STUDY OF THE GROWTH OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) IN THE INDIAN OCEAN BASED ON LENGTH FREQUENCY DATA FROM 2000 TO 2004

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ABSTRACT

The growth model of yellowfin tuna in the Indian Ocean is re-examined. The length frequencies analysis of yellowfin tuna, Thunnus albacares, caught in the Indian Ocean by purse seiners and in the Arabian sea by Taiwanese longliners and Iranian gillnets between 2000 and 2004 is used to establish growth curve. This new study takes into account the larger cohort of adult observed in 2003 and 2004. The analysis of length-frequency is made with the statistical program package R-mix (Du, 2002) using the Petersen method. The two stanza growth model developed by Gascuel and al. (1992) is fitted to these data. The growth is correctly described until 140 cm FL. We constrain the L infinity in order to have more realistic result more realistic than the Stéquert growth curve (1996) or the Lumineau growth curve (2002) used in the previous assessment. The growth of yellowfin tuna is then expressed as follows:

$$LFt = 32,511 + 16,001.t + [163,411 - (32,511 + 16,001.t)].[\,1 - \exp(-0,828.t)]^{22,326}$$

The validity of the method is discussed. Hypothesis about the two stanza growth are developed. Growth rates are compared with others studies in the three oceans: it appears this growth model is in accordance with several studies using different methods (length frequencies analysis, otoliths, tagging). Finally an hypothesis is developed to explain the larger catches of large yellowfin observed in 2003 and 2004.

INTRODUCTION

Because of the lack of large scale tagging data, previous assessments of yellowfin tuna in the Indian Ocean have been based on otoliths microstructure (Stéquert and al., 1996) or length data analysis (Marsac and Lablache, 1985; Marsac, 1991; Lumineau, 2002). But there is not one model growth accepted and the growth of yellowfin tuna is still problematic.

In 2002, the working group used two growth models for the assessment of yellowfin tuna. The first one, Lumineau growth curve, is a two stanzas growths model obtained by Gascuel and al. (1992). The same two stanzas model is used in the Atlantic Ocean. In the Pacific Ocean, the yellowfin growth is estimated with length-frequencies data, tagging data and otoliths data: they also observe a two stanzas growth. Lumineau growth curve is determined by the Petersen Method, with purse seine data (1987 to 2001), Oman and Iran drifting gillnets data respectively from 1987 to 1994 and April 2000 to March 2001. But the growth beyond 60 cm is subject to uncertainty (Lumineau, 2002): there is a lack of data for this size class. Moreover, the L infinity (152,1 cm) calculated by Lumineau seems to be smaller than we can observe in reality. So, the authors decided to propose an other growth model in order to limit the error risk. The second one is a Von Bertalanffy growth curve estimated by Stéquert and al. (1995), based on the analysis of otoliths of 151 yellowfin tuna. Even if this curve is very similar to those obtained in other studies, it does not support the working hypothesis that yellowfin tuna have two growths stanza (Stéquert and al, 1996). In addition, the L infinity (272,7 cm) is too large. The other growth curves discussed before are generally between this two curves. So, the use of these two curves should cover all the possibilities.

However, owing to the importance of the yellowfin tuna fishery in the Indian Ocean, there is a need for a better growth model to be usual in the present stock have a good assessment.

In 2003, yellowfin catches were extremely high with a level above 500 000 tons whereas skipjack and bigeye catches remained at the same level. This anomaly concerns both the purse seine and longline fisheries. For yellowfin taken on free schools it can be noted that the average weight is one of the largest observed in the fishery and that the excess of catches was observed only for large sizes (Fonteneau and al, 2004).

These big cohorts could bring new information concerning the growth of yellowfin tuna. A better follow up of the modes is maybe possible for the analysis of length-frequencies. The goal of this study is to propose a single growth model for yellowfin tuna in the Indian Ocean in order to have an age-length key for the assessment.

MATERIALS AND METHODS

- **Method of analysis**

The study uses the Petersen method. The analysis of length-frequency is made with the statistical program package R-mix (Du, 2002) for the R statistical computing environment. R-mix has the functionality of Macdonald's MIX software (1979). This software fits mixture distributions to grouped data by the method of maximum likelihood. The parameters can be constrained in many different ways: specified parameters can be held constants, equals or to follow a statistical distribution. Practically we give starting values for means and standard deviations and we use the function mix to fit the normal mixture without constraint. So, every mode clearly determined is associated to a normal distribution, with a mean and standard deviation known. Only well fitted modes are kept in the study. Moreover, modes above 140 cm are not taken in account. These modes are not clear and the growth cannot be followed with confidence.

We use the same growth model than Lumineau (2002) in the West Indian Ocean and Gascuel and al. (1992) in the Eastern Atlantic Ocean. This model combines a linear function and a generalized Von Bertalanffy model. It is possible to fit the growth curve to the two stanzas observed (Gascuel and al., 1992). In addition, in the Atlantic ocean the model proved to be in agreement with tagging data (Figure 1). In this study, we fit the model in minimizing the sum of square differences between observed values and estimated values.

$$LFt=LF0+b.t+[LFinf-(LF0+b.t)].[1-\exp(-K.t)]^{m}$$

LF0: fork length (cm) at age t=0; b: start speed of growth; Linf : asymptotic fork length (cm); K: growth coefficient; m: parameter.

There is no biological meaning for LF0. A length of 40 cm corresponds to a 6 month fish.

The curve will be compared to the few tagging data in the Indian Ocean thanks to the software PLOTREC.

Several hypothesis are made. Without any exhaustive tagging data it has been difficult to define stock in the Indian Ocean. One hypothesis is based on two stocks (East and West) which is not confirmed by the available tagging experiments and other direct methods (Nishida and al., 1998). In this study we consider a single stock. Concerning the spawning season, most gonad analyses show there is an intense sexual activity between November and February (Shung and al., 1973; Hassani and Stéquert, 1990; Stéquert and al., 2001). So we decide there is just one mode by year. Finally, we do the same hypothesis as Lumineau about migrations: we suppose tunas between 60 and 90 cm migrate through the Arabian Sea. This hypothetical migration is mentioned in several studies (Losse, 1970; Imad, 1987; Marsac, 1992).

- **Data**

Two kinds of data are used in this study. On the one hand the raw size data of the samples processed without strata substitution or extrapolation from the international purse seine fleet operating in the Indian Ocean are used. yellowfin smaller than 80 cm have been measured in fork length whereas yellowfin larger than 80 cm have been measured in predorsal length and converted in fork length. In this conversion, each class of predorsal length is converted into a normal distribution of fork length. This conversion is based on the observed variability of fork length in each class of predorsal length. We have to take into account that conversion introduces a smoothing in the subsequent fork length distribution. One of the characteristics of purse seine catches in the Indian ocean is to catch young and adults but not sub-adults (Figure 2). Sub-adults (60-90 cm) are probably not present in numbers in fishing area of purse seiners or less available because too dispersed.

On the other hand, in order to have data concerning sub-adults and in accordance with our hypothesis of migration of these individuals, we will use the Taiwanese longliners data of 2000 to 2003 fishing in the Arabian Sea. The data are collected by the fishers who measure the first 30 fishes landed each day. The length is measured or estimated. This estimate is based on their experience. The original length might be in 2 cm interval or even 5 cm interval. In order to validate these measurements, the Taiwanese longliners data in the Indian Ocean are compared with those of the Japanese longliners in common fishing areas. In both cases modes observed are identical or close each other (Figure 3). However, Taiwan fisheries data bring only restricted information on the sub-adult class: the determination of modes is not easy for this period and only the progression of some modes is interesting for our study. Iranian drifnets data from 2000 to 2003 will be also taken into account.

Concerning the gear selectivity problem only drifting gillnets can introduce a skew into the length-frequencies analysis: the size of net allows capturing fishes only beyond a certain size. Only clearly identifiable modes and whose progression is apparent will be kept for the study. Thus the risk to skew the study by gears selectivity will be decreased. Juvenile captured by purse seiners are available under the FADs; therefore they are caught in great numbers by the surface fisheries. Adults cover the first 150 meters: they are available to longliners and purse seiners.

In order to establish a good follow-up of the modes, all data are collected on a monthly basis.

RESULTS

- **Results of the analysis of length-frequency with R mix**

We separated the analysis by gear: purse seiners, longliners and gillnets.

The evolution of the sizes class of the modes with purse seiners data is easy concerning young and adults (Figure 4). But there is no information about sub-adults (60-90 cm) and the main problem is to connect the different cohorts. There are two possibilities: both suggest a two stanzas growth, but the sub-adults growth is different between the two solutions. In addition, we can notice there is a second cohort, smaller than the first one, at the end of the third quarter.

Taiwanese and Iranian data could bring more information about sub-adults but they are disappointing. We have only a few interesting modes in the sizes class concerned (Figure 5). But, with the Lumineau's work, what includes Iranian and Omanian data in the nineties, and with the information of this study, we can choose the slowest growth. Furthermore the faster growth corresponds to growth rate greater than 5 cm/month for sub-adults: it is not the case in the others oceans. We are going to fit our model with only purse seiners data and in a second time with whole data.

- **Gascuel model adjustment**

In both cases, eight cohorts with clear modal progression are selected. Fitting the model of Gascuel and al. (1992) to purse seine data and to all data provide two following equations:

Purse seiners		Purse seiners, Longliners, Gillnets	
LF0	31,998	LF0	32,040
b	16,900	b	16,582
Lfinf	147,418	Lfinf	151,664
K	1,239	K	1,065
m	83,150	m	46,354

Table 1: Estimated parameters of the growth models for yellowfin tuna in the Western Indian Ocean.

The two growth models are very close. The L infinity calculated in this study and the L infinity calculated by Lumineau are not significantly different. We can explain this by the lack of data concerning fish higher than 140 cm. Actually the catches comprise yellowfin up to 180 cm. The choice of the L infinite is not very important to determine the shape of the curve, but it becomes important to condition the size-age key and the subsequent matrix of the catches by age. Thus these results are not satisfactory.

Another adjustment is carried out by imposing a constraint on the L infinity. At the beginning of the yellowfin tuna exploitation in the Indian Ocean, nearly 1 % of the Japanese longliners catches were higher than 164 cm. We choose to make a Bayesian pseudo-approach and we fix a L infinity to 165 cm. The results are:

Purse seiners		Purses seiners, Longliners, Gillnets	
LF0	32,148	LF0	32,571
b	16,739	b	16,001
Lfinf	162,700	Lfinf	163,411
K	0,860	K	0,828
m	26,606	m	22,326

Table 2: Estimated parameters of the growth models for yellowfin tuna in the Western Indian Ocean with a constraint L infinity.

These results seem more satisfactory: the L infinity is more realistic. The two curves are almost identical (Figure 6). The adjustment of the model on the two kinds of data shows a high correlation coefficient: 0,976 for purse seiners, longliners and gillnets data and 0,995 for purse seiners data. The residuals analysis shows a good distribution centred around zero and without trend (Figure 7).

From a statistical point of view the curve adjusted on the purse seine data is the best one. But it is better to keep the model adjusted on the whole data set because it includes the sub-adult intermediate sizes. Hence we will consider the growth model according to:

$$\mathbf{LFt = 32{,}511 + 16{,}001.t + [163{,}411 - (32{,}511 + 16{,}001.t)].[1 - exp(-0{,}828.t)]^{22{,}326}}$$

Size range (cm LF)	Growth rate (cm.month-1)
30-50	1,334
50-60	1,370
60-70	1,655
70-80	2,204
80-90	2,658
90-100	2,862
100-110	2,873
110-120	2,724
120-130	2,448
130-140	1,960
140-150	1,427
150-160	0,687

Table 3: Estimated monthly growth rate of yellowfin tuna in the Western Indian Ocean.

DISCUSSION

- **Validity of the study**

The viability of the Petersen method is still open to debate. A fundamental problem of this method, and especially when applied to migratory species with prolonged spawning period, is subjectivity to the determination of the modes and their chronological connection (Anderson, 1988). For this reason only the clearly obvious modes and whose adjustment under Rmix seems most judicious are kept. Many studies based on the modal progressions were undertaken on the Indian Ocean about the yellowfin tuna. But the results obtained are very different and it is difficult to bring more credit to an interpretation than an other (Marsac, 1992).

In addition several factors could affect the growth curve. The recruitment process, mortality, sampling and size measurement or gear selectivity are as many skew which can affect this study. This last point is discussed previously.

Rmix uses the maximum of likelihood. From a statistical point of view this method is better than Battacharya method used in other studies.

The identification of the modes based on purse seiners data is easy at least until a size of 130 cm (except for sub-adults). Beyond it becomes complicated and impossible for fish greater than 150 cm. This confusion is due to slowest growth of the adults with individual variability which is larger than with juvenile. In addition we do not take into account a differential growth between males and females.

Several studies show a sexual dimorphism in large yellowfin tunas in the oceans (Capisano and Fonteneau, 1991). In the Indian Ocean, there are not data files of sizes per age and sex. However Firoozi and Carrara (1992) observe in the gulf of Oman males growing larger than females. The sex-ratio can bring more information. It is about equal to 1 until approximately 130 cm LF. Thus we can consider the identified modes correspond to groups of ages any confused sexes. The adjustment of the model in the range of size 40-130 cm leads to a growth curve valid for two sexes. Beyond the proportion of males grows gradually. Males are dominating starting from 154 cm in the Indian Ocean (Hassani and Stéquert, 1990). Timochina and Romanov (1992) observe that

100 % of fish higher than 190 cm are males. A sampling carried out in a canning factory in Seychelles in 2003 shows that this limit is at 150 cm now (Figure 8). In any case we do not know if this variation is in relation with a mortality which would be more important for females (because of the laying in particular) or with a differential growth. However, in this study, only the modes lower than 140 cm are considered. As a result the differential growth in large fish is not taken into account. Even if it is preferable to distinguish the growth according to the sex, the current state of knowledge does not allow it. Nevertheless, the constrained growth model describes a growth in a population gradually dominated by males. It indicates the average sizes, according to their age and whatever their sex-ratio (Gascuel, 1992).

The data of Taiwanese and Iranian fleets fishing in the Arabian Sea provides only few informations with Rmix. The sub-adults are quite present but the modes are not clearly obvious.

- **The two growth stanzas model**

The presence of a point of inflection in the growth of yellowfin tuna is observed in the different oceans: in the Eastern Atlantic Ocean (Gascuel and Al, 1992), in the Western Atlantic Ocean (Capisano and Fonteneau, 1991), in the Western and Central Pacific Ocean (Lehodey and Leroy, 1999), in the Eastern Pacific Ocean (Hoyle and Maunder, 2005) and in the Indian Ocean (Marsac, 1992; Lumineau, 2002).

In the Indian Ocean, this growth in two times was initially expressed in the preliminary analysis of Marsac and Lablache (1985) then in the study of Marsac (1992). If the work undertaken by scalitometry (Stéquert and Al, 1996) shows higher growth rates for juvenile, the work of Lumineau (2002), this study and the results of tagging experiments (Yesaki and Waheed, 1992) still seem to promote this type of curve.

Several assumptions can explain this unusual growth pattern for fish. From energy point of view we can describe the growth according to the following equation:

$$R = F + U + M + (Ps + Pr) \quad \text{(Jobling, 1994)}$$

where R is the energy gained as food, F is the loss as feces, M is the energy cost of metabolism, U is additional energy loss and P is growth or energy storage.

Consequently, any variation on the growth can result from the variation of one or more parameters of this equation (Lehodey and Leroy, 1999): food, metabolism or reproduction influence the growth. The low growth rate observed for small tuna can be explained by a metabolism more important than in adults. Trophic competitions inter and intra specific could also be one of the reasons.

The acceleration of growth starts from 60 cm. According to Lehodey and Leroy (1999) the development of the gas bladder starts from 2 kg (50-60 cm) in the Pacific. It would allow on the one hand fish to extend its habitat (and thus to increase the R) and on the other hand to reduce necessary energy considerably to maintain the swim (to decrease the M). The hypothesis of migration of sub-adults in the Arabian Sea, one of the most productive areas of the Western Indian Ocean, could also explain this acceleration of growth. This hypothesis of migration towards productive area was proposed by Marsac (1992) in the Indian Ocean and by Gascuel and al. (1992) in the Eastern Atlantic Ocean.

The point of inflection corresponds to a size of approximately 100 cm. Beyond a second stanza of growth is observed. This size corresponds to the average length of the females at the first maturity calculated by Maldeniya and Joseph (1986) in Sri Lanka. Energy is concentrated in the maturation of the gonads to the detriment of the somatic growth.

- **Growth rate**

A great number of studies using various methods were carried out on the growth of yellowfin tuna in the 3 oceans. Two group of results concerning the growth rates arise. The first one shows a growth rate of 3 cm/month or more for young yellowfin (Appendix 1). The second one considers a growth slower with a growth rate of 1,5 cm/month (Appendix 2). The growth rates obtained in this study belong to the second group in the case of the second hypothesis. However it is difficult to give more credit to a hypothesis rather than the other. Anderson (1988) shows it is possible to calculate again the growth rates of preceding studies. It revisited the data from by Marsac and Lablache (1985), which belong to the second hypothesis, and obtains a faster growth; in the same way he has a slower growth with the work of Marcille and Stéquert (1976).

If we compare this growth model with the other models currently used in the other oceans (Figure 9), we notice on the one hand the acceleration of growth and the L infinite are lower in the Indian Ocean. However it should be noted if the growth curve used in the Central Pacific Ocean and the Western Pacific is similar to that obtained by readings of otoliths by Lehodey and Leroy (1999), there is a poor agreement between data resulting from tagging and the growth curve (Hampton and Al, 2004). On the other hand the Gascuel curve used in the Eastern Atlantic Ocean is in agreement with tagging data obtained by Fonteneau: in both cases we observe growth rates close to 1,5 cm for the juveniles.

In the Indian Ocean, it is not possible to decide between the two assumptions. Various length frequencies analysis or readings of calcified parts lead to very variable results.

Nevertheless, we can note growth rates of the first stanza of this study belong to the same orders of magnitude as those obtained by Marsac and Lablache (1985), Romanov and Korotkova (1988), Marsac (1991), Firoozi and Carrara (1992) and Lumineau (2002). Anderson (1988) proposes a growth of 2,9 cm/mois for fish between 45 and 70 cm but do not draw aside the possibility of a rate of 1,5 cm/mois. Concerning the growth rates of the sub-adults, the results are in agreement with those of Marsac and Lablache (1985), Romanov and Korotkova (1988), Firoozi and Carrara (1995) for the females, Stéquert and al. (1996) and Lumineau (2002). The Stéquert curve and the curve of this present study are very close concerning the sub-adults (Figure 10). Only the juveniles and adults growth are different but the growth adult is higher than the reality.

The few tagging data available in the Indian Ocean seem to confirm the results of this study even if they are very limited in number and zone. Moreover we observe several negative growths. However if we overlay the apparent growth of recovered fishes of the tagging experiment in the Maldives (1992) on the theoretical growth curve thanks to software PLOTREC, it is possible to compare the results of this experiment with the given growth curve. The results of tagging are distributed evenly about the curve (Figure 11). Tagging experiment data concern fishes higher than 50 cm: these results confirm the choice carried out at the beginning of the study to choose the slower growth for sub-adults. On the other hand they do not bring additional information on the growth of juvenile or on those of the adults.

- **What about the second cohort?**

At the beginning of the study, we have chosen to consider only one cohort by year. Yet the analysis of length frequencies shows a second cohort, less important, at the end of the third quarter since 2000-2001. Then it mixed with the first cohort.

The existence of a second cohort is mentioned in other studies about the Indian Ocean but in restricted areas. Anderson (1988) has found juveniles near Maldives in January-February and in July-August. Marcille and Stéquert (1976) and Yesaki (1991) have studied yellowfin growth near Madagascar and Sri Lanka respectively. First ones have observed two cohorts per year in 1973 and 1974, the second one in 1988 and 1989 and just one in 1985, 1986, 1987. Firoozi and Carrara (1992) have also observed two cohorts per year in the gulf of Oman.

In comparison with purse seine data fishing in the Indian Ocean in the nineties, it seems this second cohort was present but it was negligible. However, the determination of the modes is visual so there is a large part of subjectivity: we have to consider this result with care.

Thanks to the growth curve of this present study or the growth curve of Stequert, juveniles of this second cohort correspond to the adults observed in 2003 and 2004. Nonetheless, it does not explain why there was a lot of large fish during these two years. We did not observe a lot of juveniles in 2000 and 2001. This could be explained by the development of a new nursery or a nursery existent yet but secondary. Some juveniles could move on in the fishing area and so would become catchable. This could explain why we can observe a new cohort but not an increase of juvenile catches.

A recent study of the NASA suggest changing winds and currents in the Indian Ocean during the 1990s contributed to the observed warming of the ocean during that period. Temperature is a very important factor for the spawning season and the survey of the larvae. An analysis of the hydroclimatics conditions could explain if yellowfin tuna have had better conditions for the reproduction latest years. We can consider three factors very important for the survey of the larvae:

- sub surface temperature has to be above to 24 °C;
- the food supply must be continuous and important during the larval period;
- Wind has to be low in order to decrease the turbulence of the water (Bakun, 1996) and so decrease the dispersion of the prey and the larvae. On the other hand, a too important stratification is not good because it limits the renewal of the prey. So a speed of 4,5 m/s seems to be an optimum for the larvae survey (Arriz, J., Gaertner, D., 1999).

In overlapping these three factors, it would be possible to find realistic area for the reproduction of yellowfin tuna. If we overlap the wind and the sub surface temperature on the average for the nineties, we underline the different areas already recognised as spawning areas (Figure 12). A detailed examination taking into account rate in chlorophyll and during 2000 and 2001 could bring more information.

CONCLUSION

This study proposes a two stanzas growth model according to a model with 5 parameters identical to that used for yellowfin tuna in the Atlantic Ocean and presented by Lumineau in 2002 for the Western Indian Ocean. The juvenile show a relatively low growth rate of 1,3 cm/month. This stanza of juvenile growth could be related to a more active metabolism (no gas bladder) than the adults and to a competition inter and intra specific more important. Then we observe a faster growth for the sub-adults (2,4cm) which could be related to a migration of tunas in more productive water (Arabian sea in particular). The development of the gas bladder also extend in-depth the habitat of fish. The inflection of the growth beginning for a size from 100 cm could be related with the beginning of sexual maturity.

Studies undertaken on the growth of yellowfin tuna can be divided in two categories: the first one, based on scalitometry essentially, proposes a growth of juvenile of 3 cm/month; the second one, based on the analysis of the length-frequencies and tagging experiments proposes a growth of 1,5 cm/month. In this study we are in the second case. On the other hand the growth of the sub-adults is appreciably equal to that observed by the reading of ototliths.

Ultimately, this study proposes a growth curve in agreement with the current data. The general shape of the juvenile growth phase is similar to those observed in the other oceans and to the limited number of tagging data available so far. The growth of the sub-adults is appreciably equal to that obtained by Stéquert and al. (1996). We can consider that the growth from 40 to 140 cm length to the fork is representative of an average individual growth, without reference to sex. Beyond, the determination of the age is more difficult. Moreover the existence of a sexual dimorphism has to be taken into account. The L infinite proposed in this study is biologically more probable than those proposed by Lumineau and Stéquert. The tagging experiments will bring more information on the growth of juvenile and the migration of the sub-adults in the Arabian sea. They will also make it possible to establish models differentiated by sex.

Finally, the length-frequencies analysis between 2000 and 2004 shows a second cohort at the end of the third quarters. This cohort was observed in the Indian Ocean but only in restricted area. Thanks to the growth curve established in this study, we notice these juveniles correspond to adults observed in 2003 and 2004. This could mean there is a new important area of reproduction for yellowfin tuna. A detailed examination of the hydroclimatic conditions in 2000 and 2001 could bring more information on this subject.

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Figure 1: Fitting of tagging results in the East Atlantic Ocean on the Gascuel model (1992)

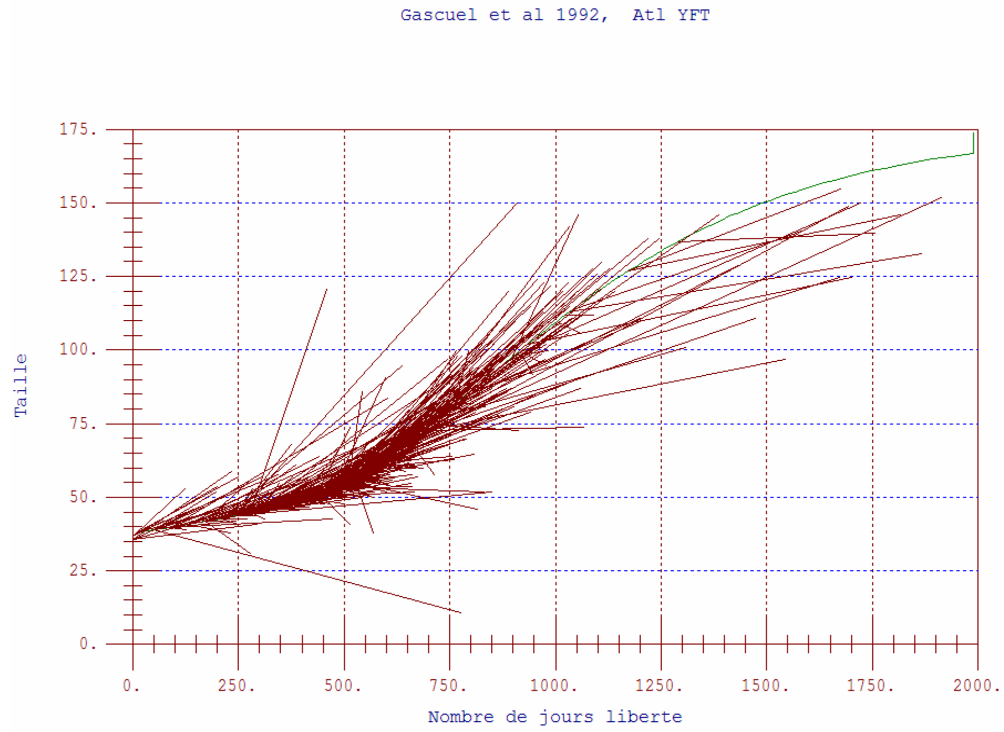


Figure 2: Average catches by size and by gears for 2003 (%).

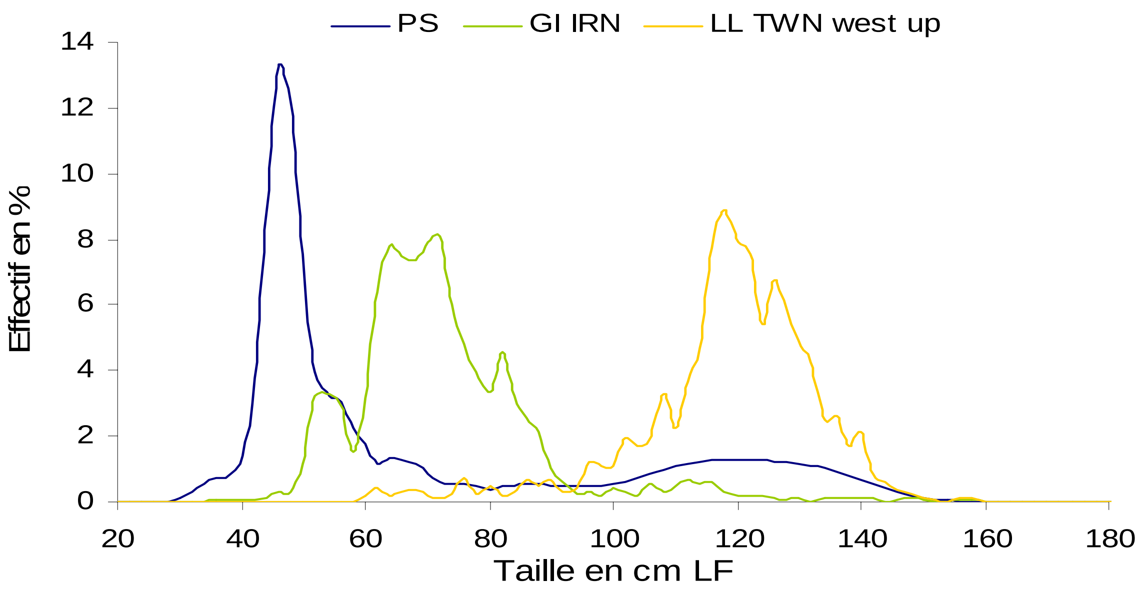


Figure 3: Comparison between Japanese longline data (blue) and Taiwanese longline data (red) from 2000 to 2003.

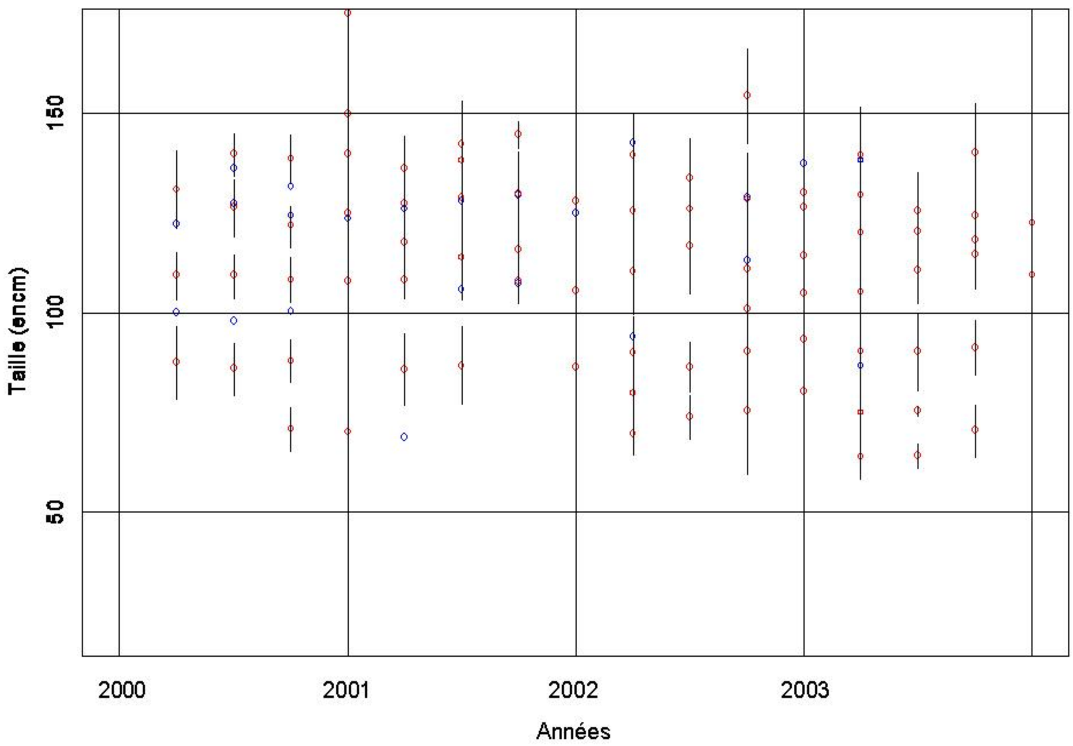


Figure 4: Mode positions identified in the size frequencies data from purse seiners catches 2000-2004

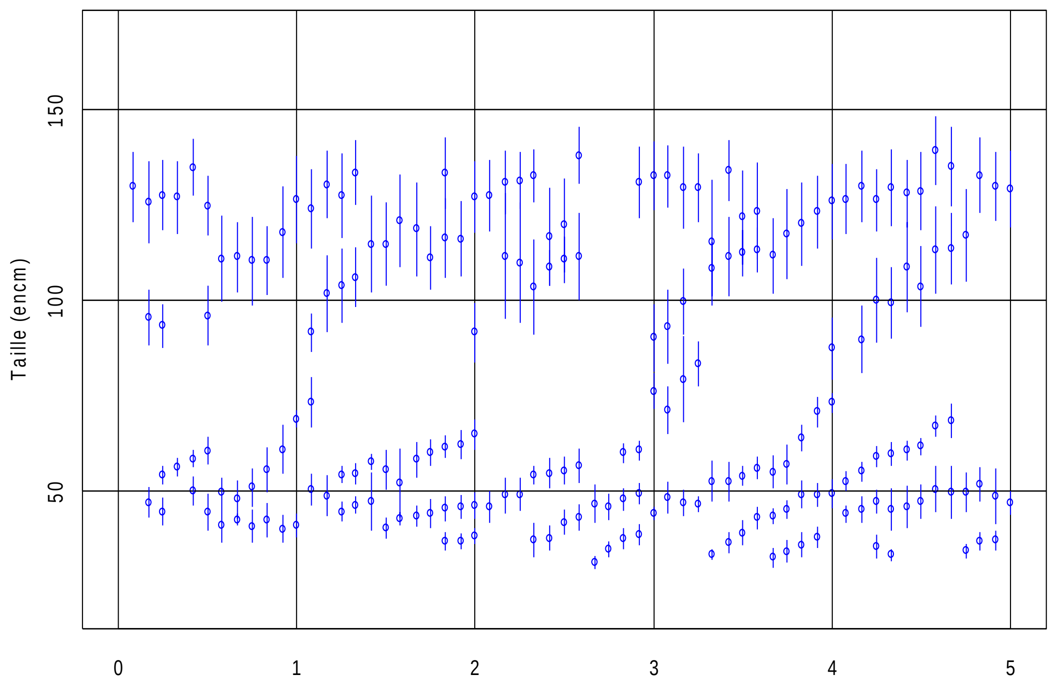


Figure 5: Mode positions identified in the size frequencies data from purse seiners (blue), Taiwanese longliners (green) and Iranian gillnets (orange) catches 2000-2004

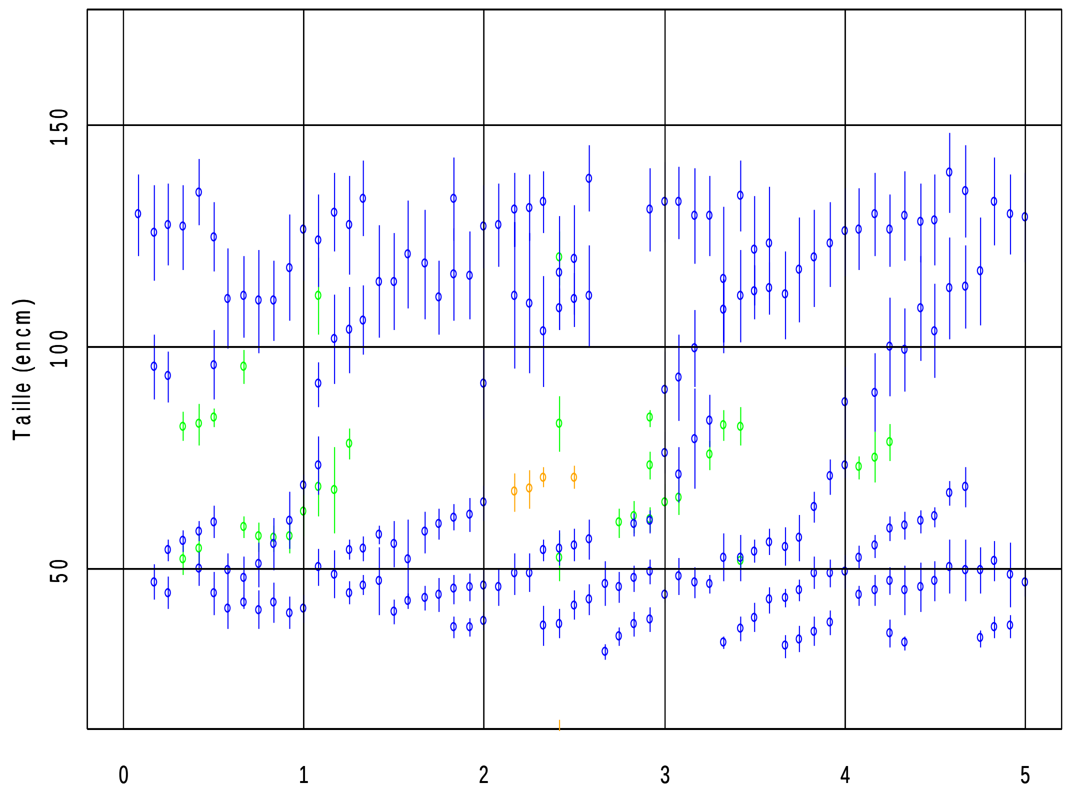


Figure 6: Yellowfin growth modelling in the Western Indian Ocean according to purse seiners data (blue) and according to all the data (red)

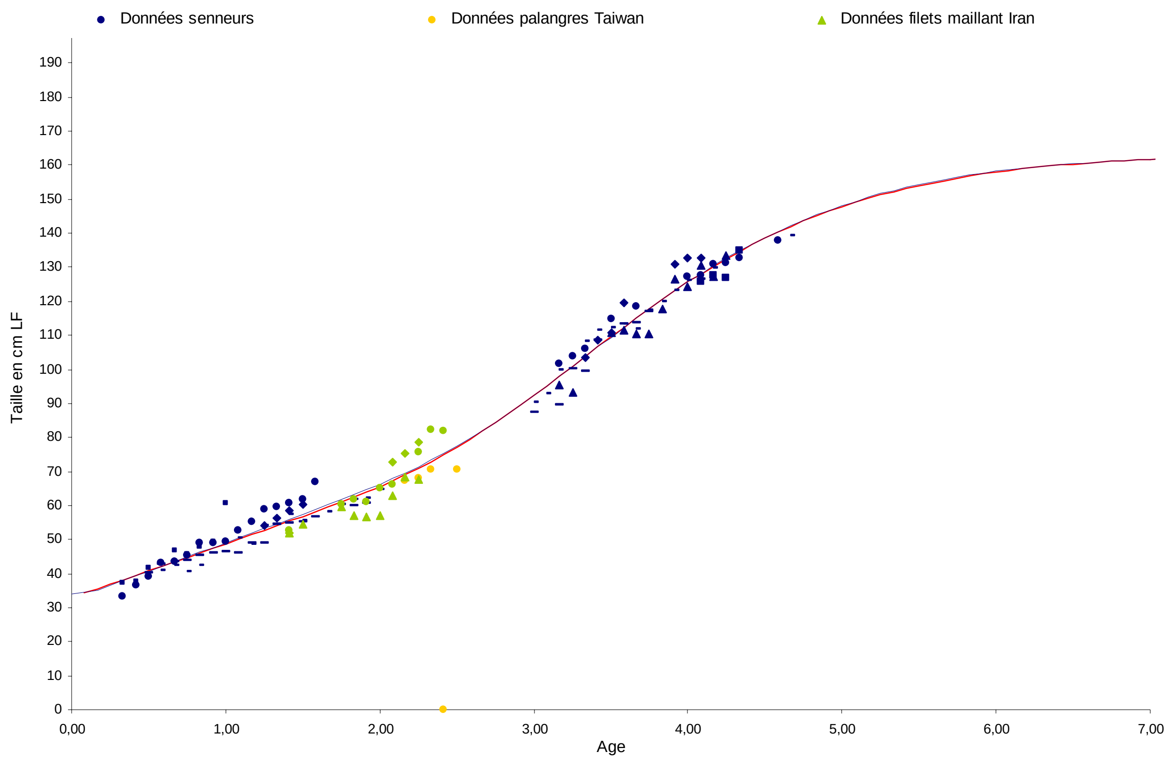
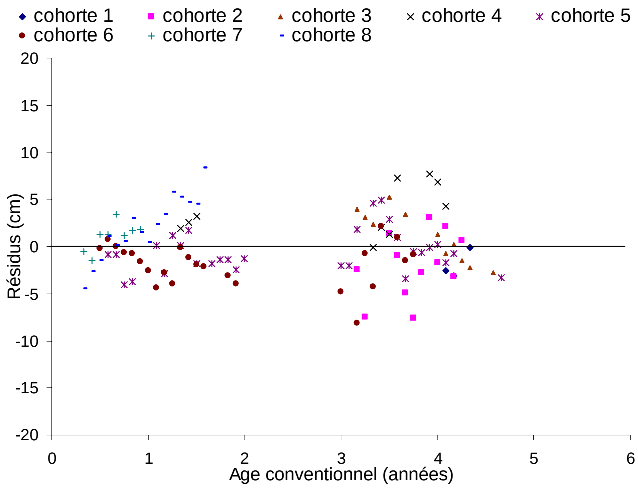


Figure 7 : Residuals analysis about the model fitted with purse seiners data (on the left) and about the model fitted with all the data (on the right).



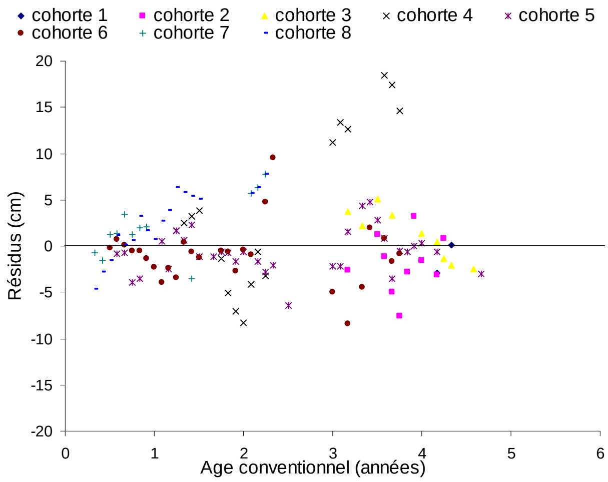


Figure 8: Comparison between the sex ratio known and the sex ratio from the sampling in the canning factory (Fonteneau, unpubl.).

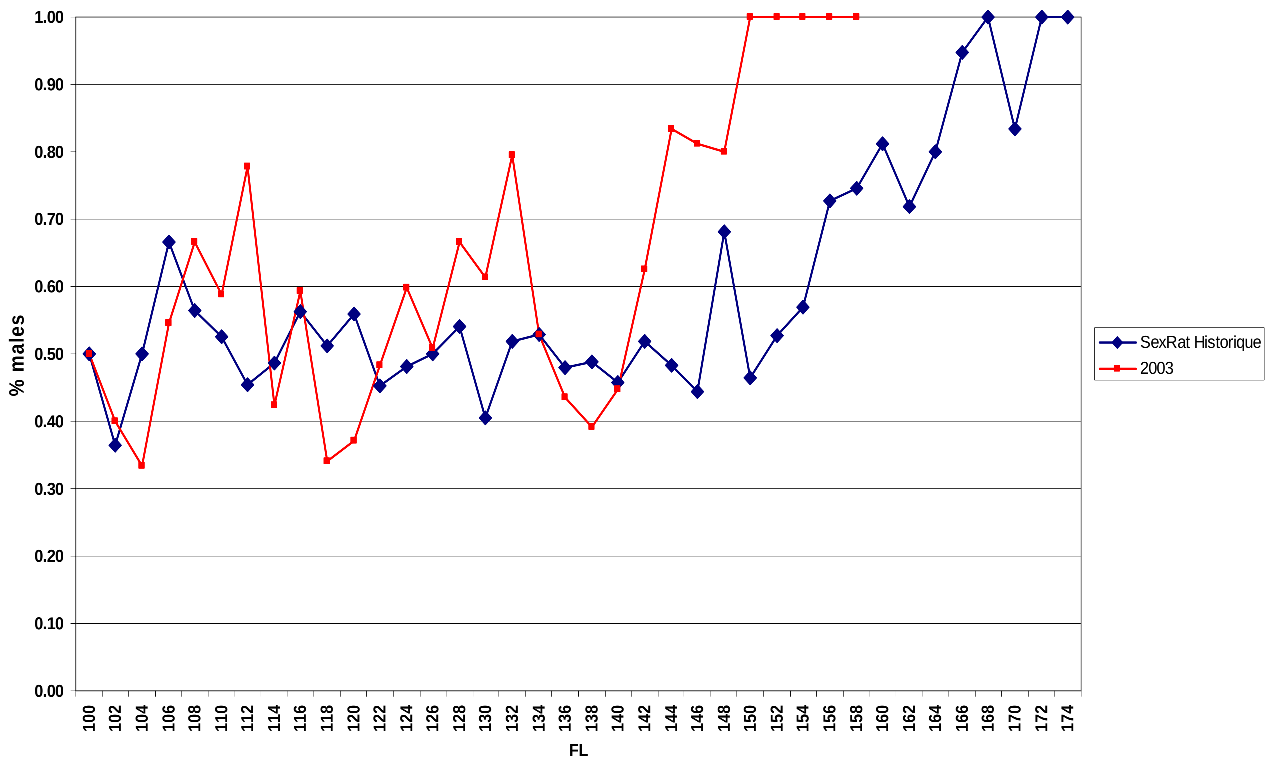


Figure 9: Comparison of yellowfin tuna growth curves established by several investigators.

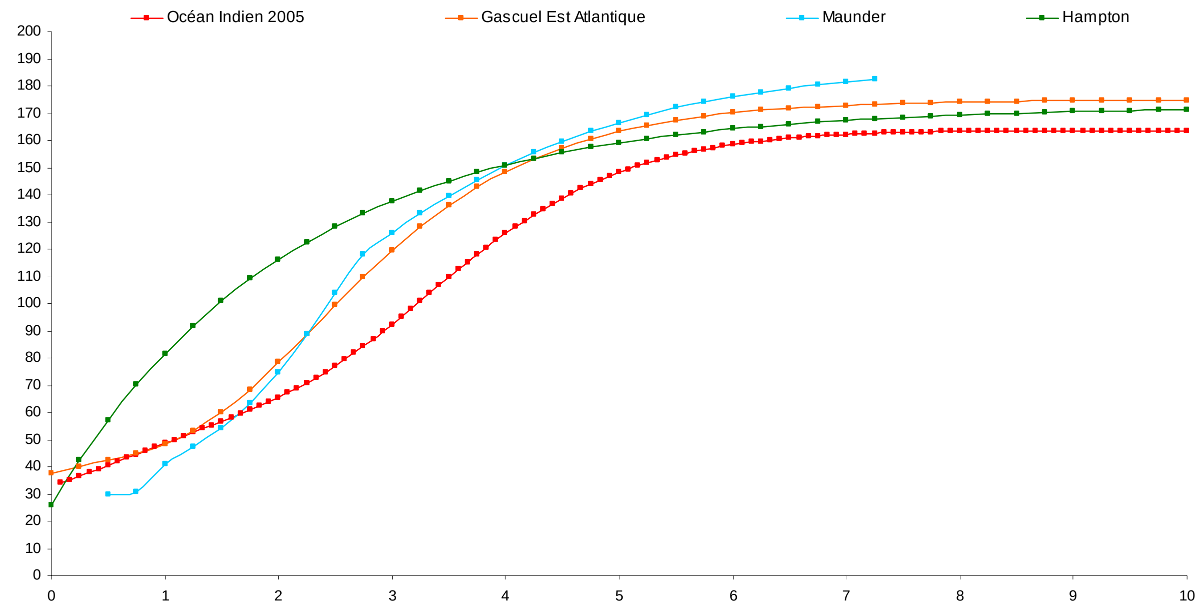


Figure 10: Comparison of Stéquert growth curve (1996) (violet) and the growth curve of this present study (blue).

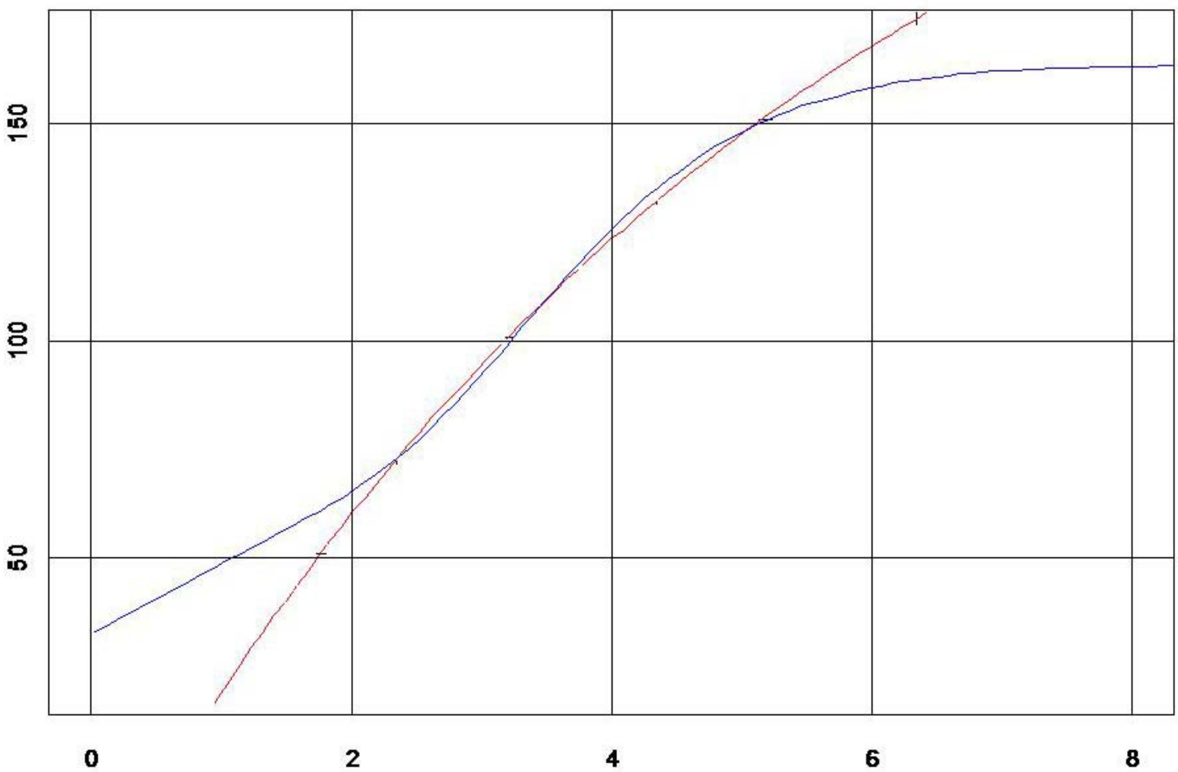


Figure 11: Fitting of tagging results of the Maldives on the growth curve of this present study.

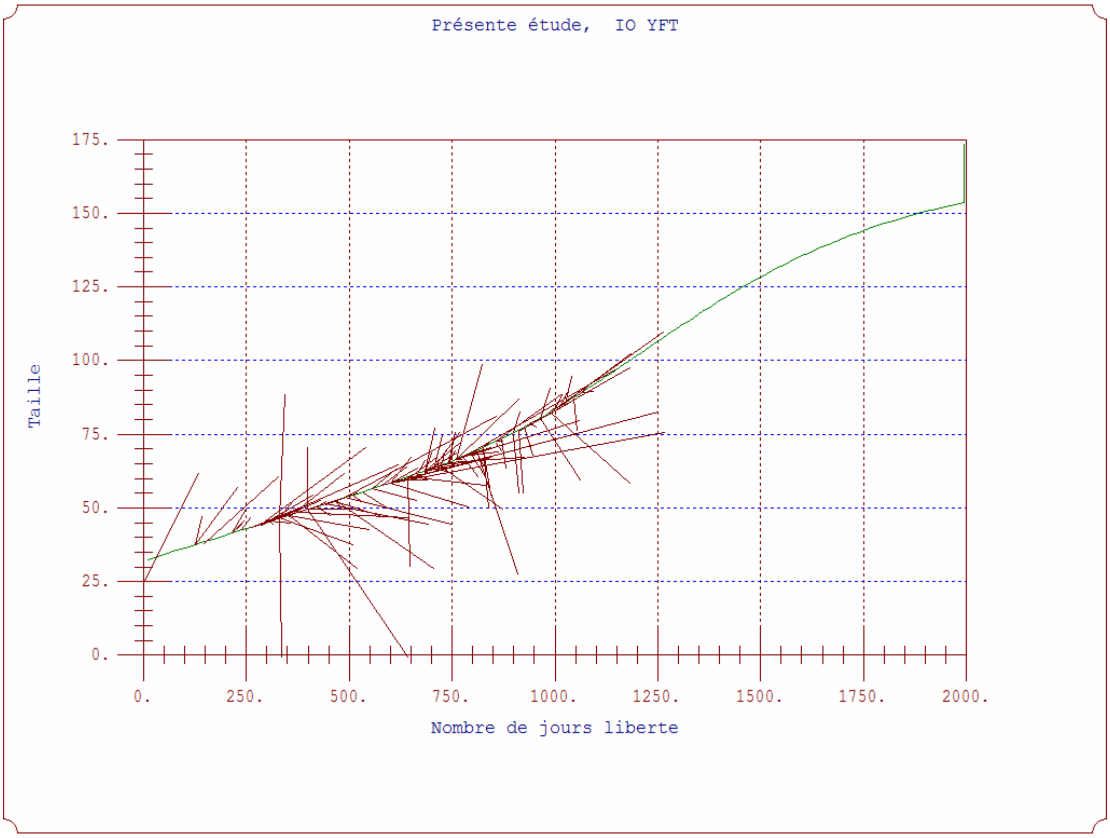
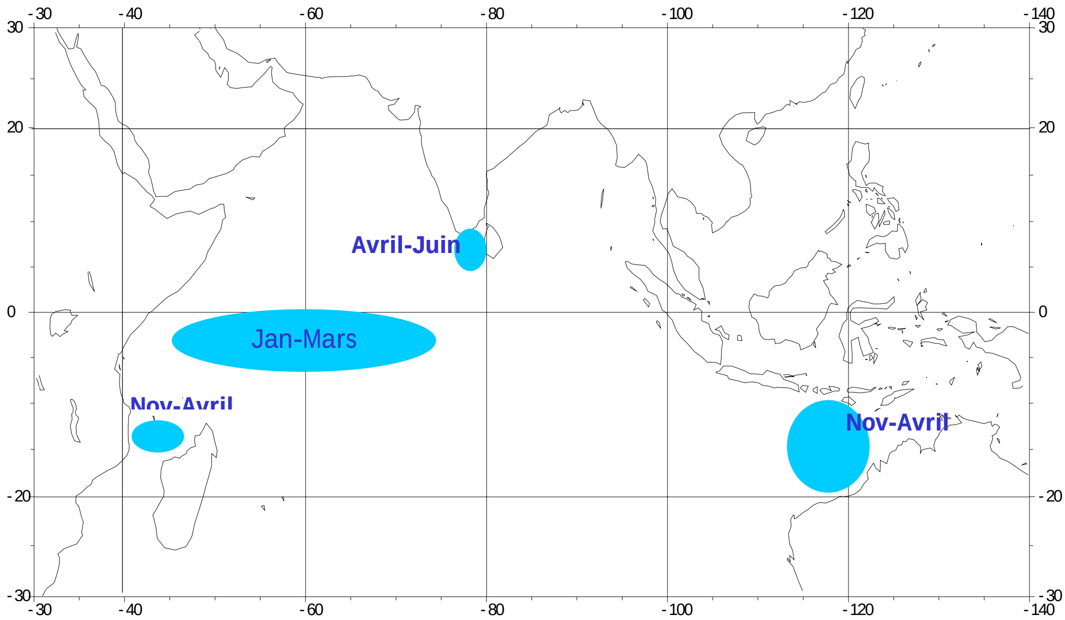


Figure 12: Concentration area of larvae of yellowfin tuna (modified from Stéquert and Marsac, 1986)



Appendix 1: Growth rates (3cm/month) of yellowfin tuna estimaded in and outside the Indian Ocean

Area	Method	Growth rates (cm/mois)	Length range (cm)	Source
Central Pacific Ocean	Otoliths	4,2	17 to 64	Uchiyama and Struhsaker, 1981
		2,7	64 to 93	
Pacific Ocean Eastern	Otoliths	3,0	50 to 115	Wild, 1986
Western Pacific Ocean	Otoliths	7,5	15 to 35	Yamanaka, 1990
		2,9	35 to 79	

Area	Method	Growth rates (cm/mois)	Length range (cm)	Source
Indian Ocean	Scales	3,39	52 to 92	Huang and al, 1973
NO Madagascar	Length-frequencies	3	45 to 70	Marcille and Stéquert, 1976
				Wang and Tanaka, 1986
Central	Length-frequencies	2,9 (ou 1,5 ?)	30 to 70	Anderson, 1988
Central	Length-frequencies	2,5 to 3,2	41 to 95	Yesaki, 1991
Western	Otoliths	3,3	30 to 60	Stéquert and al, 1996
		2,9	60 to 80	

Appendix 2: Growth rates (1,5cm/month) of yellowfin tuna estimaded in and outside the Indian Ocean

Area	Method	Growth rates (cm/mois)	Length range (cm)	Source
Atlantic Ocean	Tagging	1,5	Tagging < 60 cm Liberty<90 days	Fonteneau, non publié
		2,9	Tagging > 65 cm All duration	
Pacific Ocean	Tagging	2,0	Tagging < 60 cm Liberty<90 days	Fonteneau, non publié
		2,7	Tagging > 65 cm All duration	
Vanuatu (SW Pacific)	Length-frequencies	1,3	30 to 50	Brouard and al, 1984

Area	Method	Growth rates (cm/mois)	Length range (cm)	Source
Western	Length-frequencies	2	35-76	Marsac and Lablache, 1985
		3	76-143	
NW	Vertèbres	1,1 to 2,9	55 to 178	Romanov and Korotkova, 1988
Western	Length-frequencies	1,5	44 to 62	Marsac, 1992
		4	66 to 81	
Gulf of Oman		1,3	Males de 61 to 70	Firoozi and Carrara, 1992
		3,9	Males de 85 to 107	
		1,2	Femelles de 62 to 70	
		2,5	Femelles de 83 to 103	
Western and gulf of Oman	Length-frequencies	1,3	36 to 66	Lumineau, 2002
		2,5	66 to 120	