalanffy models, as these species are showing slower growth rates at their early juvenile stages. This 2 stanza model is also apparent for skipjack but at a lower degree. It can be noted that growth rates of yellowfin and bigeye appears to be very similar for juvenile fishes under 60 cm (and 4 kg), but later widely different, yellowfin showing a much faster growth than bigeye.

Summary of summary

Tagging results confirm that tuna growth curve shows two outstanding periods of accelerated growth: the post larval and the sexual maturation

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Résumé

De document de travail analyse les taux apparents de croissance en fonction de leurs tailles des albacores, listaos et patudos marques et récupérés à ce jour dans le cadre du grand programme de marquages de thons de la CTOI. Cette étude repose sur les données provisoires de recaptures disponibles en Juin 2008 et diffusés par le secrétariat de la CTOI. Le premier point de ce travail conduit à décrire les critères retenus pour éliminer diverses erreurs potentielles qui demeurent dans le fichier actuel. L’analyse se concentre ensuite sur l’estimation des taux de croissance apparents en function de la taille moyenne entre le marquage et la recapture. Cette analyse ne vise pas à ajuster un modèle de croissance sur ces données, considérant que les résultats actuels des taux de croissance en fonction de la taille peuvent déjà être introduits dans les modèles d’évaluation des stocks. En outre ce travail considère que de tells résultats sont souvent plus réalistes que ceux obtenus par un modèle de croissance souvent inadéquat. Ces résultats sont compares avec les taux de croissance précédemment employés par les groupes de travail de la CTOI pour ses évaluations de stocks. Cette comparaison montre que la croissance des albacores et des patudos suivent clairement des courbes de croissance à 2 “stances” et nullement des courbes classique de Von Bertalanffy, la croissance des juvéniles étant très ralentie aux stades juvéniles. Cette croissance ralentie de jeunes individus est aussi apparente pour les listaos, mais à un degré moindre. On note aussi que les taux de croissance des juvéniles d’albacore et de patudo sont très voisins en dessous de 60 cm (soit 4kg), puis très différents ensuite, l’albacore grandissant beaucoup plus vite que le patudo.

1- Introduction: goal, data and method

The main goals of the present working paper were to analyse the growth pattern of the 3 tuna species (yellowfin, skipjack and bigeye) tagged during the IOTTP programme. In order to do this, the potential problems and errors in the present IOTC file of the tuna recoveries (available in June 2008) were first identified and eliminated. In this study the growth rate of each species were estimated as a function of their sizes, and without targeting a modelling of these apparent growth rates. From growth rates, apparent growth curves and sizes at age were deduced. This approach has various major advantages:

- This result will show for the 3 species “an observed truth” in the size specific growth rates obtained from the tagging/recovery results (in the range of recovered sizes). On the opposite, growth models based on a theoretical equation are often difficult to fit to recovery data, especially because they are often mis-specified when compared to the real growth patterns observed on the recovered fishes (for instance Von Bertalanffy model applied to tunas), and because of the basic and major uncertainties in the real biological asymptotic sizes of these recovered tunas (the L infinity, the average size reached by an average cohort of very old fishes).

- At least these observed results could easily be compared to the estimated growth rates and growth curves obtained from other more complex *ad hoc* growth models.
- These growth rates at size can be easily compared between species, this comparison being for instance very interesting between yellowfin and bigeye.
- These basic growth rates at sizes can also easily be compared for a given species and between the results of tagging programs done in other oceans, such as the Atlantic, the Western and Eastern Pacific (when the results obtained from more or less complex given growth models are often much more difficult to compare).
- The growth curves derived from growth rates only cover the range of tag-recoveries data and thus cannot provide estimates of growth for largest adults (or for Linfinity). But a combined model can be built using the apparent growth curve for small and medium animals and a Von Bertalanffy models for the largest. Therefore, this provides size/age relationships required as an input of assessment models

2- Data and method

The recovery file was the June 8^{th} 2008 version released by the IOTC and this file still contains anomalies and errors. Various types of these errors, potential or/and obvious ones, have been first identified and eliminated from the basic file of recoveries circulated by the IOTC secretariat, as they may bias the subsequent analysis of growth rates. The following types of potential errors have been identified and subsequently eliminated from the analysis.

The second step of the work was to estimate for each species the average growth rate in each range of fork length.

2-1- Elimination of doubtful recoveries

The following types of potential errors have been identified and subsequently eliminated from the analysis.

- Reliability of fish measurement

This analysis has been only carried out on the recovery file selecting all the tags showing an index of Return Measurement Reliability classified as “GOOD”; all the records with a “BAD” quality have been eliminated. All length recorded in round fork length and in predorsal length have been converted in estimated fork length, when the reliability of the record was classified as being “GOOD” (a total of 1733 recoveries involved). This ad hoc conversion has been introduced assuming that the potential errors in such conversion are minor ones compared to the other ones in the recovery process..

Unknown or doubtful recovery date

The date of recovery is often, but not always, well identified in the recovery file, but in various cases this date is unknown (2797 yellowfin, 3789 skipjack and 1668 bigeye) and these records will be eliminated from the analysis. For some other recoveries, there are some uncertainties concerning the exact recovery date, for instance a fish caught at an unknown date during a 1 month trip). This uncertainty can be estimated in relative term of numbers of days, as the recovery file provides a range of two potential dates, between which the recovered tuna may have been fished. The ratio of days at liberty vs the number of uncertain days has been calculated for each recovered tag, and only the recoveries showing an uncertainty lower than 10% have been kept for the growth analysis. A total of 2854 recoveries (911 yellowfin, 1536 skipjack and 407 bigeye) have been identified following this basic criterion about the fishing date uncertainties.

Species changes between tagging and recovery:

A basic criterion that the species should be identical at tagging and at recovery has been accepted and used in the present analysis. Some of these changes of species could have been "acceptable", for instance when a small tagged bigeye was misidentified during its tagging as being a yellowfin, and later recovered as being a bigeye, its real species (so called "*Pianet effect*": a well know ORSTOM tagging pioneer, he tagged several yellowfin during the early seventies in the Atlantic, but all these yellowfin were recovered later as bigeye…..). However, as the reasons explaining these species changes remain questionable (for instance they may well be due to errors in the identification of a sequence of tags numbers during the tagging), all these questionable recoveries have been eliminated from this analysis. A total of 53 recoveries (25 yellowfin, 13 skipjack and 15 bigeye) have been eliminated using this criterion.

Errors in tagging/recovery sizes

It appears that even after the elimination of recoveries showing an index of BAD Return Measurement Reliability and of our 3 other criterions, there are several potential fishes showing highly unrealistic growth rates: too fast, too slow or quite often negative ones. The elimination of recoveries showing negative growth could easily be done, but this elimination is not satisfactory, unless when the opposite "too fast growth errors" can also be identified eliminated (Otherwise, the elimination of negative growth tend to introduce a systematic negative bias in the assessment of the growth rates). In such spirit, a small and arbitrary percentage of 1% of the slower and faster growth rates have been eliminated for each species from the recovery file. It was assumed that this small amount of data loss cannot introduce a serious bias in the subsequent growth analysis. This selection eliminates a total of 280 recoveries (94 yellowfin, 134 skipjack and 52 bigeye recoveries, 50% of each set showing too fast and 50% too negative growth rates).

Minimum duration at liberty

All the tunas with a too short duration at liberty over 30 days were kept for the present growth analysis in order to allow some visible growth between tagging and recovery. A total of 2844 recoveries (911 yellowfin, 1536 skipjack and 407 bigeye) have been identified and eliminated from this analysis using this criterion.

Tuna shrinkage?

It appears from the literature (for instance in Schaefer and Fuller 2006) that there may be a systematic bias in the analysis of the recovery data, due to tuna shrinkage: sizes of tagged fishes are always taken on live tunas during the tagging operation, while the sizes of the same fish are most often measured on frozen tunas (frozen in brine, and in wells where tunas are most often severely "compressed"). This systematic shrinkage has been estimated for bigeye by Schaefer and Fuller 2006 at about 1.95 % of the original fork length, this shrinkage being simply due to the fact that a frozen tuna measured during its landing tend to most often show a bended or twisted shape, and subsequently an average loss of size. There are very few studies of this phenomenon, but if it is real and systematic -and this is probably the case- it would leads to a systematic loss of length + or - in proportion of the total fish length. In such context, all the present growth analysis have been conducted under 2 working hypothesis:

(1) no shrinkage

(2) a shrinkage of 2 % of the fork length of all the recovered tunas, due to a post mortem effect and to their freezing (a quite reasonable results obtained by Schaefer and Fuller on bigeye; the same hypothesis of shrinkage being used for the 3 species).

Numbers of selected recoveries

The cascading selection of the criterions previously described did allowed to select the following numbers of tunas that will be used in the growth analysis.

Table 1: Numbers of tunas in the original recovery file used (June 2008) and after elimination of recoveries that were estimated to be doubtful

Species	Total recoveries	Selected recoveries
Yellowfin	7994	4698
Skipjack	11502	6707
Bigeye	4528	2581
Total	24024	13986

2-2- Analysis and method

This paper estimates the average growth rates as a function of their sizes, by fork length classes of 2 cm. The same calculations are done for the 3 species tagged and recovered: yellowfin, skipjack and bigeye. For each selected recoverie, the growth rate is estimated comparing the size at tagging (L1) and at recovery (L2), as G=(L2-L1)/Δt.30 (where Δt is the duration at liberty in day) . This growth rate, expressed in cm/month, is considered an observation of the growth rate for the average size (L1+L2)/2. Then, mean growth rates by 2 cm classes are calculated, as well as standard deviations and confidence intervals of estimate for each class.

Therefore, an average growth rate Gi is estimated for each ΔLi size class. From there, we derived a relationships between the relative age of fish and their size. Starting at age 0, for the first size class, ages associated to lengths Li+1=Li+ΔLi are calculated step by step as ti+1 = ti + ΔLi/Gi. Values of Li and ti are used to draw the related growth curves. Such curves only cover the size range where tag-recoveries are observed. For the largest tunas, growth curves are completed using a von Bertalanffy model estimated in previous studies.

The hypothesis of a tuna shrinkage (see above) has been also added in an additional calculation of each of these apparent average growth rates.

All these results are given for each species using 3 forms of figures:

(a) the growth rates at size, shown as the average monthly increase of size estimated in each class of 2 cm of fork length, and expressed in terms of cm per month,

(b) the traditional curve showing the growth patterns as a function of time/relative age in the range of recovered sizes and the Von Bertalanffy growth pattern used in the previous IOTC stock assessments, are also shown. These figures are also associated for each species to the figures showing the average catches at size observed in the Indian Ocean during recent years (average period 2000-2006), in order to illustrate for each species the correspondence between tagged and fished sizes.

(c) a “PLOTREC” figure (cf Fonteneau and Nordstrom 2000) showing the observed growth pattern and the observed growth of all the tags selected and recovered after at least 3 month at liberty. This PLOTREC figure is considered as being a useful tool that is showing well the potential discrepancies between the estimated growth pattern/curve, and the real apparent growth of the individual tunas tagged/recovered.

3- Results

3-1- Yellowfin growth

The present analysis was based on the analysis of 4698 recoveries, and its results are showing that the growth of yellowfin tuna as estimated from recoveries, tend to show a quite clear 2 stanza pattern (see figure 1):

=> between **40 cm and 60 cm**: during their early stages in the PS fishery, in this range of sizes (about 1 to 4 kg), yellowfin tunas tend to show a very slow growth at an average monthly rate of 1.5 cm /month, when the previously used Von Bertalanffy model proposed by Stequert et al 1996 estimated an average growth rate of 3.8 cm / month in this range of small sizes. Although uncertainty is rather big due to the small number of very small yellowfin tagged, these smallest sizes tagged, for instance in the range between 38 and 44 cm, tend to show higher growth rates. Growth rates are minimum around 48cm, followed by a flat and low growth rate until about 58 cm..

Commentaire [DG1] : Mais si, c'est significatif. Cf. les intervalles de confiance.

=> between **60 to 75 cm** (about 8 kg) of fork length, there is a steady increase of the apparent growth rate, from 1.4 cm/month to nearly 4 cm/month (average 2.5 cm/month), when the previously used Von Bertalanffy model proposed by Stequert 2004 estimated a declining growth rate at an average of 3.2 cm / month in this range of sizes.

=> fishes **larger than 75 cm** are showing a slowly declining growth rates, then a trend similar to the Von Bertalanffy model, but at relatively high absolute growth rates of 3 cm/month, that are constantly higher than the growth rates of 2.2 cm /month estimated by the Stequert et al 1996 Von Bertalanffy model in this size range.

Furthermore, these growth rates could be increased of about 10 %, when assuming a 2 % shrinkage factor after the tuna death and their freezing (Figure 10a).

As a conclusion, based on these results, thecomposite growth model is built, first using the recovery data in a range of size between 38 and 90 cm, and later using the Stequert et al 1996 Von Bertalanffy growth rates at size after 90 cm. Such rebuilt growth pattern has been used to make the figure 7a and its plotrec diagram (Fonteneau and Nordstrom 2000) showing the recoveries and this growth curve. Figure 7b shows the same recoveries adjusted to the Stequert et al 1996 growth model (and clearly, as expected, this fit to the Von Bertalanffy model is not good).

3-2- Bigeye growth

The present analysis is based on the analysis of 2581 recoveries, and its results are showing that the growth of bigeye tuna estimated from recoveries, shows as for yellowfin, a clear 2 stanza pattern (see figure 3):

=> **40 cm and 55 cm**: during their early stages in the purse seine fishery, in this range of sizes (about 1 to 3.5 kg), yellowfin tuna tend to show a very slow growth at an average monthly rate of 1.57 cm /month, a growth rate nearly identical to levels observed for yellowfin in other oceans (when the previously used Von Bertalanffy model proposed by Stequert 2004 estimated an average growth rate of 3.2 cm / month estimated in this range of sizes.

=> between **55 to 70 cm** (about 7.2 kg) of fork length, there is a steady increase of these apparent growth rates, reaching an average rate of 2.3 cm/month during the period.

=> fishes **larger than 70 cm** (these tunas being still smaller than 1meter) are showing rather stable growth rates, at an average rate of 2.4 cm/month, a trend and an absolute level that are similar to the Von Bertalanffy previously used growth model.

Furthermore, these growth rates of could be increased of about 12 %, when assuming a 2 % shrinkage factor after the tuna death and their freezing.

Based on these results, the composite growth model is built, using the recovery data in a range of size between 38 and 90 cm, and using the Stequert Von Bertalanffy growth rates at sizes over 80 cm. Such rebuilt growth pattern has been used to make the figure 9b and its plotrec diagram (Fonteneau and Nordstrom 2000) showing the recoveries and this growth curve, figure 9b showing the same recoveries, but adjusted to the Stequert et al 2004 growth model (and clearly, as expected, this fit to the Von Bertalanffy model is not good).

3-3- Skipjack growth

The analysis of skipjack growth rates as a function of their average sizes during their time at liberty was estimated on 6702 selected fishes, in the same way as for the 2 other species. The estimated growth rates cover a range size of tunas that is very similar to the range of sizes caught by the present fisheries. As for the other two species, these estimated growth rates, shown on figure 2, tend to be quite different from the well accepted family of Von Bertalanffy models and parameters proposed by Adam 1992.

Furthermore these growth rates would be increased of about 36 %, when assuming a 2 % shrinkage factor after the tuna death and their freezing (Figure 6b).

Based on these results, a composite growth model could be built, using the recovery data in a range of size between 38 and 58 cm, and using a Von Bertalanffy growth curve at size over 58 cm. This growth curve has been selected based on an estimated L infinity of 73cm and an annual k=0.4, i.e. at absolute levels of these parameters that are quite different from the Adam 1999 values. This choice was made because of the very small size of the L infinity kept and proposed by Adam as being its best values (around 60 cm), and because this low L infinity tend to be incompatible with the size structure of the skipjack catch at size. The alternate higher L infinity and lower k are statistically equivalent to the Adam's parameters and based on the same maldivian data set of tag recoveries (Fonteneau 2003)..

3-4- Potential bias introduced by tuna shrinkage

The potential bias introduced by an average shrinking of 2% for all recovered tunas is shown by figure 6, for yellowfin, skipjack and bigeye. It appears that such shrinkage of 2% could introduce an average "moderate" bias underestimating the growth rates of about 11% for yellowfin and 12% for bigeye. This bias would be much more important and reaching an average bias of 36% for skipjack.

Further studies of this question of tuna shrinking should be conducted, for instance through an ad hoc programme evaluating these shrinking rates on the 3 tuna species as a function of their sizes; and also reanalysing the tagging data and the growth rates at size as a function of the condition of the recovered fishes (frozen or fresh).

3-5- Comparison of yellowfin, skipjack and bigeye growth rates at size

In the context where the fished ecosystems and the tuna stocks and fisheries are clearly plurispecific, it is always of great interest to compare the growth rates at size estimated for the various tuna species targeted by the fisheries. Figure 5 shows at the same scale, the apparent growth rates at sizes estimated for the 3 species (in cm/month). This figure shows that the skipjack growth rates are always much lower than the growth rates of the 2 other species (in a ratio of 0.5 in the 40 to 65 cm size range), but that more interestingly and surprisingly, it also shows that the **yellowfin and bigeye growth rates are nearly identical at small sizes lower than 65 cm. These sizes are** the modal sizes of small tunas frequently caught in mixed schools by purse seiners (figure 1a and 3a), and predominantly by the FAD associated purse seine fisheries. This great similarity of the tuna sizes from the 3 species taken under FADs in the Indian Ocean is well shown by figure 13. On the opposite, growth rates of pre-adult and adult bigeye and yellowfin (that are most often caught on free schools) are quite different: being 40% faster for yellowfin than for bigeye (average 3.6 cm/month vs 2.5 cm/month) in the studied range of sizes (80-96 cm).

4- Discussion

The method used in the present analysis is a very simple and basic one, and it helps to provide an interesting quick overview of the growth rates at size as well as catch at size. However, it may also introduce some bias in the estimated levels of the growth rates assigned to a given size class: this type of problem/uncertainty is for instance increasing for long times at liberty, when during a large period there is during the period at liberty a “mixing” of various types of growth rates: possibly a growth of a juvenile (tagged fishes), of a preadult (fast growth) and of a slower adult growth. This result will be artificially assigned to a given size class, but without being representative of its real growth rate. A more complex statistical analysis of the growth rates would be necessary to handle this complexity of growth patterns.

However and despite of its basic limitations, the present simple analysis may provide various interesting and realistic results, for instance when comparing relative levels and trends of growth rates between sizes and between species.

The significance and coverage of the age/sizes recovered in the present tagging results are widely different between the three species tagged, as shown by figure 10 comparing the sizes tagged and fished in the Indian Ocean:

- Young yellowfin recruits in the fisheries at sizes under 40 or 45 cm have been very seldom tagged (only 3.7% of the recovered yellowfin), when the dominant mode in the yellowfin fishery, between 45 and 70 cm, has been tagged in great numbers. Large yellowfin have been very seldom tagged (only 16 yellowfin tagged over 1 meter have been recovered, i.e. 0.3 % of the yellowfin tagged), but as PS fisheries are catching a large proportion of these large yellowfin, and as the reporting rate of tagged fishes has been very good on this fleet, a large number tagged yellowfin will soon by recovered by this fleet. A total of 1525 recoveries of large yellowfin caught over 90 cm (33% of the recovered yellowfin) have been already reported (i.e. potential spawners, in a size range between 90 and 156 cm). It can then be concluded that yellowfin growth will soon be well estimated from these recoveries and during the entire life of this species, based on the large number of recoveries of large yellowfin expected during the next 3 to 5 years from purse seiners.
- A majority of the skipjack sizes/ages significantly fished in the Indian Ocean have been quite well tagged by the recent IOTC tagging program, keeping in mind that small sizes under 40 cm and large ones in the range between 60 and 75 cm have been seldom tagged. Large numbers of these skipjack have been already recovered, nearly at all the sizes caught by fisheries (still with a weakness of very large sizes over 60 cm and 4.5kg, sizes that are significant in the Indian Ocean fisheries (estimated at 20 % of the total skipjack catches in weight during the 2000-2006 period). Despite of these limitations, it can then be concluded that skipjack growth should soon be well estimated from these recoveries and during the entire exploited life of the species.
- Young bigeye recruits in the fisheries at sizes under 40 or 45 cm have been very seldom tagged (Only 288 fishes tagged in this range in the recovery file, i.e. 11% of the present recoveries), when the dominant mode in the fishery, at about 50 cm, has been very well tagged. Large bigeye, for instance at sizes over 70 cm have been very seldom tagged (in the recovery file, only 55 bigeye were tagged at sizes over 70 cm, i.e. 2 % of the recovered bigeye). Longline fisheries are catching a large proportion of these large bigeye and the reporting rate of tagged fishes by this fleet is most often quite poor (presently, only 19 recoveries of bigeye have been reported by longliners, probably a too low number).Then there is a limited hope to recover many adult bigeye taken at large sizes. It can then be concluded that bigeye adult and longevity will probably be difficult to estimate, unless IOTC scientists could widely improve the reporting rate of bigeye taken by longliners (mainly from **Taiwan**, a fleet catching

about **50%** of the longline caught bigeye, and of Indonesia and Japan (these 2 fleets catching about 30 % of the longline caught bigeye in the Indian Ocean).

The present estimates of growth rates obtained from tagging results are widely different from the previous estimates of growth obtained from age readings of daily rings. A similar large heterogeneity of the results obtained from tagging and from age reading of otoliths has been already observed in the Atlantic Ocean and in the Pacific oceans, each of these growth showing patterns similar to the patterns observed by the 2 methods in the Indian Ocean.

Our firm present conclusion is that the tagging results are probably much more significant than the previous hard parts reading, as the evidence of a given growth observed for a large number of well identified tunas tend to be much more stronger and convincing that the theoretical results from few age reading, that are widely limited by various uncertainties and potential bias in the daily age readings, and by the potential lack of daily rings in the hard parts. As an example: the growth of juvenile yellowfin tuna that has been presently estimated based on 2040 significant recoveries of fishes recovered at sizes under 67 cm, showing an average growth rate of **only 1.6 cm/month**, are a much stronger proof of a small growth than the fast growth at **3.7 cm/month** previously estimated in the same range of small tunas from questionable age readings done on few fishes. Lehodey and Leroy (1999) show that the same phenomenon have been observed in the Western and Central Pacific, and they provide a comprehensive discussion of these observations.

The alternate hypothesis that the recovery results are biased, for instance the growth of small tunas being reduced by their tags, cannot be eliminated, but such hypothesis is for us quite unrealistic. Furthermore, it can also be noted that if the first validation of the yellowfin and bigeye that have been recovered after a tetracycline injection, would tend to validate the daily rings but also the slow growth pattern presently estimated. The divergence between the present results and the previous otoliths readings should be analysed by an ad hoc study, if possible doing a new reading of the original otoliths used by Stequert et al in their 2 studies on yellowfin and on bigeye.

At this stage, the more realistic conclusion is probably that tropical tunas do not follow a Von Bertalanffy growth curve, but most often (yellowfin and bigeye) a much more complex growth curve in relation with the changes in the biology and in the ecology/behaviour of these fishes:

- **Post larvae to 40 cm** (1 kg), yellowfin and bigeye: an initial fast growth necessarily takes place during the cryptic pre-recruitment and pre-tagging period, between the end of larval stages (first month in the life of a tuna) and the size at recruitment in the fisheries: these very young fishes are probably showing an increase of size between larvae and juvenile of about 30 cm during about 6 month (Eastern Pacific, Wild 1992) or during only 4 month in the Atlantic, based on the seasonality of the spawning season (Capisano and Fonteneau 1990), i.e. with a fast average growth rate of these early pre-recruited fishes of about 5 cm or 7.5 cm /month.
- At larger sizes in the **40 to 70 cm range**: juvenile growth is slowing down to an average monthly rate of only 1.9 cm /month in the 40 to 70 cm (1.47 cm/month in the Atlantic, Capisano et Fonteneau 1990), when a much faster growth is predicted by the Von Bertalanffy model during this early period. During this recruitment period, juvenile tunas tend to be concentrated in their equatorial nurseries, in the shallow and warm equatorial waters, between 10°N and 10°S (see figure 12 showing the average geographical distribution of small and large yellowfin caught by

purse seiners and by longliners). During this period, most of these tunas are fishes in mixed species schools, these small yellowfin and bigeye associated to skipjack, being simultaneously caught in 72% of the FAD sets.

- At preadult sizes, between **70 and 100 cm**, there is an apparent marked increase of growth rates, probably in relation with a change in behaviour of these tunas (so called "chicaneurs"): a reduced catchability in the purse seine fishery, these tunas being more mobile, deeper and scattered in a wider geographical area toward the south and the North, and probably also in relation with their sexual maturation[3] and the biological effect of increasing sexual hormones.
- At **adult spawning sizes**, the geographical distribution of adult yellowfin and bigeye tend to be widely scattered, these fishes inhabiting a wider range of colder waters (shown by the fishing zones of purse seiners and of longliners), and their growth rates tend to stabilize and later to decrease at increasing fish sizes (as expected in every growth models). However this logical decline of the growth rate is not clearly visible for bigeye, at least in the present handling of the present data set (with very few fishes recovered over 1m: only 41 fishes versus 2986 recoveries used).

It should be kept in mind that if such complex growth pattern has not yet been commonly used in many tuna stock assessments, these complex patterns are highly common in the living world, for instance for human growth. We can also notice that the shape of the observed growth curve is quite similar to the growth model proposed by Gascuel et al. (1992) and since used by the ICCAT for the assessment of the Atlantic yellowfin stock.

In other terms and in conclusion, the present tagging results are showing that:

- Juvenile yellowfin tunas are exploited during a period of **23 months** between 40 and 80 cm (i.e. between 1 and 10 kg), while in the previous Von Bertalanffy model this range of size was exploited during a much shorter period of only **13.7 months**. It would also mean that the age at first spawning of 1 meter yellowfin would have now an age of approximately 3 years, while this spawning size was reached at an age of about only 2 years in the previously used Von Bertalanffy model.
- Juvenile bigeye tunas are exploited during a period of **17.5 months between 40 and 70 cm** (i.e. between 1 kg and 7.2 kg), while in the previous Von Bertalanffy model this range of size was exploited during a shorter period of only **9.8 month**.
- Skipjack tuna: the potential change in the Von Bertalanffy and present tagging results are much less important, but may be still significant.

These wider durations of the early exploitation should of course be kept in mind in the future modelling of the yellowfin and bigeye stocks, and also skipjack: **such long duration of the early exploited lives and with a slow growth, when compared to a short duration and**

[3] Faster growth of early juveniles and at puberty : tunas may well be like kids, growing at faster rates during their sexual maturation…as it was concluded by Davenport in 1922: "human growth curve shows 2 outstanding periods of accelerated growth, the circumnatal and the adolescent", a conclusion that could be easily transferred to the world of tunas as ***"tuna growth curve shows 2 outstanding periods of accelerated growth, the post larval and the sexual maturation"***

a fast growth (each cohort suffering in each interval of time a given natural mortality at age), could produce widely different results in terms of yield per recruit, estimated fishing mortality at age, levels of recruitments and potential interaction between fisheries catching juvenile or adults tunas. Then this confirmation of slower growth patterns should also reinforce the pressure on IOTC scientists to use assessment models that are using a reduced time scale such as **quarters** (such as the assessment models presently used on the Eastern and western Pacific tuna stocks), and **never the previously used yearly intervals**, that are too wide to handle the complexity and variability of tuna sizes and ages caught.

5- Conclusion

The present analysis of the tuna growth, voluntarily conducted without any attempt to model these growth patterns, shows that the present results of the IOTC tagging program are breaking the previous paradigms on the growth of juvenile yellowfin and bigeye tunas in the Indian Ocean. None of the studied growth follows a typical Von Bertalanffy, but more complex growth patterns, where the growth rates are highly dependent of the fish sizes. Growth of small tunas can already be well evaluated by the present recoveries, and the estimated growth of adult tunas will probably be improved quite soon after a better validation of the recovery file, and during the incoming years with the expected recovery of aging and larger fishes. The large numbers of tagged tunas released by the IOTTP should allow to recover many old fishes then also to estimate the adult growth rates and the L infinity of the 3 species. However, the present results on bigeye and yellowfin are already very convincing and strong, and they should quickly be introduced in the future IOTC assessment models.

These rather surprising results should also be compared with similar growth rates at size estimated in the other oceans from similar tagging programmes, and especially for yellowfin and bigeye, the two species facing a major divergence between growth estimated from tagging and the Von Bertalanffy growth most often estimated from hard parts readings. A quick comparison done on the yellowfin growth estimated from tagging in the Atlantic, Indian and Western Pacific oceans tend to show very similar growth rates at size in each of these 3 areas (see Gascuel et al 1992 for the Atlantic, and Lehodey et Leroy 1999 for the Pacific, and figure 4 a and b). Further eco biological investigations should probably allow to understand the reasons explaining these changes in the growth rates.

However, several serious pending questions still remain today, among them, why do we have such major differences in the estimated growth using recoveries and/or age readings? This question remains an entire one, especially for juvenile yellowfin and bigeye. This question may be soon at least partly solved by the expected results of otoliths readings taken on yellowfin and bigeye tunas recovered after having a tetracycline injection. However, the growth rates estimated from the tagging results should already be introduced as soon as possible in the stock assessment models on the 3 species, as there is no need to wait the results of these highly recommended investigations.

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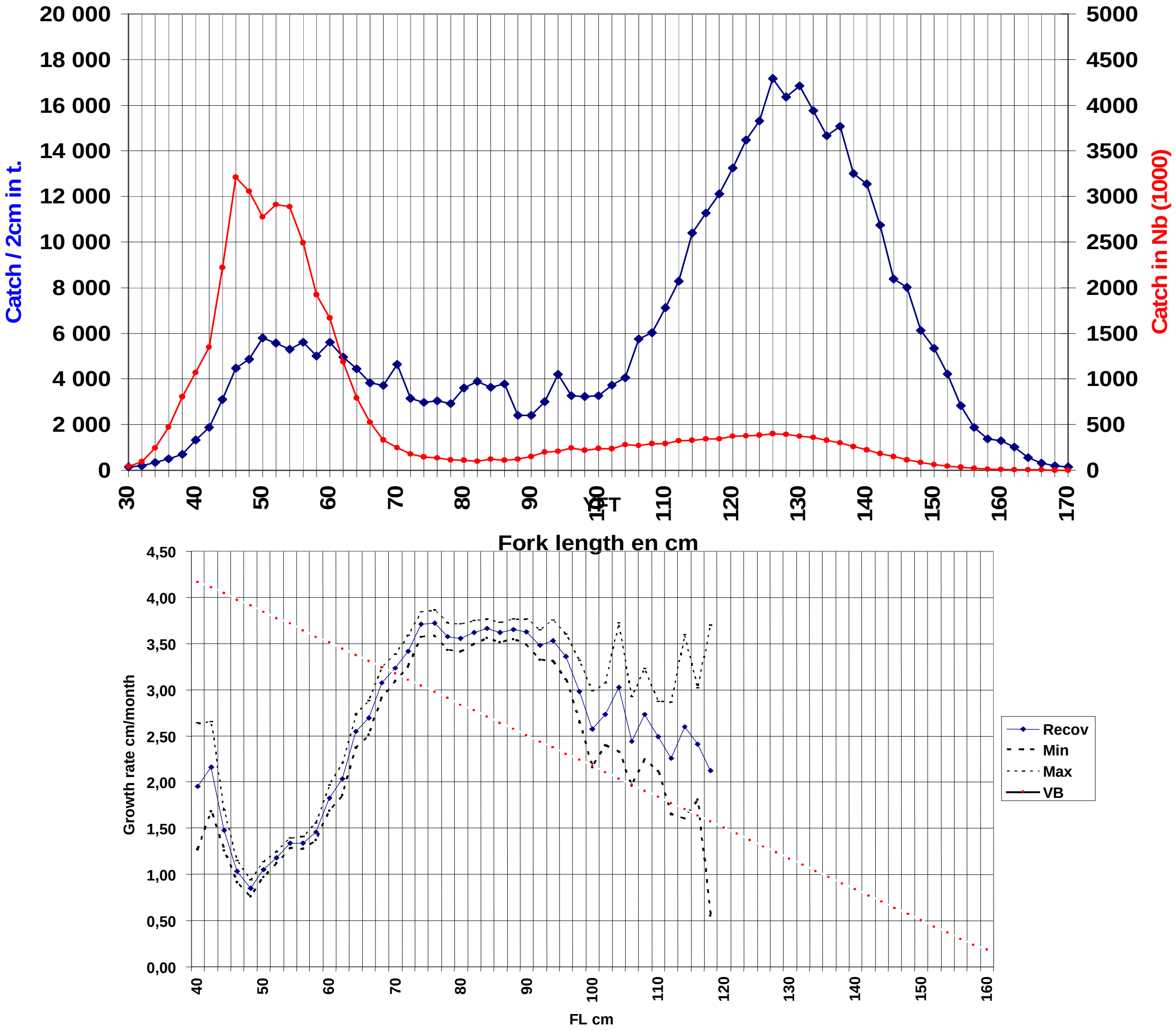
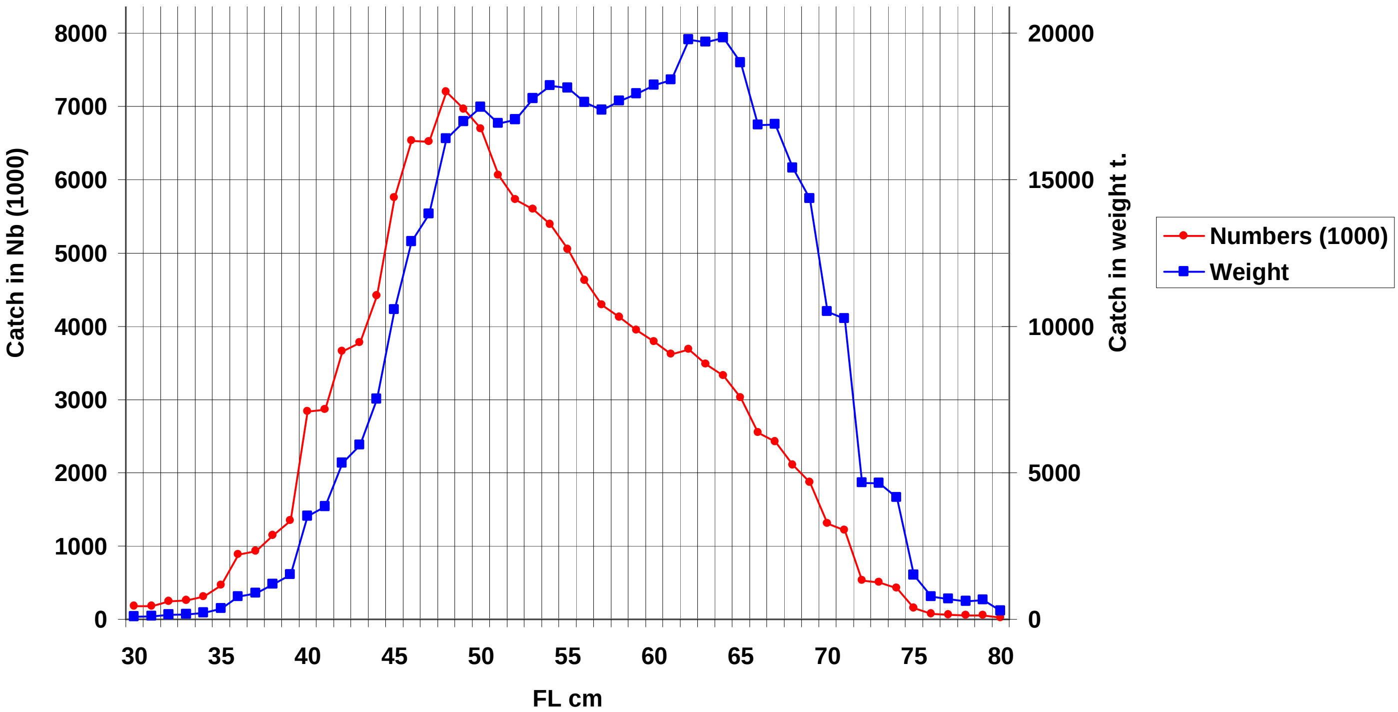


Figure 1: Yellowfin total catch at size (in number and in weight, 2000-2006) and growth rates at size estimated from tagging results. The Von Bertallanfy growth curve done with the parameters proposed by Stequert et al 1996.

Duration between 40 & 80 cm:
=>from tagging: duration = 23.1 months
=> From VB: only 12 months



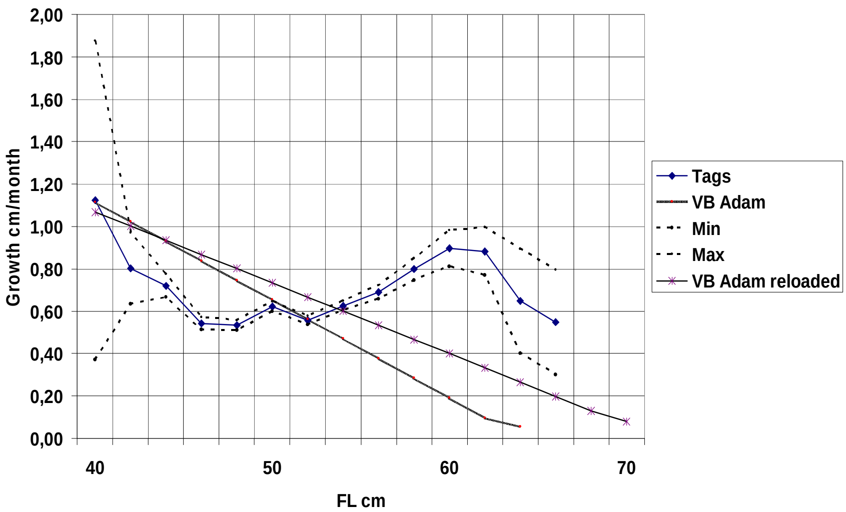


Figure 2: Skipjack total catch at size (in number and in weight, 2000-2006) and growth rates at size estimated from tagging results. The 2 Von Bertalanffy growth curves shown are the original best one porposed by Adam 1999 (L infinity at 65cm, lower curve) and a revised and equivalent estimate proposed by Fonteneau 2003 (upper curve)

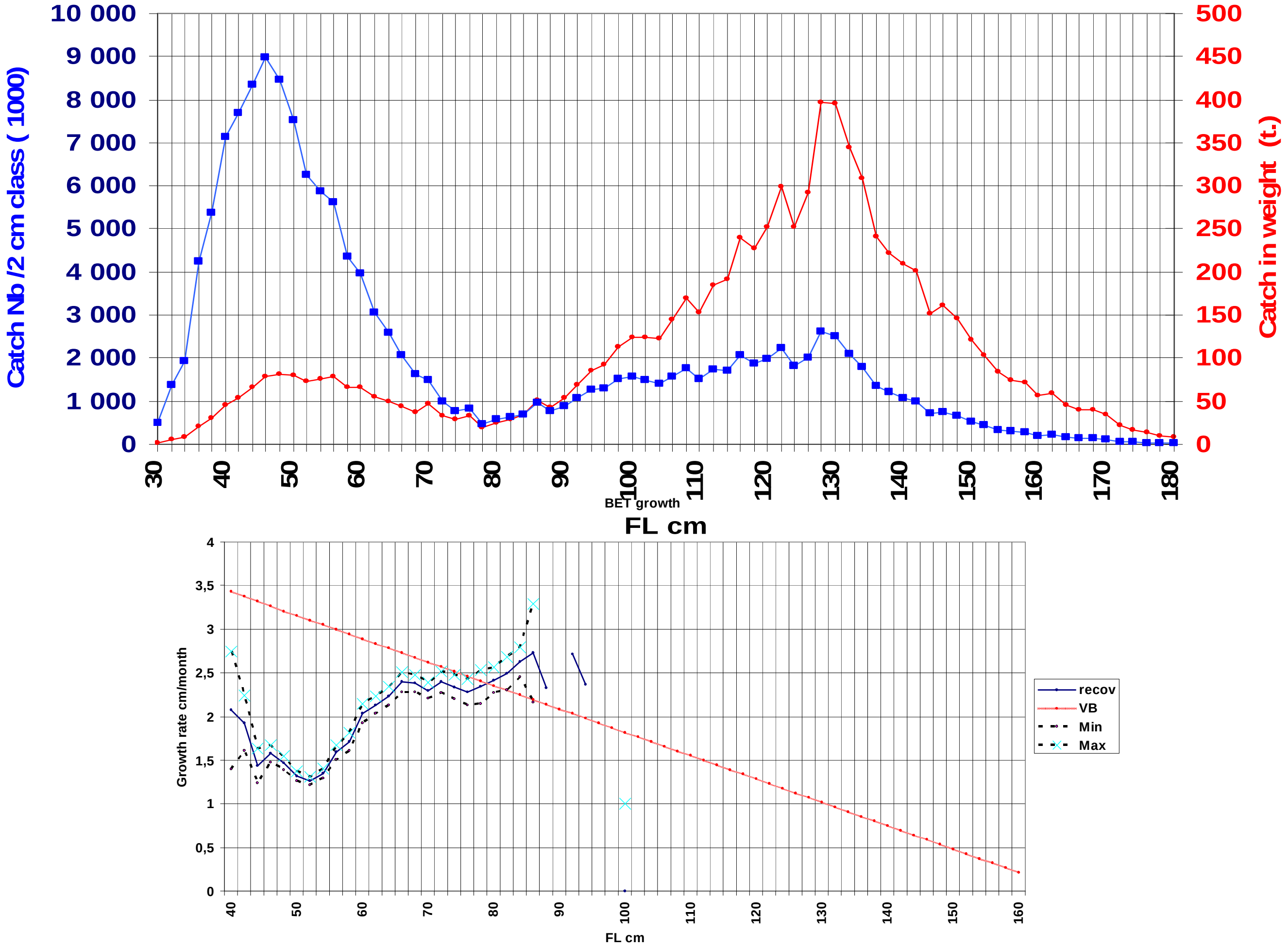


Figure 3: Bigeye total catch at size (in number and in weight, 2000-2006) and growth rates at size estimated from tagging results. The Von Bertallanfy growth curve done with the parameters proposed by Stequert et al 2004.

Duration between 40 & 70 cm:
=>from tagging: duration = 17.5 months
=> From VB: only 9.8 months

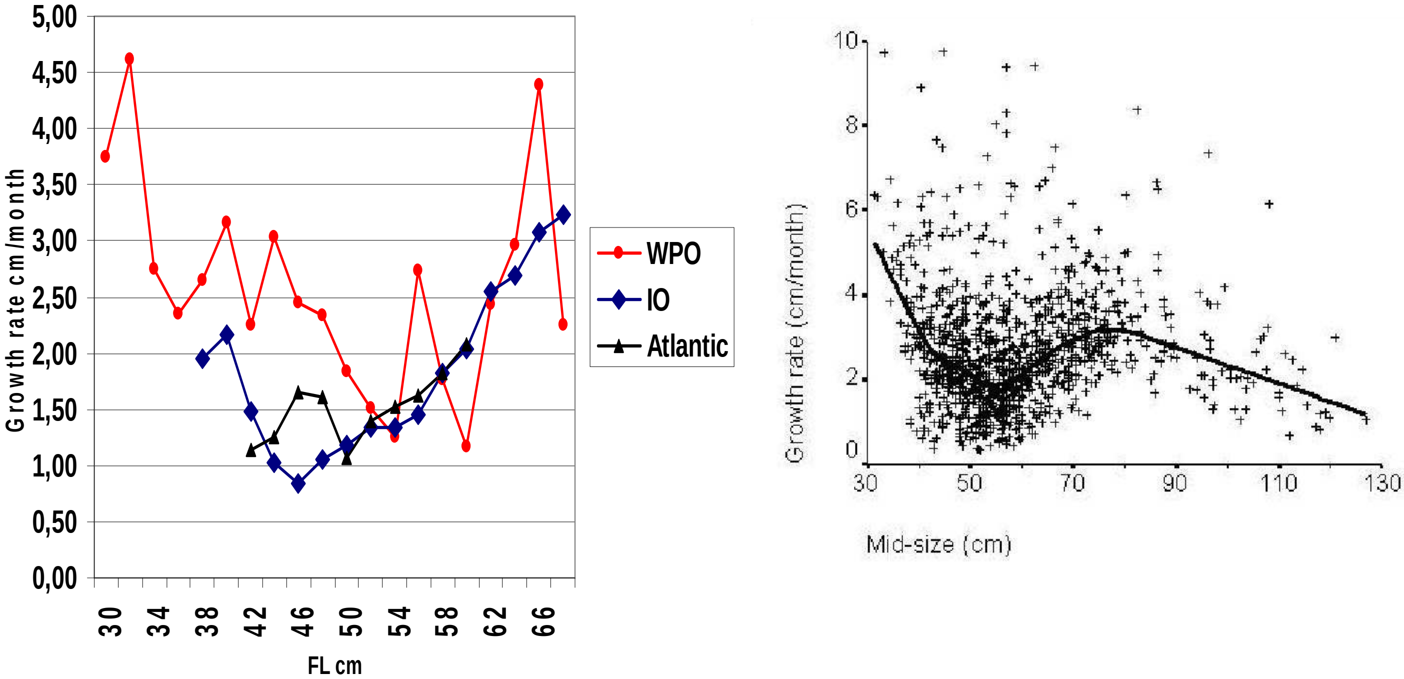


Figure 4: Growth rates at size (in cm/month) presently estimated for juvenile yellowfin from recovery data in the Western Pacific (Hampton subset of recovery data) and the Atlantic. Figure on the right taken from Lehodey, P., Leroy, B., 1999 shows the daily growth of individual recoveries in the Western and central Pacific.

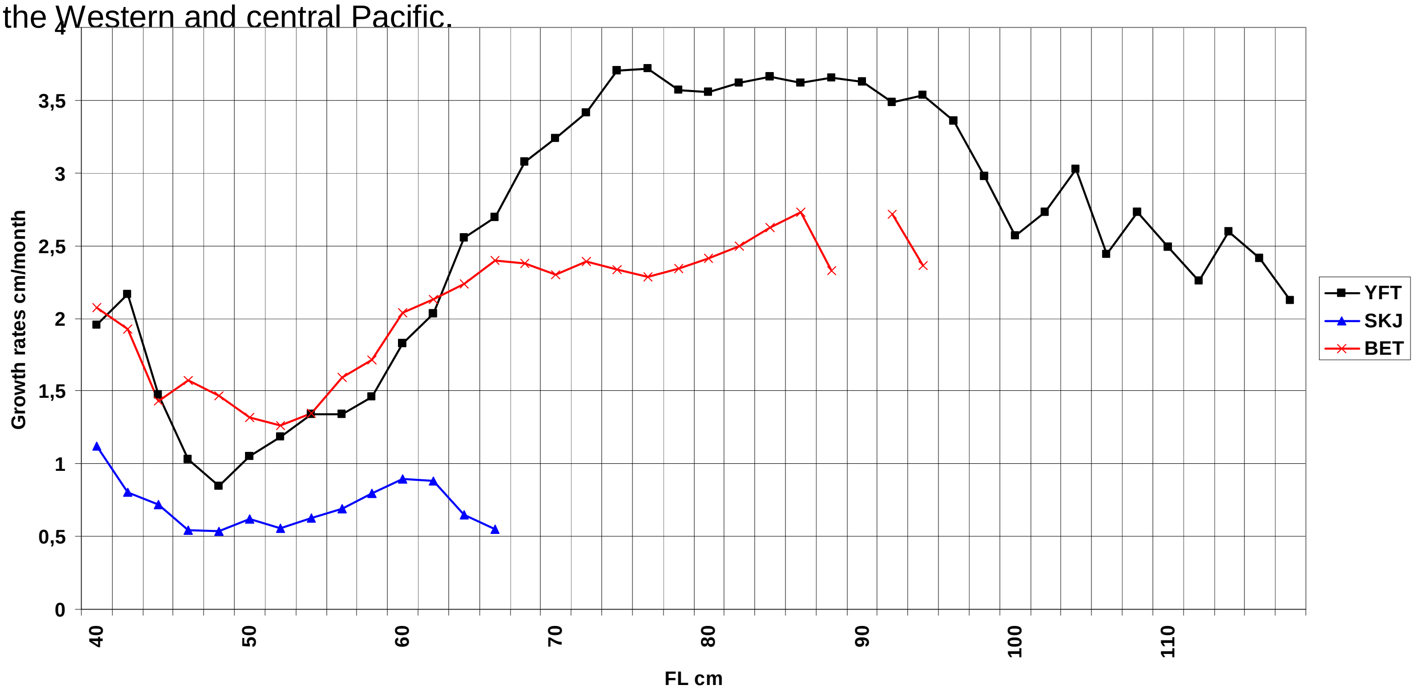
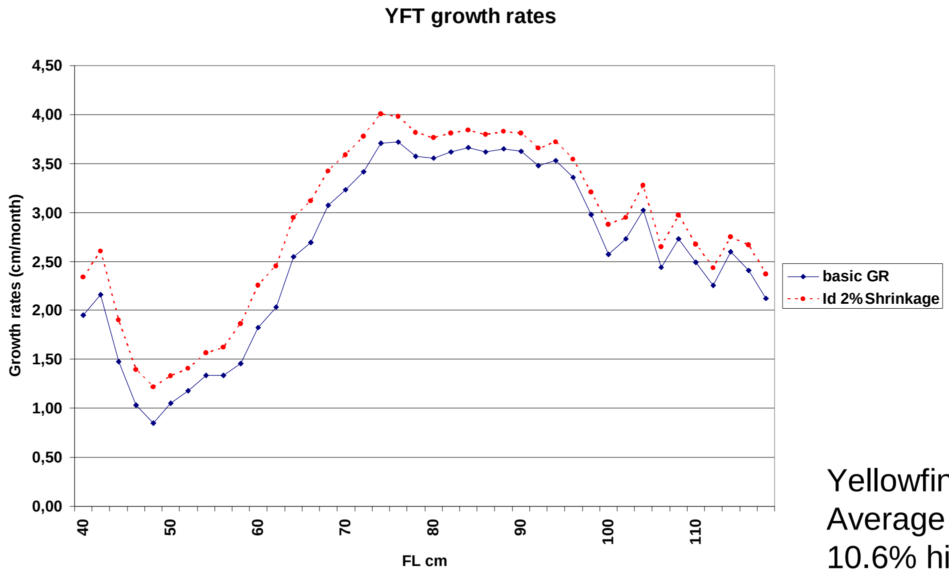
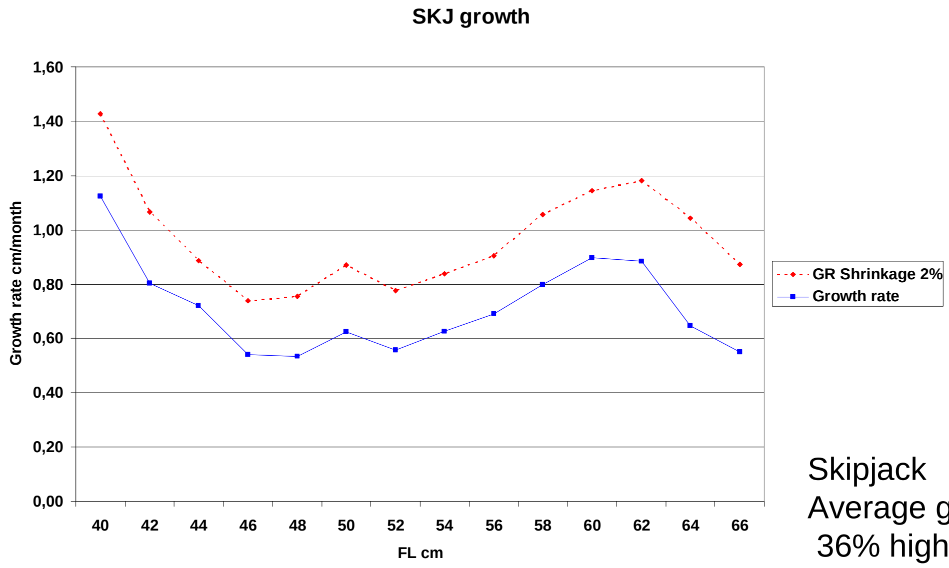


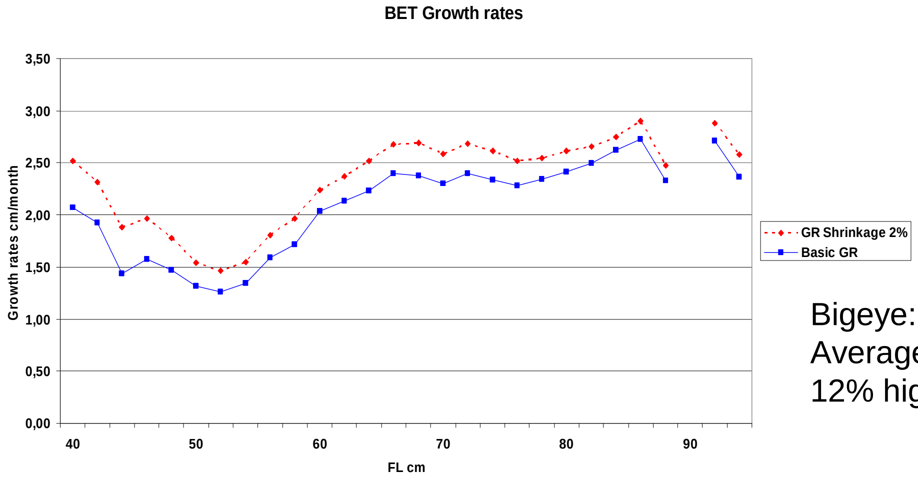
Figure 5: Average growth rates at size (in cm/month) presently estimated for yellowfin, bigeye and skipjack tuna from the recovery data



Yellowfin
Average growth rates
10.6% higher

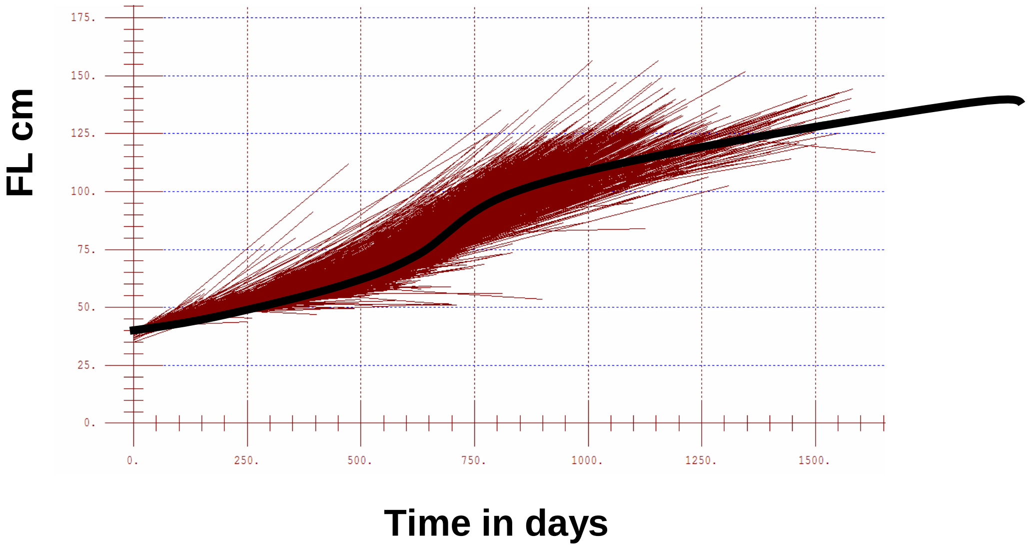


Skipjack
Average growth rates
36% higher



Bigeye:
Average growth rates
12% higher

Figure 6: Average growth rates at size (in cm/month) presently estimated for yellowfin, bigeye and skipjack tuna from the recovery data, without and after a 2% of shrinkage constant at all sizes and for the 3 species



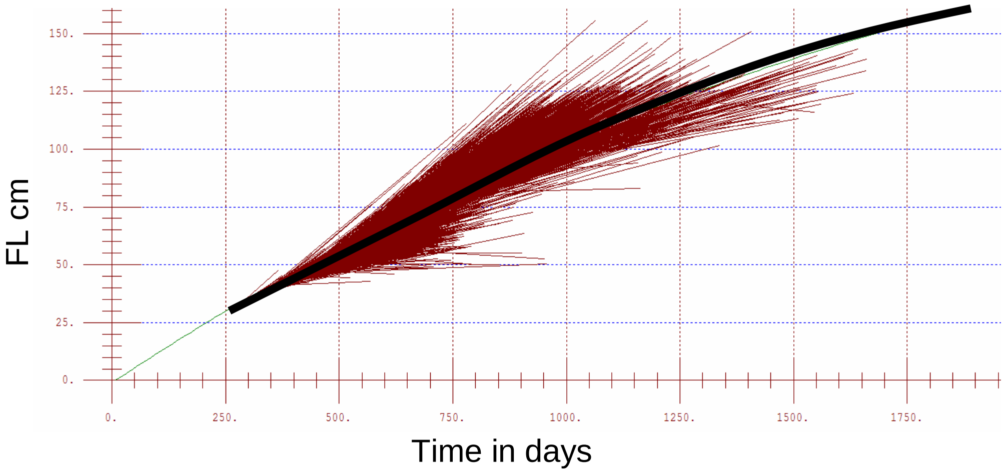


Figure 7: PLOTREC figure showing the changes at size of the yellowfin: recoveries adjusted to a Stequert VB model (lower figure) and to average growth rates at sizes followed by a Stequert VB cirve after 100 cm (upper figure)

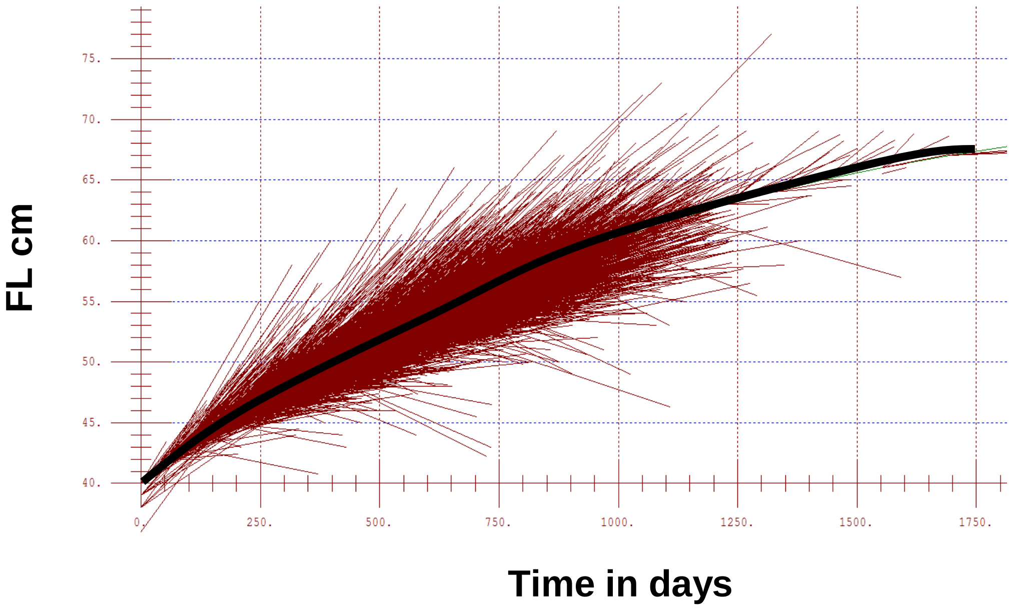


Figure 8: PLOTREC figure showing the changes at size for the skipjack recoveries adjusted to a the recovery data in the range 40 to 56 cm, followed by a VB growth curve using L infinity= 73cm and k=0.40)

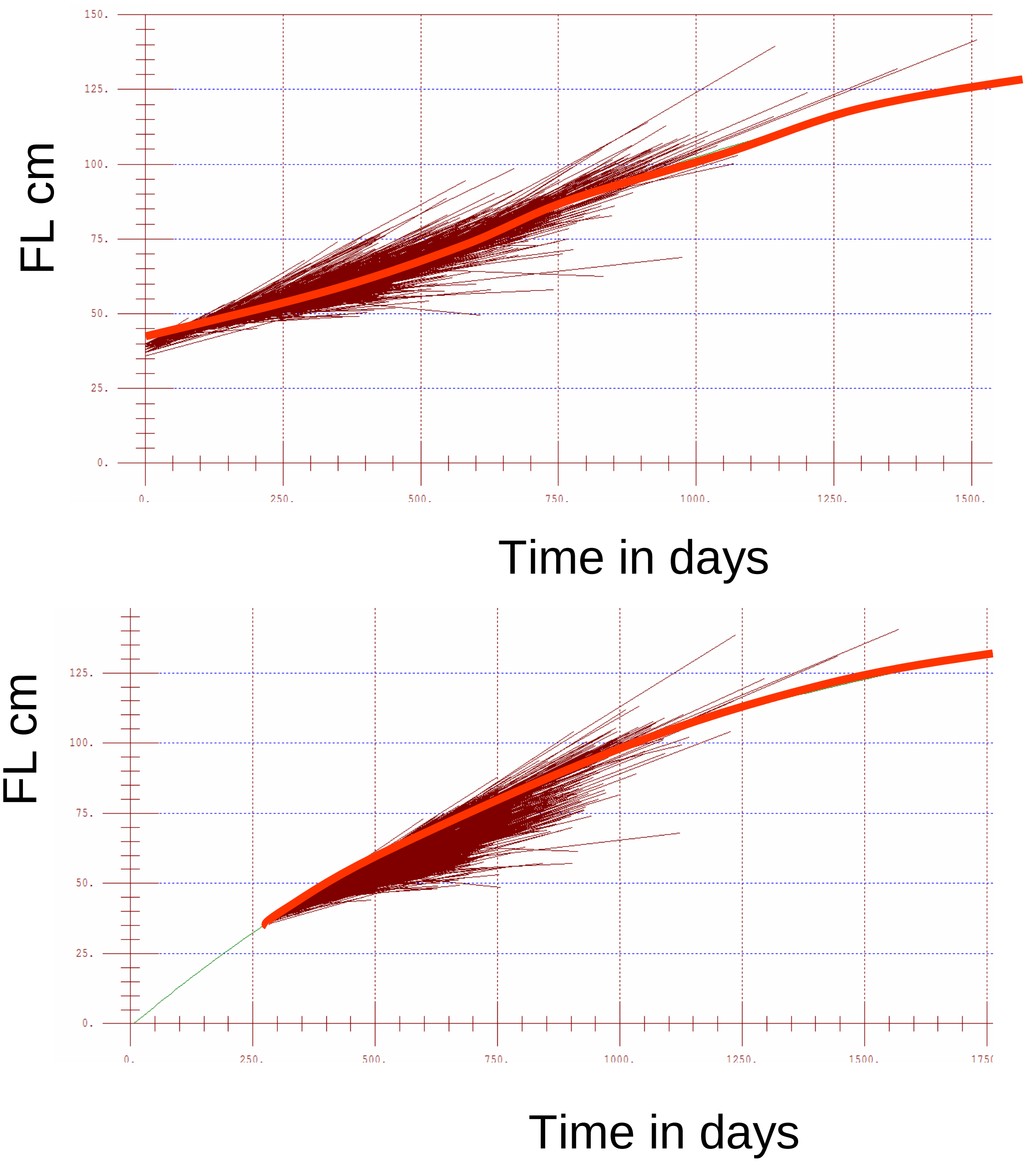


Figure 9: PLOTREC figure showing the changes at size for the bigeye: recoveries adjusted to a Stequert VB model (lower figure) and to average growth rates at sizes followed by a Stequert VB curve after 80 cm (upper figure)

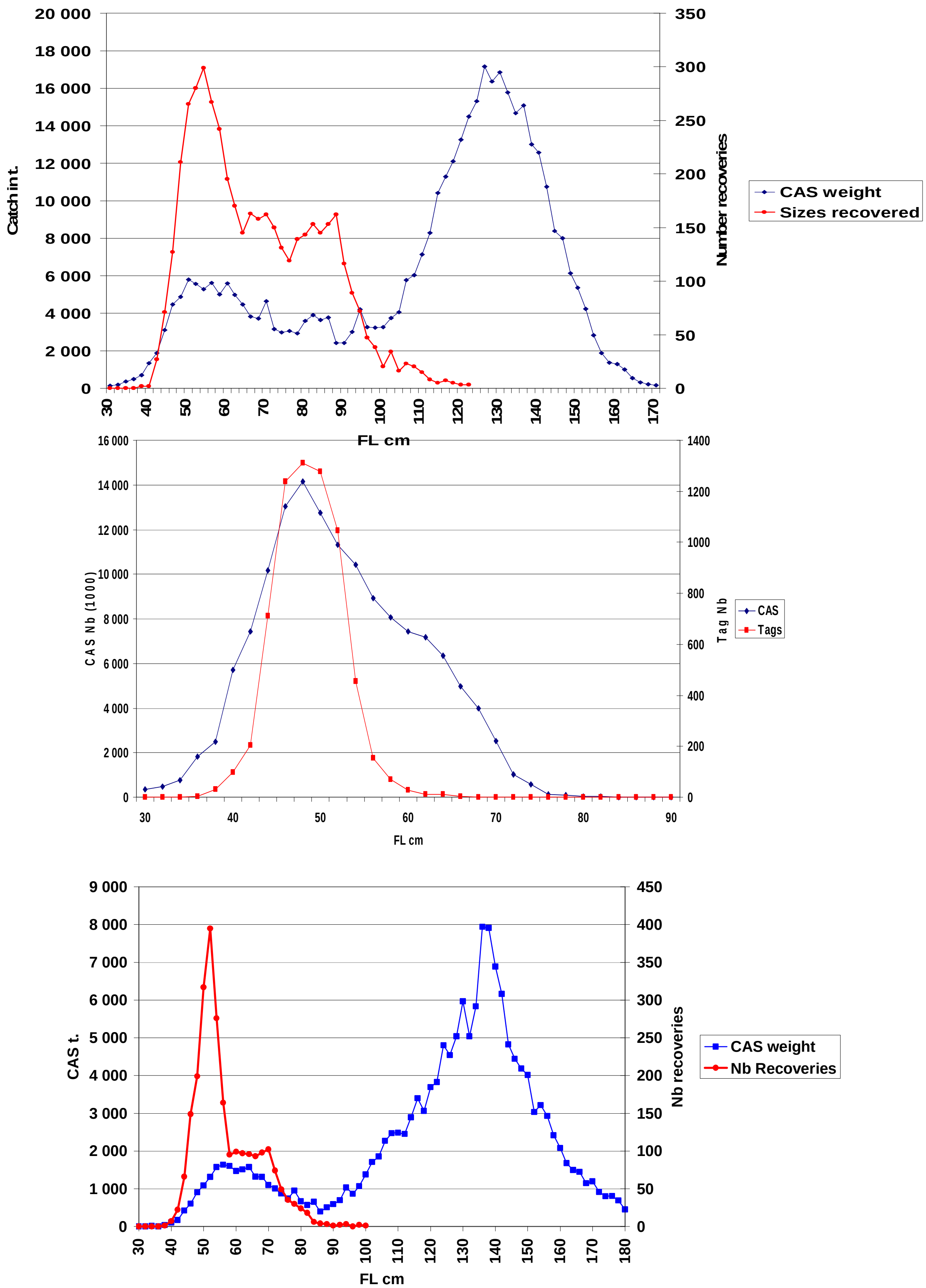
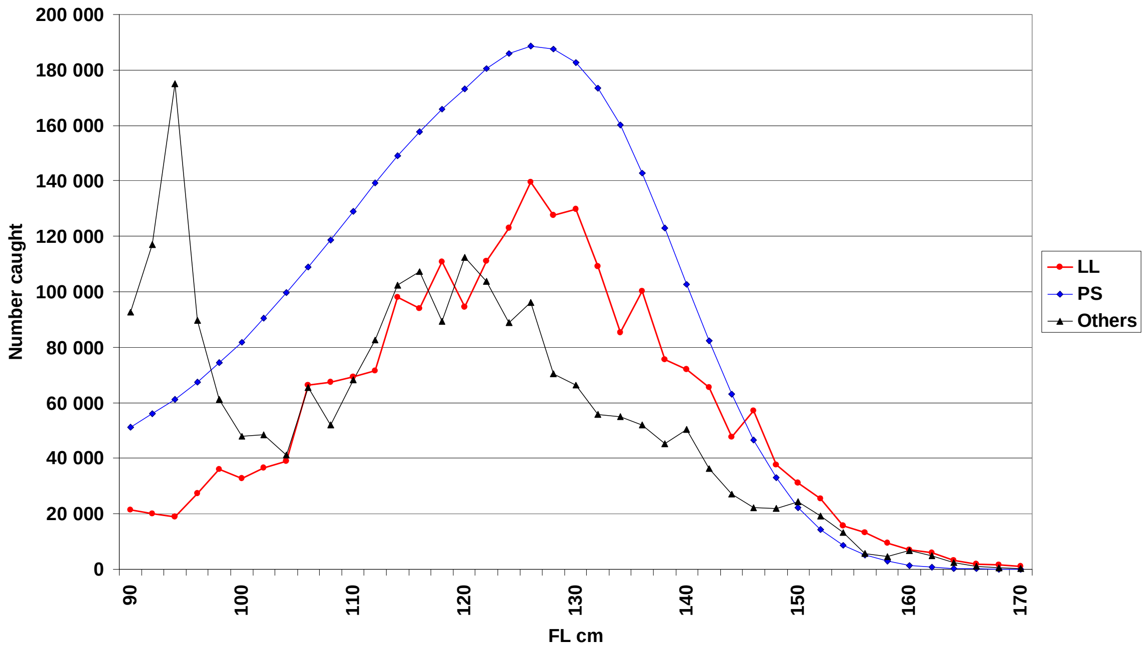


Figure 10: Average catch at size (in ton/class) of yellowfin (10a), skipjack (10b) and bigeye (10c) and numbers at sizes of the recovered tags for each species (average sizes tagging/recov, in red)



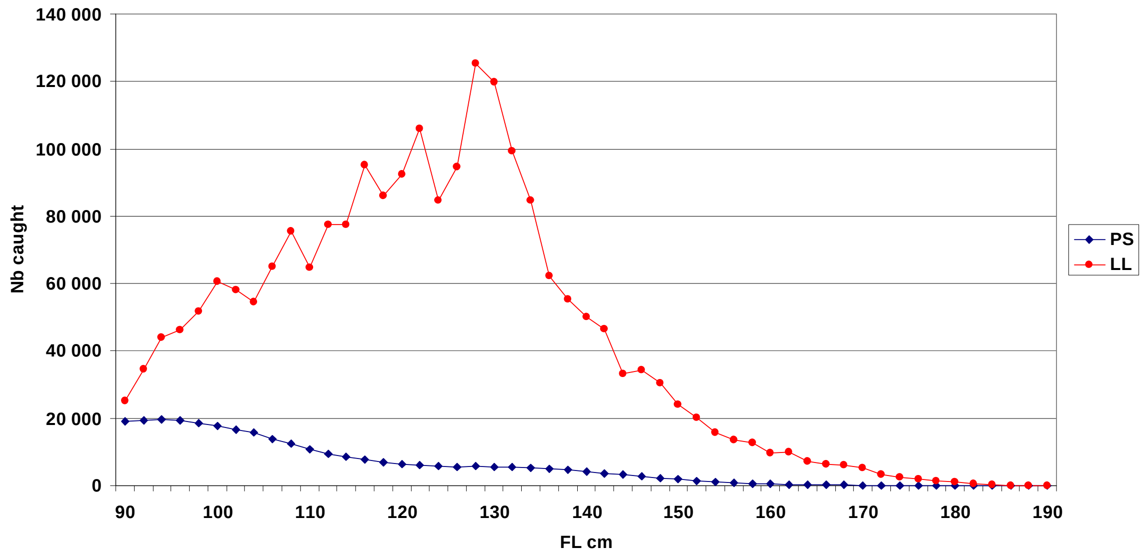


Figure 11: Average catch at size by gear of yellowfin and bigeye in the Indian Ocean during recent years (average period 2000-2005)

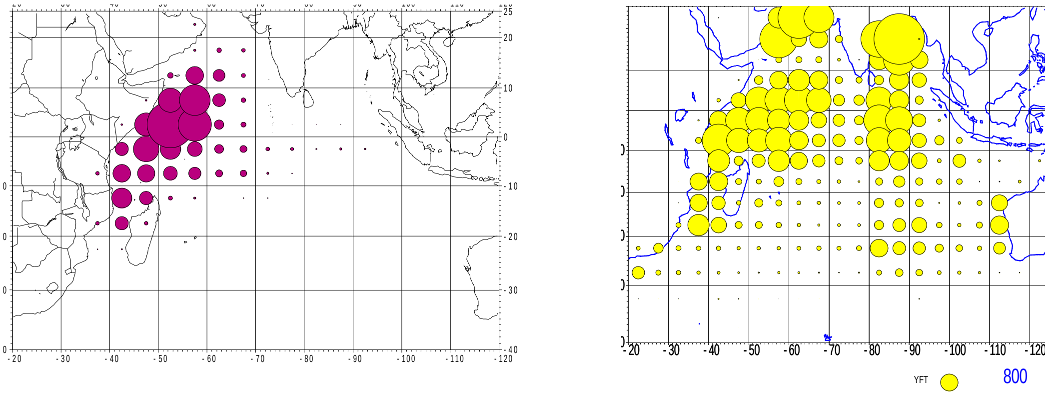


Figure 12: Fishing map showing the average catches of small yellowfin (<90cm) by purse seiners, left, and of large yellowfin by longliners, right (period 2000-2006). *Catches by longliners are showing well the potential geographical distribution of adult yellowfin, when catches by purse seiners tend to indicate some of the major yellowfin nurseries. These 2 figures are showing a well known fact that adult yellowfin have a much wider geographical distribution than the juveniles of the same species. The same observation can also be done for bigeye.*

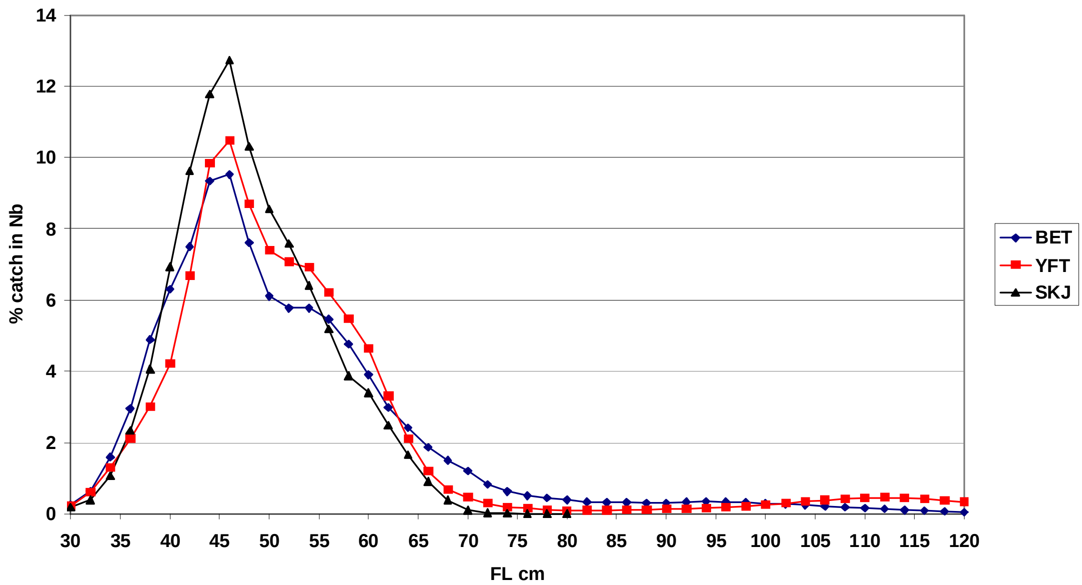


Figure 13: Average sizes of yellowfin, skipjack and bigeye tuna smaller than 120 cm and caught in the Indian Ocean associated to FADs (1991-2006 period), the 3 size distributions being shown in term of percentages.