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An overview of 10 years of IATTC bigeye stock assessments in the Eastern Pacific Ocean

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Summary

This working paper examines and discusses the bigeye stock assessment results obtained by the IATTC since 2000. It concludes that there was a large variability, uncertainties and potential bias in these past results, while these basic problems were seldom or never discussed in the yearly assessment reports. The paper tries to identify the potential causes that could explain these often wide uncertainties. A combination of statistical, biological and modelling uncertainties have been identified and they are discussed in the paper. In its conclusions, the paper makes a series of research recommendations that would improve the future quality of the bigeye stock assessment in the EPO.

1-Introduction

It should be noted that bigeye tuna has been a major species in the EPO fisheries at least since the mid seventies (Figure 1 and 2), in terms of quantities taken, these bigeye catches, by longliners and recently by purse seiners, showing a permanent steady increase during the last half century. The major importance of bigeye catches is mainly in terms of its high value, as bigeye was mainly taken by longliners (before the development of FADs fishery) and sold at a high value on the sashimi market (mainly in Japan). It can then be estimated that at least during the period 1986-1995, the value of the bigeye catches by longliners in the EPO was probably much higher that the value of yellowfin tuna taken by purse seiners and sold to canneries at much lower prices (Figure 3). Surprisingly and despite of this very high value, few bigeye stock assessments have been done by the IATTC staff before 1998 and there was a global lack of investigation by the IATTC on this species.

However, the bigeye stock fished in the Eastern Pacific has been carefully assessed each year during the last 10 years by the IATTC scientists. All the yearly assessment reports presented by the IATTC scientists to the IATTC Commission have been making each year the "best" stock assessments in the context of each year, but as these reports were primarily targeting the best and most recent stock status diagnosis, the year to year variability between these yearly results have not been examined in a comprehensive way in any of these yearly reports nor in an ad hoc IATTC report.

The main goal of this paper is to compare the yearly stock assessment results obtained on this EPO bigeye stock. Our goal is to evaluate and to discuss the year to year variability in the methods, in the input data (catch and effort statistics, sizes of fishes caught by the various fleets) as well as biological parameters used yearly in these assessments. The final step of this comparison will be to compare the diagnosis obtained each year by the most recent analysis for the most recent years, to the revised/improved analysis done on the same final years, but during subsequent years. The paper will try to identify if these estimates were consistent over time, or if they were systematically biased. The paper will discuss these additive uncertainties

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in the input and results of the recent bigeye stock assessment results, and it will make various recommendation allowings a better understanding of the real uncertainties of these results.

2- Changes in yearly assessment: last year diagnosis

2-1- Studied question

The main goal of this paper is to compare the diagnosis done each year on the status of the EPO bigeye stock, comparing the estimated status of stock/fishery, i.e. biomass and Fishing mortality, as a function of the corresponding MSY levels:

(1) during the last year of the analysis, when this most recent year was presented to the Commission as being the current stock & fishery situation,

(2) to the estimated status of the same years, but estimated by the models 1 and 2 years later. This basic comparison is done in the accepted hypothesis that the status of the stock is always better known, when it is estimated after several years of exploitation.

This comparison will be done using the so called Kobe diagram, as this plot of the biomass and fishing mortalities levels and trend, is quite informative of stock status, keeping note that for the IATTC commissioners, the most recent year used in the analysis tend to be the most important, in term of its subsequent management measures. This study will then mainly analyze the year to year variability in the estimated levels (relative biomass and trend in relative fishing mortality) of this most recent year.

2-2- Observed Changes in stock assessment diagnosis

2-2-1- Increasing recruitments and increasing MSY?

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

Such a major increase of MSY may be real, for instance due to environmental anomalies (the positive effect of good El Niños? Cf Lehodey 2001) and being the consequence of increasing recruitments that have been compensating the increased fishing pressure. This increased MSY could also be due to an improved yield per recruit obtained by fisheries catching the bigeye close to the optimal weights in term of Y/R (about 35kg for bigeye?). The observed declining trend[3] in the average weight of bigeye caught in the EPO area (shown by Figure 2) does not support this hypothesis, as the recent average weights of bigeye are quite low compared to the optimal weight (the MSY should have declined during the period 1994-2006 due to the increasing catches of small bigeye, Figure 5, and to the subsequent expected decline of yield per recruit).

Based on multiple similar cases in the world wide history of the tuna stock assessments (including in the IATTC area: yellowfin stock), it could also well be envisaged/concluded that this increasing MSY is artificial, and due to the fact that during the first years of the series, the MSY were widely underestimated due to the lower exploitation rates and especially on the low levels of juvenile bigeye caught (real or not, as discussed in chapter 3) . There is no doubt that a such structural bias has often been observed in tuna stock assessments (as it was discussed by Fonteneau et al 1998). Furthermore, in the peculiar case

[3] A decline of average weight due to the increased catches of FAD associated catches, and to the relative decline of the longline catches

of this bigeye stock, the increasing MSY may simply be due to the recently introduced improved estimates of bigeye catches by purse seiners (while the 2000 MSY estimates at 60000 t. was estimated based on a much lower catch, Figure 4a). At least it is striking to note that the increased recruitment takes place when the corrected and higher series of FAD associated catches by purse seiners were introduced in the input data set.

Strangely, this marked increasing trend in the MSY is seldom/never discussed in any of the yearly IATTC stock assessment reports. Our feeling is that it would be necessary to try to explain this major trend, at least to discuss it, and probably also to conclude that when the estimated MSY have been increasing, this may be the consequence of analytical bias, while the real changes of MSY remain unclear.

2-2-2- Variability in the status of the most recent years

The standard method recently approved by the various tuna RFO during the Kobe meeting, the "Kobe plot" is a simple and efficient way to summarize a stock status: simply showing the estimated (1) position of the yearly biomass of the stock (total or spawning) vs the equivalent biomass at MSY and (2) position of the yearly Fishing mortalities vs Fishing mortality at MSY.

In each of these yearly diagrams, one of the key stone results tend to be the "position" of the last year estimates. Even if we recognize that the last year tends to be (always and by nature) the most uncertain, it always plays a "logical" major role in the management of the stocks, since management action are most often taken on the most recent situation of stocks and fisheries.

In this context it is very simple and it should be of prime interest, to do a retrospective analyses of the validity of these "last years diagnosis", simply comparing their relative position in their initial position of "last years", and the position of the same year, but 1 year and 2 years after (these revised estimates being much more realistic, at least if the stock assessment is consistent). As this interesting retrospective comparison has not been done routinely during the IATTC yearly stock assessment we made a first attempt to do such a retrospective analysis, based on the published yearly bigeye stock assessment results during the 2000-2007 period. The selected parameters were the total biomass of the last year, as estimated during each assessment, and the biomass of the same year as it has been estimated in the subsequent years. The basic result of this comparison is shown by Figure 6.
This Figure shows 3 types of changes in these successive estimates:

- ⇒ The biomass of the year 2003 was nearly identical in the 2004, 2005 and 2006 assessments. This is the ideal case: and it can be concluded in this case that the biomass estimated the 1st time in 2004 was probably/possibly unbiased and well estimated (or facing the same bias/errors in each of the 3 successive assessments)
- ⇒ On the opposite, there was a major decline of the 2000 estimated biomass: this biomass was first estimated at 530000 tons, and later in 2002 at a lower level of 375000 t. and then in 2003 at 430000 tons . Such variability cast serious doubts on the validity of the first year estimated biomass (it was probably seriously overestimated in 2001 or underestimated in 2002?).
- ⇒ Concerning the other 4 years (2001,2002, 2004 and 2005), there was a significant steady increase of these "last year" biomasses, showing nearly identical rates of increases for each of these 4 fishing years and an average rate of 28% of increase during the 3 successive assessments.

This large variability of the last year estimated biomass is of course partly due to logical reasons, as the most recent cohorts fished in the purse seine fishery (for instance the 2 younger cohorts) are still poorly estimated. However, as the total estimated stock biomass of bigeye contains 10 year classes, this uncertainty in the biomass of the youngest cohorts cannot explain the large scale of the recruitment variability and trend shown by Figure 3.

Another important point to keep in mind in these changes, is the fact that, as the total yearly catches during these fishing years have been relatively stable during these assessments, it means that the average fishing mortalities estimated by the models during each of these 4 years have also been widely variable, but in the opposite way: for instance, when there was a 28% increase of biomass estimated for the last years 2001, 2002, 2004 and 2005, the Fishing mortalities estimated by the successive models for each of these last years will necessarily show a subsequent decline of the corresponding fishing mortalities (this decline could easily be calculated, but unfortunately the data presently published by the IATTC does not allow to calculate the rate of this logical declining trend).

It can thus be concluded from this overview that in the most recent bigeye stock assessments the biomass and the fishing mortality was poorly estimated, during a majority of the years, and most often shows a stock status diagnosis that was by far too pessimistic. During the period 2001-2005 several of the "last years" would have been in the red area of the Kobe diagram during the assessment year, while the assessment diagnosis of these same years would have been much more optimistic for 4 of these 5 last fishing years: showing much larger biomass and lower fishing mortalities and then easily moving from a red area towards a green zone of the Kobe diagram.

2-3- What potential causes for these past errors

The present overview of changes in the recent bigeye stock in the EPO has showed that there are still wide uncertainties in these past analysis, these uncertainties being very seldom discussed in the past assessment reports. The present paper will try to examine and to discuss the various potential causes that may explain these serious uncertainties in the assessment results (chapters 3, 4 and 5). This review also leads to research recommendations that are envisaged in the conclusion.

3- Errors and bias in Catch and effort data

Catch and effort data from the longline fisheries can be considered as being of fairly good statistical quality, simply because the longline fishery has been dominated by Japanese longliners, a country that has been always providing reliable C/E statistics and good size data. The potential bigeye catches by IUU longliners, that have often been identified in other oceans, have not yet been reported and therefore ignored, but they could also exist in the EPO (from high seas vessels or from coastal countries). On the opposite, it should be kept in mind that these IUU catches are tentatively estimated by other RFOs.

However there are still significant/major uncertainties in the levels of the historical bigeye catches taken by purse seiners in the EPO. The real species composition of the EPO purse seiners and the real catch at size of bigeye caught by purse seiners has been estimated yearly in the EPO only since 2000[4], then the real bigeye catches and sizes taken by purse seiners before 2000 are still widely uncertain. Ad hoc estimates of bigeye catches have been done by the IATTC for the 1994-1999 period, but during the earlier years, the bigeye catch series remain uncorrected, assuming that the species composition was OK before 1994 (before the FAD fisheries). The presently assumed percentage of bigeye in the FAD associated

[4] . species sampling: when these species sampling were developed in the Atlantic and Indian oceans in 1980 and 1982

catches is shown by Figure 7. This estimated low percentage of bigeye taken under logs/FAD during the early period 1974-1993 could “easily” increase, assuming that small bigeye were caught under natural logs at the same rate as today (see Figure 8). The real bigeye catches during the period 1965-1992 could well be in this range, and not at its minimal present values. The “real” levels of the historical bigeye catch trend remains probably highly questionable, and this uncertainty is fully apparent, for instance when comparing 2 average fishing maps of the FAD associated school catches (Figure 9 a and 9 b): during the early period 1986-1989 (an average bigeye catch of only 3.2 %) and during recent years (2000-2005) with 24.5 % of bigeye. There is a serious potential that the pre 1994 historical bigeye catches may be significantly underestimated in the data set used in the present bigeye stock assessments (even keeping in mind the fact that the % of bigeye under FAD is always much lower in the traditional coastal areas of the EPO).

The potential consequences of these basic statistical uncertainties in historical catches should be better estimated, as the trend and levels in the total yearly catches remains in all the assessment models, a key parameter that is conditioning many basic results, such as recruitment levels, total biomass and MSY estimates.

Furthermore, the recent/present uncertainties in the bigeye catches are also well visible on Figure 11 showing the historical yearly catches of bigeye during the 1970-1999 period and used in the 2000 and 2007 stock assessments: the revised present estimates are much higher than the previous ones, showing that the basic data were then widely unrealistic and underestimated (when this was not the case for yellowfin and skipack, as these 2 species have been showing stable and realistic series of catches).

A last important point is also that one of the major uncertainties in all the bigeye stock assessments should always be kept in mind: all these assessments are de facto widely conditioned by longline fisheries and by the assumed relationship between their CPUE and the local densities and biomass of bigeye. A positive factor is that the EPO is one of the few fishing zones where bigeye tuna has always been the main/only target species of longliners (during most years and especially during the recent period, bigeye corresponding to more than half of the total catches by longliners). A serious pending problem remains that the longline fisheries have developed a wide range of major changes and improvements (Ward 2007) that are very difficult to incorporate in the assessment models. These changes should at least be kept in mind as they may lead to too optimistic diagnosis: these technological improvements masking to some extent the real decline of the biomass.

4- Errors in biological parameters

4-1- A western frontier at 150°W?

Most bigeye stock assessments done by the IATTC have been conducted in the hypothesis of a strict W-E frontier at 150°W, such a frontier being primarily based on the low rate of transpacific bigeye recoveries. This lack of tag recovery is of course real, but this conclusion may be widely invalid due to the severe weakness of tagging programs in the area close to the frontier at 150°W. Even if bigeye tuna resources sometimes tend to be highly viscous, as it has been well demonstrated by the limited movement shown by the recent IATTC bigeye recoveries (Schaefer and Fuller 2005), **these results do not prove that there is a biological frontier at 150°W**. In the same way, they do not prove that bigeye born in the Equatorial areas do no migrate to the Northern Pacific at age 3 towards their feeding zones North of 20°N, even if this “obvious” movement pattern has not yet been confirmed by the tagging results.

The following facts should be recognized concerning this 150°W IATTC frontier:

- There is no environmental barrier restricting the E-W potential movements of juvenile and of adult bigeye at 150°W (cf Longhurst areas, Figure 17).
- All the equatorial areas E and W of 150°W are a potential spawning zone for bigeye (Taiwanese observer data) (see Figure 10), and there are permanent catches of adult bigeye east and west at this frontier, an area that has permanently been the core of the bigeye distribution of adults. This fact is well shown by monthly fishing maps of longliners in the area (these 630 maps have been done, and they are available upon request) a diagram of the monthly catches by longliners around the IATTC frontier (between 120°W and 180°W), by longitudinal zones of 5°, tend to show permanent movement of the longline fishery E and W around this 150° frontier (Figure 13). We consider that there is a high probability that these geographical mobility of the catches and fisheries do correspond to movements of fishes (followed by the longliners), and this hypothesis should at least be envisaged and analysed.
- The major feeding zones of bigeye tuna in the Pacific are located in the North Pacific between 20° and 35°N (see Figure 14,15 and 16). It should be kept in mind that the total distance between Asia and America at 30° Norh is much smaller than at the Equator: 5000 nautical miles at 30°, versus 10000 miles at the Equator. This smaller size of this northern area and its character of a feeding zone, should increase the probability for a mixing of fishes born in the Eastern and/or the Western Pacific.
- It is also clear that juvenile bigeye are also distributed in both side of the 150°W frontier, as it can be seen in the FAD fishery around 150°W, and that these juvenile are easily crossing this legal frontier.

Furthermore, it should also be envisaged that **if the ecological trap hypothesis could be confirmed**, i.e. if bigeye tunas are firmly associated with the network of drifting FADs (as it was proposed by Marsac et al 2000), that there could nowadays be a dominant output flow of juvenile bigeye from the EPO to the Central Pacific due to the dominant westward drift of FADs in the equatorial current (Figure 18 and 19). In the EPO environment and its dominant westward surface current (Figure 19, taken from Travisña pers. com.), a majority of FADs that are seeded south of 4°N could move to the western Pacific, and possibly "carrying" a fraction of the EPO bigeye biomass associated to FADs (keeping in mind that these tunas may well come back later to the EPO, for instance if they are showing a homing behaviour). This ecological trap hypothesis is still controversial, but the recent paper by Hallier and Gaertner 2007 would tend confirm its validity (especially for juvenile bigeye that are often showing a firm association with FADs (not under a given FAD, but associated to a network of FADs), and the faster potential movements of tagged tunas associated to FAD. On the opposite, it could be envisaged that the tagging of tunas associated to anchored FADs (as the recent IATTC bigeye tagging) could underestimate the "real" movement rates and pattern of the stock.

It should then be of prime importance to better recognize this potential for E to W and/or W to E bigeye movement, directly within the Equatorial areas, and N-S indirectly, towards the Northern feeding zones, i.e. producing either an average potential loss or a gain of fishes during the life of each cohort. This movement of adult bigeye toward their northern feeding zones is for instance well suggested by the seasonality of these fisheries, Figure 12 showing the higher northern CPUEs of bigeye during the 1st and last quarter of each year (when equatorial CPUEs tend to be quite stable).

Such potential loss or gain of fishes in the EPO during the life of the exploited cohorts should be better explored and tentatively introduced in the assessment models, as it may well explain the frequent bias in the too pessimistic "last year" assessment: for instance if there is a permanent net-transfer of biomass (then a recruitment) of fishes from the central Pacific to the Eastern EPO.

It is also quite interesting to note the EPO peculiarity with the events observed in 2000 and 2001 (Figure 22), when surprisingly the majority of the bigeye tuna caught under FADs were not juvenile, but adult bigeye predominantly over 1 meter, an event that goes against the well known fact or belief that FADs only attract juvenile bigeye tuna.

This question should be fully recognized and a tagging program on tunas associated to drifting FAD would be the only way to solve this major uncertainty.

4-2- Uncertainties and changes in basic biological parameters

4-2-1- Natural mortality at age and longevity

The level and pattern of Natural mortality as a function of age is a biological parameter of outmost importance in every tuna stock assessment, and especially for bigeye tuna, as it widely conditions the recruitment level and stock sizes, as well as the potential interaction between juvenile and adult fisheries. This factor is always of key importance in all the bigeye tuna fisheries world wide, due to the increasing competition between FAD purse seine fisheries predominantly catching juvenile bigeye, and longliners catching only the adults (Figure 22 and 29).

Various additional comments can be done upon this potential interaction:

If M is low for juvenile, for instance in the 2007 bigeye stock assessment, then there is a huge potential for such a Y/R competition, at least when the stock is suffering a high exploitation rate.

On the opposite, if juvenile M is high, as in the 2001 stock assessment (this should be a universal biological rule: larvae and juvenile are always suffering a much higher M, for all animals, and including human), this competition may be quite limited, due to the much larger levels of recruits that are "necessarily" recruited and fished in this hypothesis.

Unfortunately this vector of natural mortality as a function of age remains widely unknown for bigeye. This major uncertainty is still faced by all tuna RFO and also in the IATTC area, as it can be seen when comparing the wide yearly variability of the assumed/estimated M_{age} vector (Figure 20) (keeping in mind that the true levels of Juvenile M could well be outside this range). It could also be envisaged that the real levels of natural mortality at age could be widely outside these levels used. Our feeling is that the constant M hypothesis used in the 2000 and 2007 assessments should never be used for bigeye, as it is totally unrealistic and against all biological laws (Beverton and Holt 1957, Ricker 1975, Peterson & Wrobleski 1984, McGurk 1986, Finch 1990), and against all the tagging results (Hampton 2000) to assume that natural mortality is the same for a 2.5 kg and for a 50 kg bigeye.

It could also be interesting, upon the level of bigeye natural mortality of juvenile bigeye, to positively envisage the ICCAT hypothesis ("Gulland's hypothesis") that juvenile yellowfin and bigeye should have very similar natural mortalities during their juvenile stages, these juvenile bigeye being:

- ⇒ very difficult to identify: same shape, same colors, similar behavior
- ⇒ living mostly in mixed schools, in shallow waters and in the same equatorial nurseries and both species often under FADs,
- ⇒ probably eating the same preys and being the preys of the same predators,

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Furthermore, the bigeye longevity is also an important but poorly known parameter for the bigeye stock: this species may easily show a longevity over 10 years or more (bigeye recoveries were observed > 12 years at liberty, even with small numbers of tagged bigeye, and a poor reporting of tagged fishes by most longline fleets). We see a realistic probability that the bigeye stock could have a significant fraction of very old fishes and producing significant catches during at least 12 or 15 years (a similar uncertainty has been noticed for southern bluefin, a species commonly fished at ages over 20 years as it was well shown by Kalish et al 1996, when the present southern bluefin stock assessments also faces difficulties to incorporate such longevity) .

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

These major uncertainties concerning the level and pattern of the natural mortality as a function of age should at least be fully explored in the basic IATTC stock assessment, and the ICCAT hypothesis should at least be envisaged having similar levels of juvenile M for yellowfin and bigeye for small sizes (i.e. at sizes <70 cm?). The hypothesis of a constant and low natural mortality of juvenile bigeye should never be used in any bigeye stock assessments.

4-2-2- Sex ratio at size

This biological parameter is important in modern stock assessment, as it indirectly condition the spawning potential of the estimated stocks: a 50/50 sex ratio will lead to relatively large spawning biomass, while a sex ratio of adults widely dominated by males as in the 2000-2002 analysis, will correspond to much lower spawning biomass, especially at higher exploitation rates. This important biological parameter is very easy and unexpensive to obtain, but for bigeye tuna it should be based on the sex of bigeye caught by longliners, as the adult bigeye are primarily caught by this gear. Surprisingly, it can be noted that this basic parameters remains poorly estimated in the EPO and shows a surprising year to year variability. Even the presently estimated sex ratio at size (Figure 21) remains possibly questionable, due to the limited sample available, especially for the larger fishes (for instance bigeye taken at sizes over 1.50m, i.e. 40 % in weight of the recent EPO catches).

It is possible that this biological uncertainty produced significant errors in past/present bigeye stock assessments and further investigations should be developed in this field by the IATTC. A major sampling effort on longliners should be conducted in order to reduce this uncertainty.

4-2-3- Relative fecundity at size

This biological parameter is also an important one, as in the model it conditions the expected recruitments levels. Based on the observed variability of this parameter observed in the recent IATTC assessments (Figure 26), it can be concluded that there are still a wide range of uncertainties in this parameter. The age at first spawning remains widely uncertain in the EPO, and when the Schaefer et al 2005 study indicate a late size at maturity at 135 cm, various other studies or results indicate a much smaller size at 1st maturity at about 1 meter, as in other areas of the Pacific Ocean (Farley et al. 2006, Sun et al 2006, and Taiwanese EPO observer unpublished data). It should be kept in mind that the sample from longliners in this study was very limited: only 120 fishes, fishes that were possibly taken outside spawning strata. This biological uncertainty should be easily clarified, and necessarily targeting a large biological sampling of longliners fishing in the best spawning strata (+ or – shown by Figure 10).

One of the further pending question on this topic is also the potential existence of a **parental effect**, i.e. the oldest/larger females having a real biological potential much greater than the estimates based on the counting of their eggs, simply because the eggs produced by these very old females have a much better survival and a wider spatio-temporal distribution, thus a much higher probability for producing larvae (Birkeland & Dayton 2005). This topic of a parental effect should be better evaluated for bigeye tuna (as for other large tuna species) as it would have a great impact on stock conservation and on the management of the bigeye stock (for instance through the closure of strata where the larger fishes are predominantly taken).

It is possible that this biological uncertainty produced significant errors in past/present bigeye stock assessments and further investigation should be developed in this field by the IATTC.

Our recommendations are (1) that a major biological sampling effort, especially on longliners, should necessarily be conducted as soon as possible in order to reduce these uncertainties (this would be easy and inexpensive to do) and (2) that further biological research should be developed on the potential parental effect of bigeye tunas.

4-2-4- Growth

Growth is always a basic parameter of key importance in all analytical tuna stock assessments (SPA, A-SCALA, SS2 or other models such as MF-CL). The growth pattern is either fixed by existing data (VPAs) or estimated by the models as a best fit. The year to year variability of the bigeye growth estimated during recent stock assessments (Figure 23) is rather important and difficult to understand and to justify. Furthermore, one of the basic fact that has often been observed on bigeye tunas (as for yellowfin) is their clear 2 stanza growth curve , (as analyzed for yellowfin in the Atlantic by Gascuel et al 1992) that has been fairly well shown by the recoveries from various tagging programs (Figure 24 from the Indian Ocean tagging). This potential slow growth of juvenile bigeye should be better investigated, and if it is confirmed, it should permanently be kept as a fixed prior in all future assessment works.

A large scale tagging programme tagging bigeye at various sizes and in various areas would be the best/only way to solve this major biological uncertainty.

4-2-5- Size of the spawning stock

The size of the spawning stock has been estimated yearly by the IATTC, this result being the “consequence” of the various parameters and results in the yearly models (recruitment, growth, sex ratio at size, fecundity at size, exploitation rate, etc..). These estimated yearly sizes of the spawning stock are shown in Figures 27 and 28 (as given in the yearly IATTC reports). These Figures are showing a global declining trend, logical in the context of increasing catches, but with a quite surprising/misleading variability:

1) During the assessment years 2001 & 2002, the spawning stock is at very high levels close to the total biomass: it probably corresponds to an estimated biomass of mature bigeye, males + females, and it cannot be a spawning stock of females.
2) During the assessment years 2000, and 2003-2004, the « spawning stock » is probably an estimated biomass of mature females
3) Since 2005-2007, the size of the « Spawning stock » was estimated using a relative index, and if this index shows a potential relative trend, it does not show the real level estimated for this spawning stock.

We consider that the year to year variability of the estimated spawning stock sizes observed during the successive IATTC bigeye stock assessments is excessive: the declining trend in the spawning biomass is highly logical, but the “real” spawning biomass remains for us widely uncertain. Keeping in mind that the spawning biomass of such a long living species should show a moderate yearly variability. This structural uncertainty should be at least better discussed and explained. Our recommendation is also that these results should always be given at the same scale, and preferably as absolute biomasses.

Further biological research on bigeye spawning should be conducted, and especially on the size/age at 50% spawning, as we consider that the recent values used in the assessment (50% spawning at about 6 years) is fairly unrealistic and probably not representative of the real age at first spawning (probably in a range between 3 and 4 years. A more intense spawning on longliners fishing on the spawning bigeye grounds would be the best and only way to obtain such representative sampling (this would be easy and quite inexpensive to do).

5- Uncertainties due to the assessment methods used?

During the last 10 years, the IATTC staff has been using 3 main types of assessment models: (1) the "traditional" cohort analysis proposed by Murphy 1965 and generalized by Tomlinson in 1970 and widely used by the IATTC during many years, (2) the A-SCALA model recently developed by Maunder (Maunder and Watters 2003) and (3) since 2007 the SS2 model developed by Methot 1990. Each of these models have advantages and disadvantages, but none of them is very efficient to handle the age specific movement of tunas[5], or the permanent changes in the targeting of the various fleets, and the permanent major changes in the age specific fishing selectivities and catchabilities (probably with major trends of increasing catchability for most purse seine fleets, for instance due to the new and highly efficient EU purse seiners (Gascuel et al 1993, Gaertner and Pallares 2002), and especially on bigeye caugh on FADs. None of the present model can handle well such permanent increases of FAD fishing power, and as a consequence it is impossible, in the absence of a tagging program, to know if a CPUE increase of FAD associated bigeye is due, (1) either to an increased recruitment or (2) to an increased efficiency of purse seiners and their FADs.

Furthermore, all these models are also widely "prisoners" of the assumed or estimated biological parameters and of the quality of catch and effort data (as these parameters remain their fundamental basis): if the historic catches of small bigeye remains widely under estimated, then none of the models (past, present or future ones) will correct this structural bias!

The same comment can be made upon natural mortality at age, a factor that is widely conditioning the potential interaction between FAD and longline fisheries: none of the assessment model can obtain realistic estimates of the real potential Y/R interactions when the natural mortality at age are widely erroneous (for instance if the juvenile M_i are widely underestimated), and this was possibly the case in some of the past analysis.

The same major basic uncertainties are also potentially faced at the geographical levels: all present models are very weak to handle the complexity of tuna movements that are still very poorly known. None of the present models can efficiently handle a major change in the size of the area fished, a factor that is always increasing the apparent recruitment and the estimated MSY (Laloe 1989). Furthermore, bigeye movements remain widely uncertain: showing sometimes a great viscosity (well shown by some tagging recently done in a given context of equatorial anchored FADs by Schaefer and Fuller 2005), or the "necessary" large scale N-S movements of adult bigeye between their spawning and feeding zones (Figure 15). There is no doubt that major uncertainties will remain upon these movements in the absence of large scale tagging experiments covering the entire fishing zone and a wide range of sizes

[5] Models and tuna movements: there is a major difficulty in all the present assessment models to incorporate realistic small fishing areas, and tunas moving each month between these areas, at variable rates, as a function of there age and of the environment variability.

tagged, and using a wide range of tags (dart and electronic). Furthermore, even when the real age specific movement patterns of a tuna species are perfectly known by scientists, they will always be very difficult or impossible to introduce in an optimal model based on fine scale realistic geographic strata and with realistic seasonal movements that should be variable as a function of age, and also from one year to the other or between cohorts (Atlantic bluefin).

We also consider that a realistic bigeye stock assessment in the EPO should necessarily start during the early fifties, and it should incorporate all the initial years of an already quite high exploitation rates (starting in 1954 with a virgin stock! What an interesting case!) and during which Japanese longliners (and their good data base: C/E & sizes) were widely dominant. The very interesting first years of the fishery that have been well followed should never be abandoned from the analysis (for us these analyses have been facing a "Shifting baseline syndrome" well analyzed by Pauly 1995). Subsequently, we consider that the IATTC staff should take action to recover from Japan all the historical bigeye size data that –surprisingly- are not presently available in the IATTC data base and conduct all its future bigeye assessments since 1954/1955.

We consider that an in depth reanalysis of the seasonal catch and CPUEs by sizes and by time and area strata (similar to Figure 13), could also help to better evaluate more realistic movement patterns and the potential frontiers between stocks and to better incorporate these results in the assessment models.

Our conclusion is that most assessment models applied to tuna stocks (VPA, A-SCALA or SS2) may well tend to often underestimate the real potential productivity of most tuna stocks. This frequent structural bias is due to the fact that various fractions of tuna stocks can often be quite cryptic and unavailable to fisheries during many years. In this context analysed by Fonteneau and al 1998, many tuna stock assessments tend to conclude each year that the stocks are already fully exploited or overfished, when further changes in fishing patterns or areas or fishing depth, easily tend to increase the sustainable catches and the estimated MSY (as for the bigeye and yellowfin MSY in the EPO)

6- Conclusion

The analysis of the multiple major changes in the IATTC results of bigeye stock assessments shows that these results were most often questionable (the increasing MSY, trend in recruitment, variability of yearly stock biomass, see Figure 26), highly variable or false (the last year diagnosis in all the yearly Kobe diagrams). We consider that these past uncertainties in the results should be fully recognized and carefully analyzed by the IATTC, as these past problems and errors tend to reduce the credibility of present and future analysis. Looking at these past errors, many IATTC commissioners would easily question their validity, especially in the context of past IATTC reports in which all the estimated parameters are *de facto* most often presented as being "real scientific truth", although these results are only temporary, fragile and provisional "best estimates of the year".

The basic causes of these uncertainties and errors should be better analysed, but they are probably due to a combination of uncertainties -statistical, biological and analytical- and to the fact that even the best and most complex tuna stock assessment models are still quite unrealistic to model the complexity and variability of such highly migratory species, especially when these species show a combination of a viscous behaviour (Mac Call 1990) as it has been well shown by the results of recent IATTC tagging but also **obviously** doing large scale movements (for instance towards their northern feeding zones: these bigetye are not born at 35°N!). One of the more critical limiting factor is probably the weakness of tagging results in the area, recent tagging being very interesting ones, but too limited to peculiar sizes and areas components of the stock, possibly biased by the TOA anchored buoys (equivalent to anchored FADs).

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

It should then be recognized that all the bigeye IATTC past stock assessment have been facing major uncertainties and that their results have been most often severely biased: for instance underestimating the productivity/recruitment of the stock and its MSY and often providing a too pessimistic diagnosis upon the status of the bigeye stock during the last year of the assessment. We consider that these errors are due to a combination of major statistical and biological uncertainties faced in the bigeye analysis: these major problems should be better identified, they should be fully recognized, and they should lead to large scale international research programs coordinated by the IATTC.

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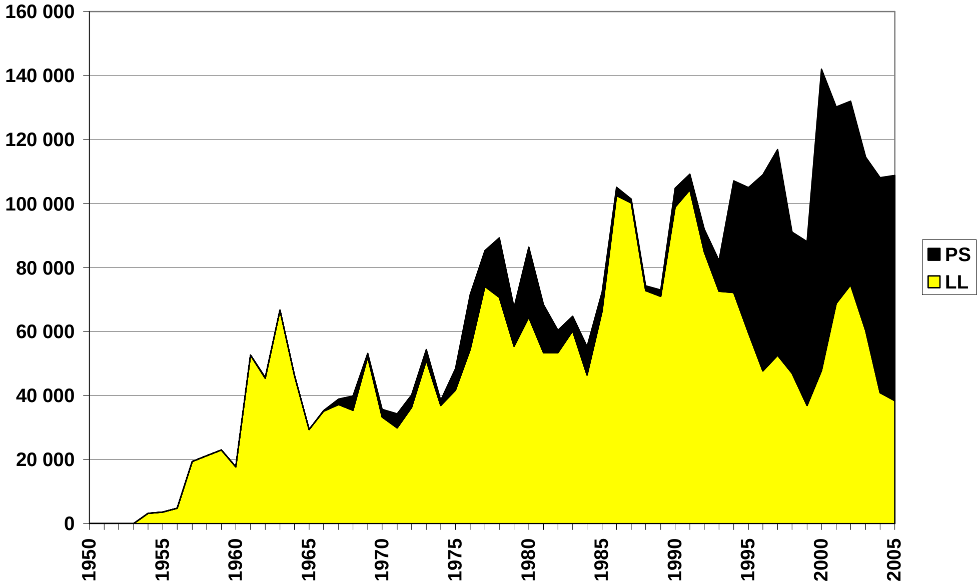


Figure 1: Yearly catches of bigeye in the EPO

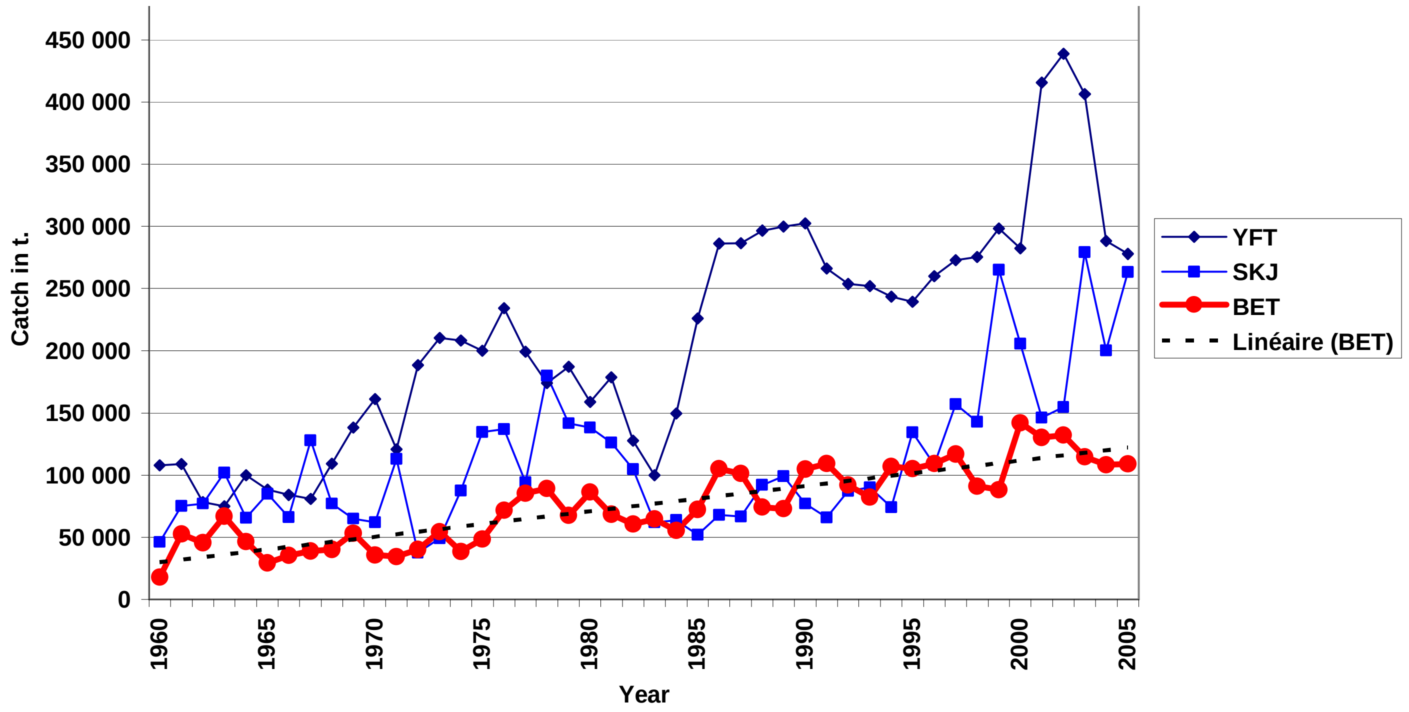


Figure 2: Total tuna catches by species in the EPO during the 1960-2005 period, and linear trend adjusted to the bigeye catches

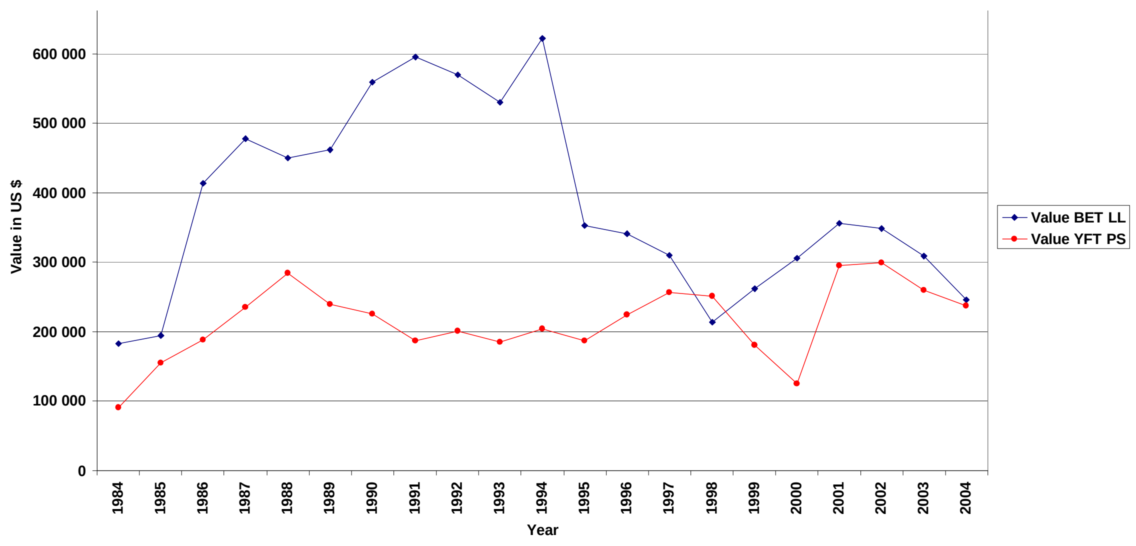
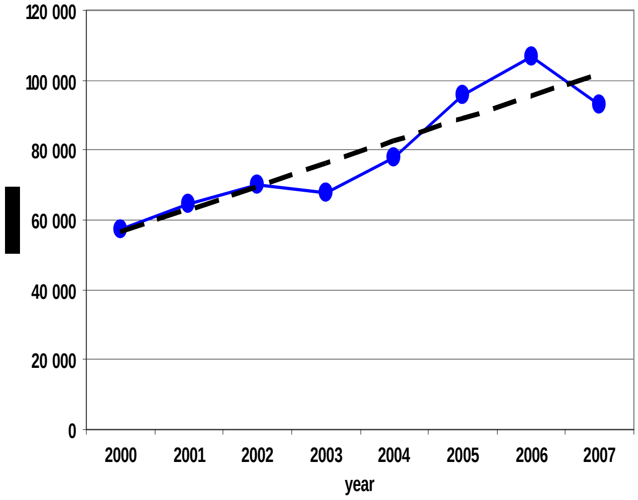


Figure 3: Estimated values in 1000 US $ of the yearly bigeye and yellowfin catches, based on the yearly catches by gear and on the estimated landing values of the 2 species caught by longliners and purse seiners *(NB: this preliminar figure should be checked and validated with detailed and exact data concerning the real landing values of these yearly catches by each gear, but this figure is probably realistic when it shows the dominant values of BET catches in the EPO during the 1986-1995 period)*



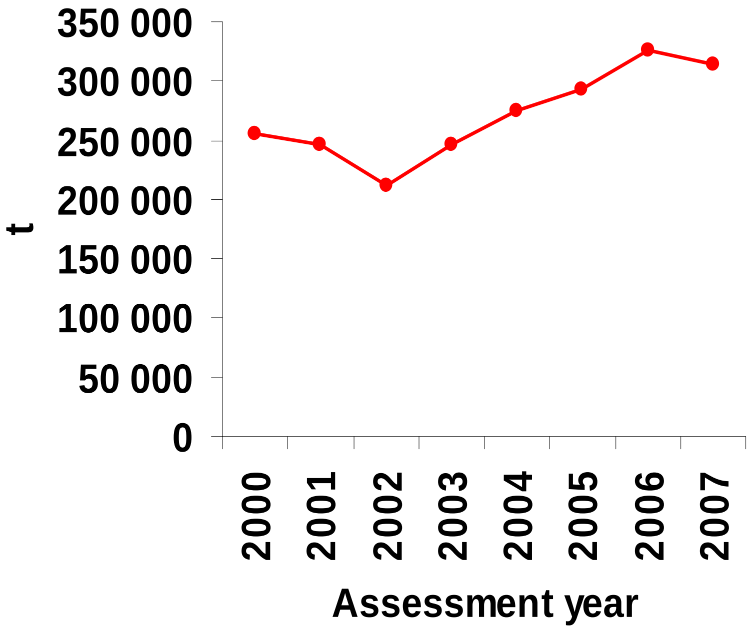


Figure 4 a

Figure 4 b

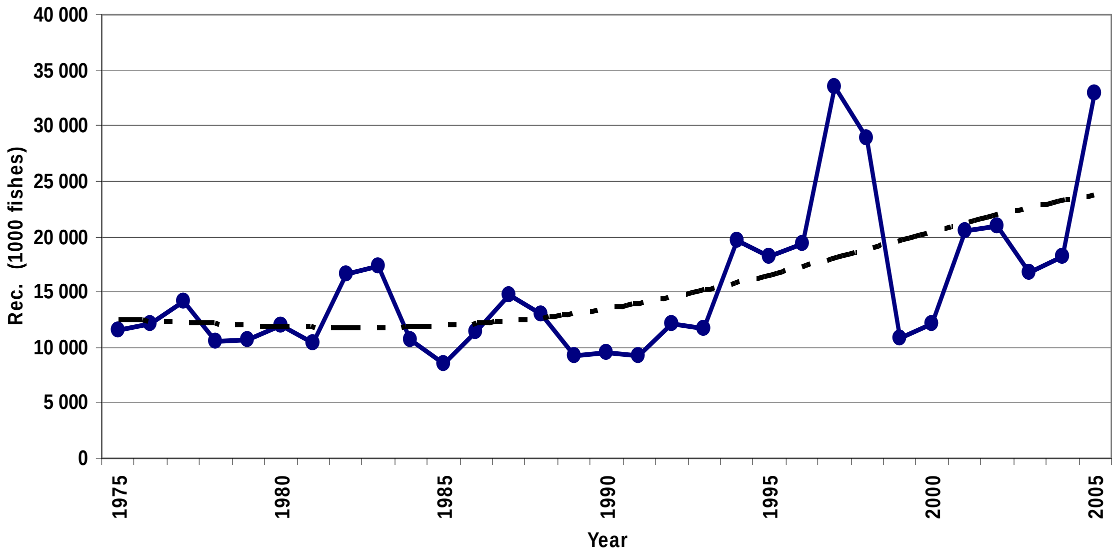


Figure 4 c

Figure 4: Estimated MSY of the bigeye stock (4a) , biomass at MSY (4b) estimated yearly by the IATTC during its most recent stock assessments and recruitment levels estimated in 2007 (Figure 4c) (its trend shwon by a dotted line)

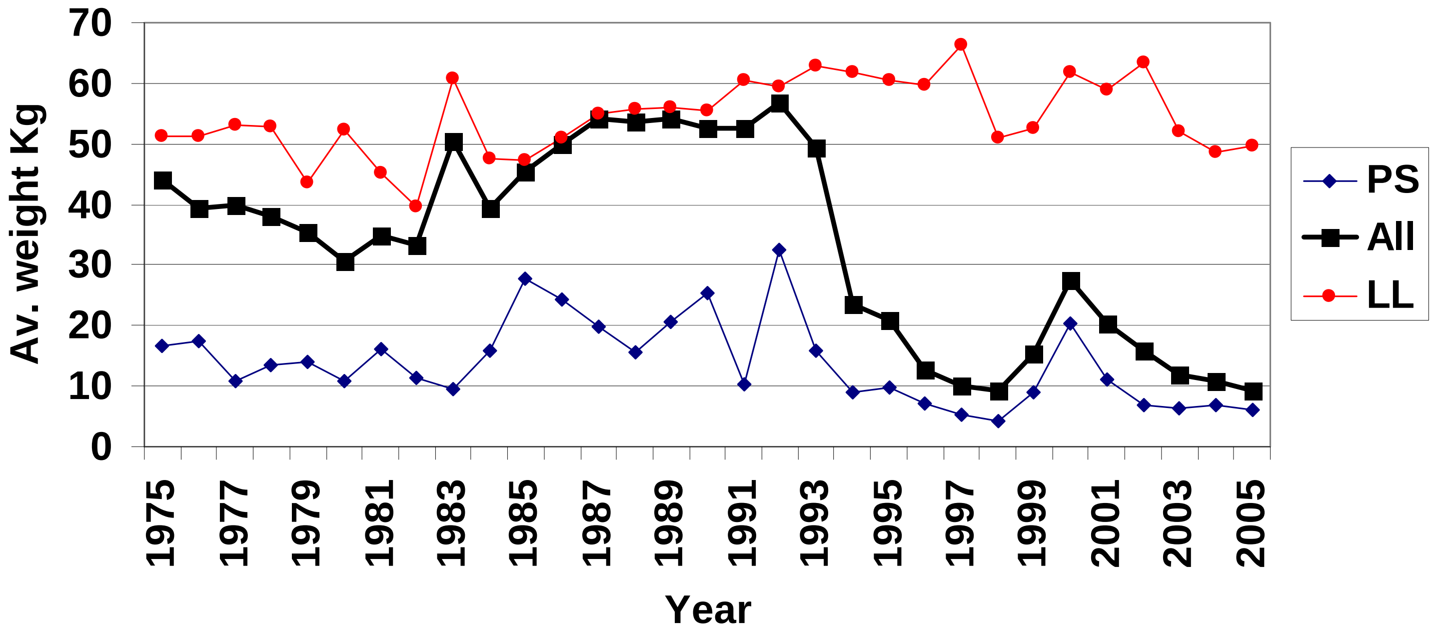


Figure 5: Yearly average weight of bigeye in the EPO landings, by gear and for all fisheries combined

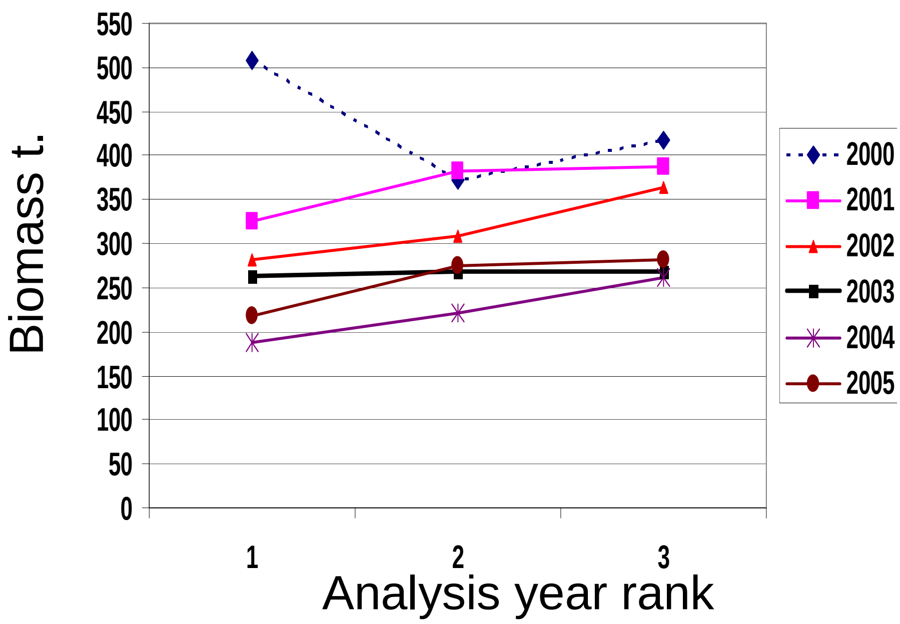


Figure 6: Changes in the estimates of the « last year biomass » : rank 1 is the biomass of the last year during the assessment year, rank 2 is the estimate of the biomass of the year one year after, and rank 3 two years after

This figure shows a that there was a major decline of the 2000 estimated biomass, a stability of 2003 biomass, and a significant steady increase of the other 4 last year biomass (an average 28% of increase after 3 successive assessments)

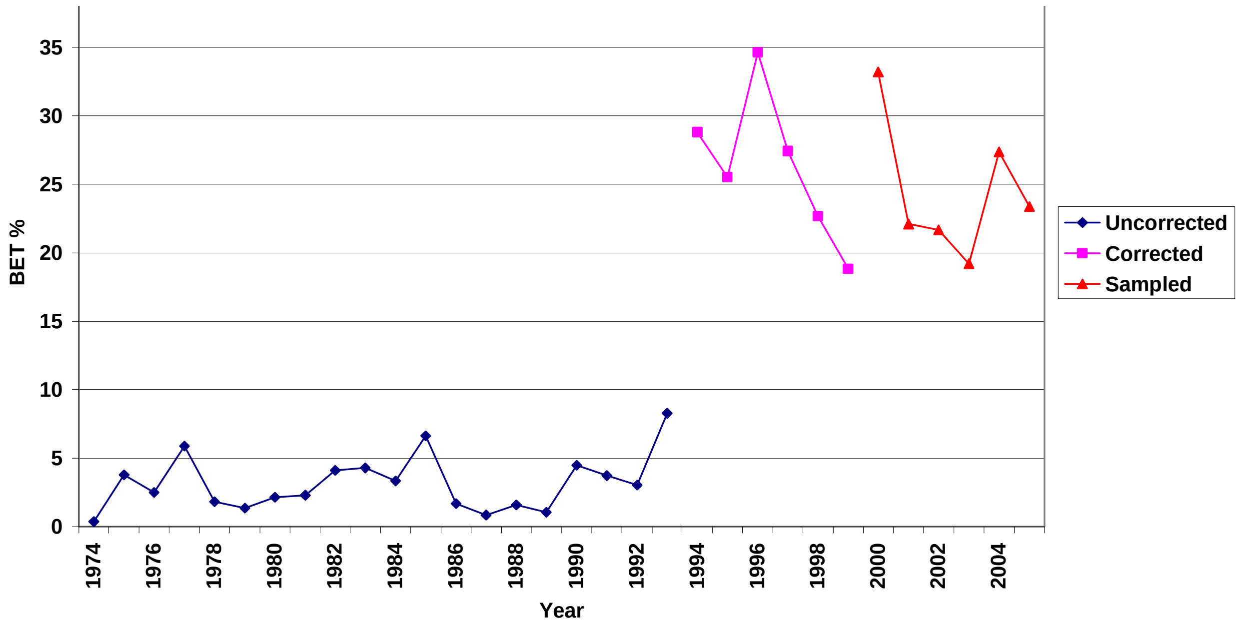


Figure 7: Yearly percentage of bigeye in the FAD associated catches of the EPO purse seiners. The initial period 1974 1992 is not corrected (for its species composition), the period 1993-1999 has been corrected on a statistical basis, the 2000-2005 period is based on an ad hoc species sampling.

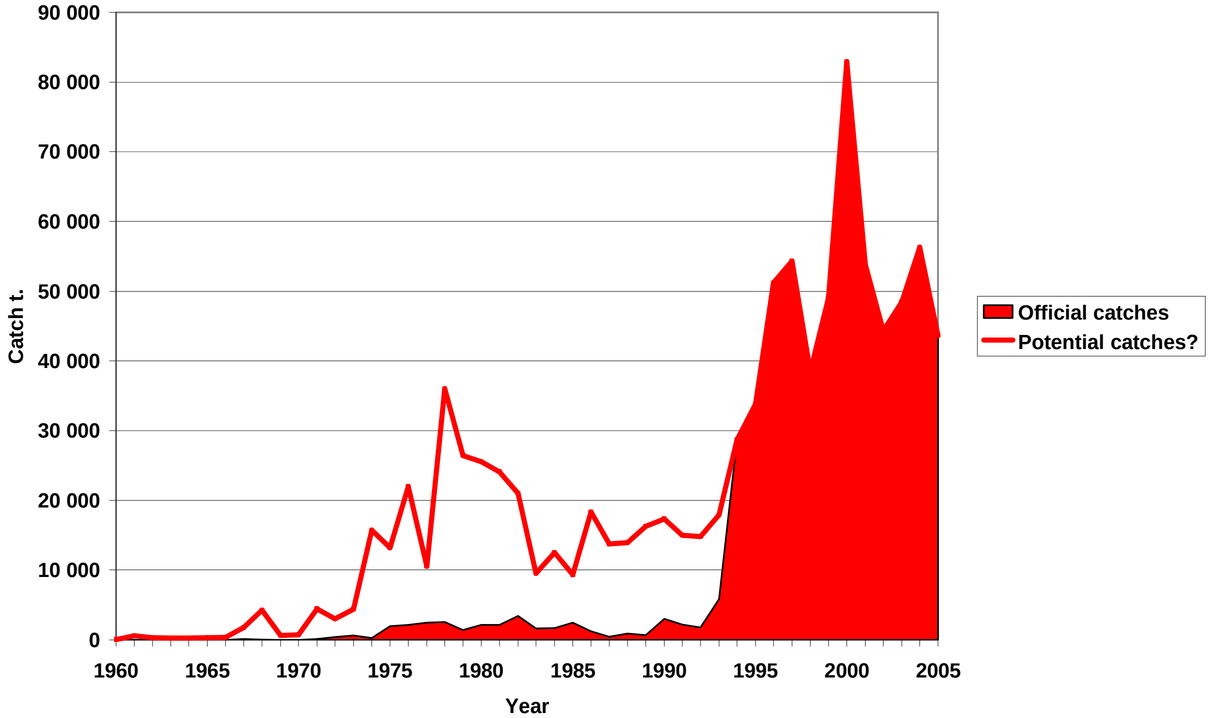


Figure 8: Total yearly catches of bigeye in the EPO purse seine FAD fishery: the red area shows the « official » present levels of yearly catches, the red line shows an estimate of potential EPO bigeye catches in the hypothesis that historical bigeye catches under FADs were at the same % as during recent years. *The potential historical bigeye catches are possibly in this range….: and not necesssarily at the lower red level….*

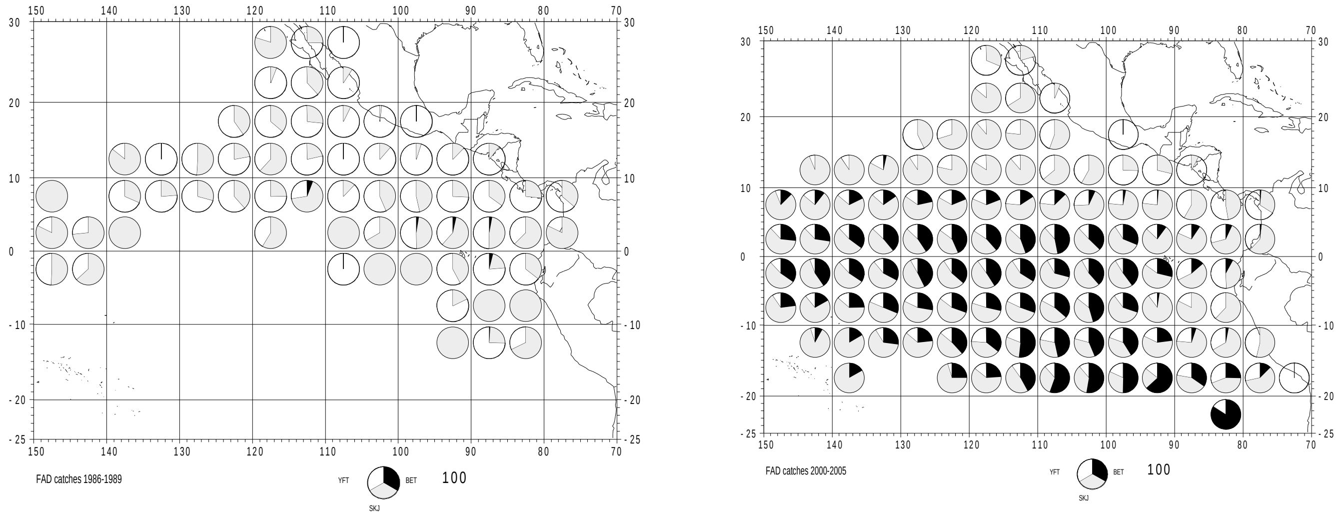


Figure 9 : Average species composition of the FAD associated catches, expressed in %, during the 1986-1989, a period of uncorrected species composition, and during recent years 2000-2005 a period during which bigeye % have been estimated by a consistant scientific sampling scheme.

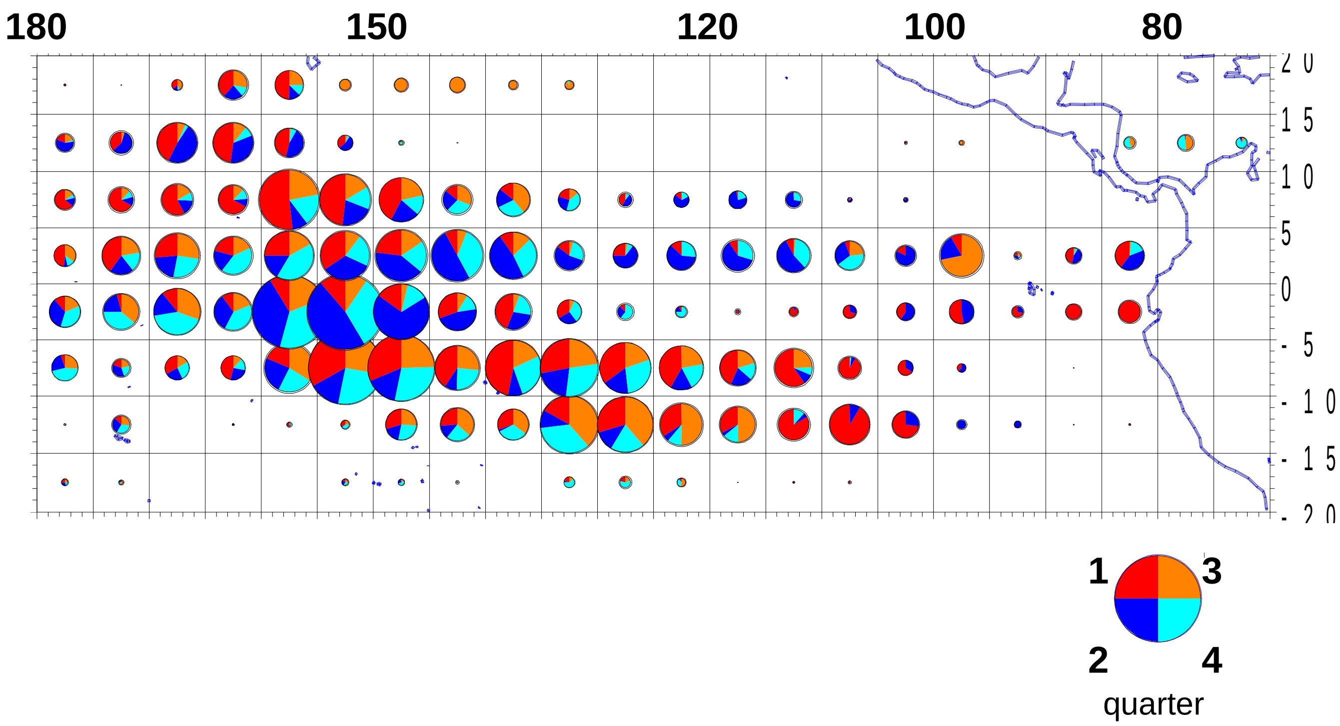


Figure 10: Average fishing map of quarterly catches of bigeye tunas taken during recent years (period 1995-2004) by longliners in warm waters with SST > 24℃ (in each 5 ° squares and quarter).

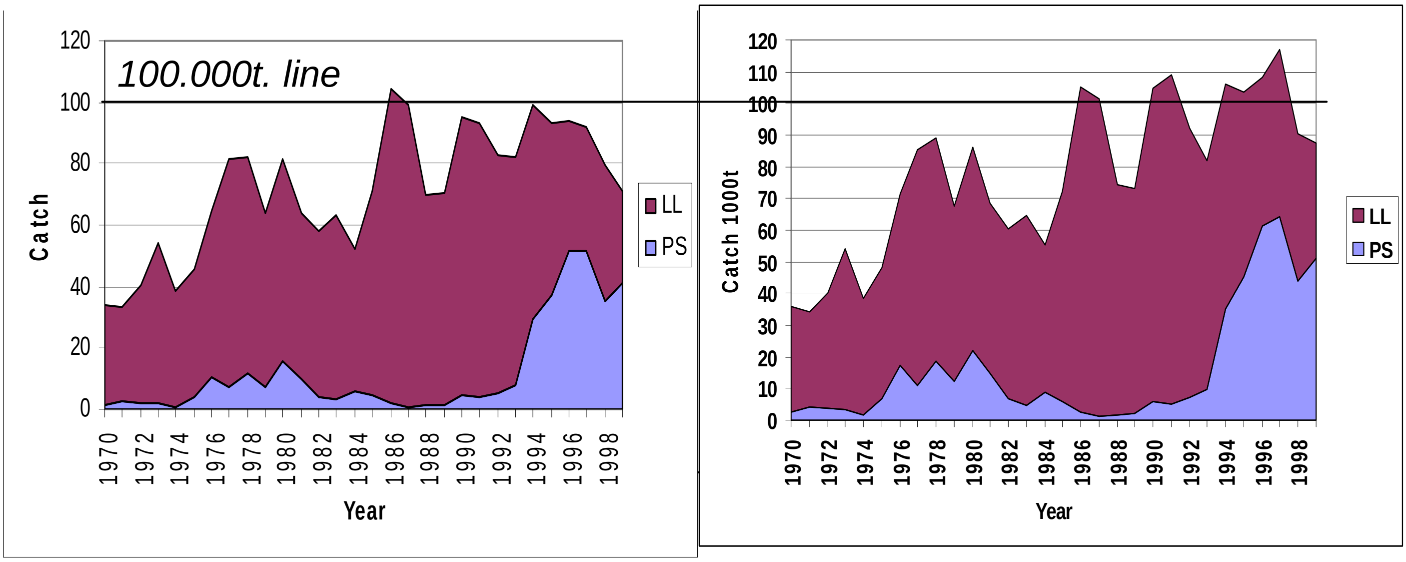


Figure 11: Yearly catches by gear used in the 2001 and in the 2007 bigeye stock assessments.
This figure well shows that the total catches of bigeye during the nineties have been widely corrected and increased during recent years (yearly catches being now over 100000t for 9 years, and only for 2 years in 2001).

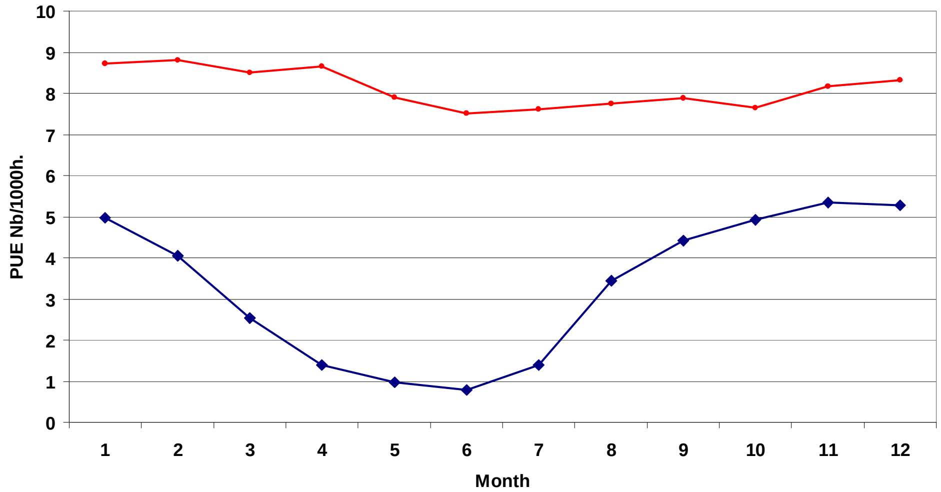


Figure 12: Average monthly levels of the bigeye nominal Bigeye CPUEs of Japanese longliners in the equatorial Pacific, 10°N-10°S) and in the Northe rn area (North of 10°N)

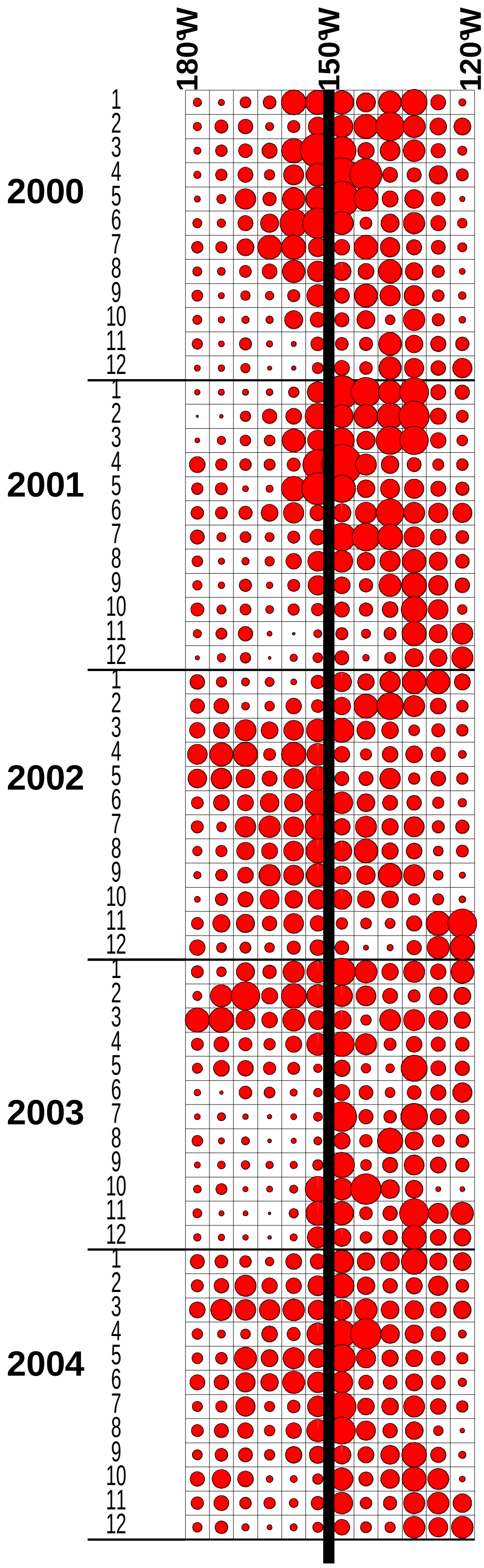


Figure 13: Diagram showing during the 2001-2004 period, taken as an exemple, the total monthly bigeye catches by slices of 5° of longitude, taken by longliners in the area between 15°N and 15°S (the main fishing gear of longliners). This figure shows that the area around 150°W, the traditionnal frontier between the 2 assumed Western and Eastern bigeye stocks, is during each year and all year round, a major fishing zone for adult bigeye. These monthly patterns of catches as a function of longitude also suggest that this figure may correspond to E-W movements of adult bigeye.

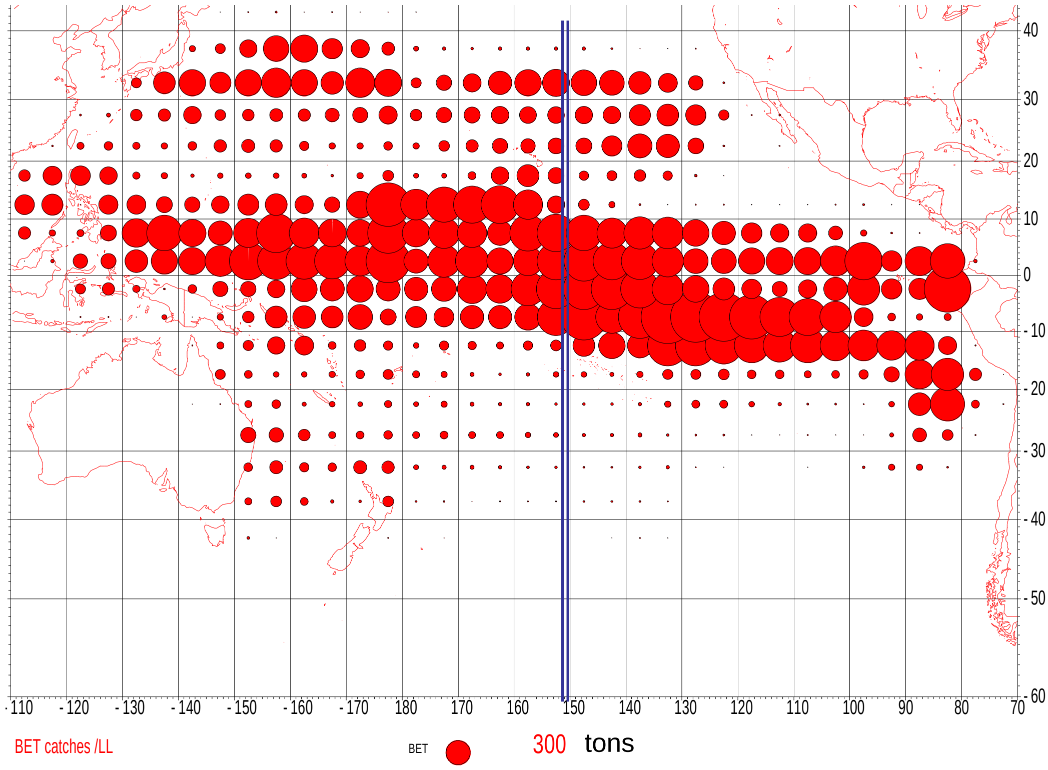


Figure 14: Map showing the average total catches of longliners by 5°squares observed during the 1955-2004 period in the entire Pacific Ocean and 150°W IA TTC stock limit.

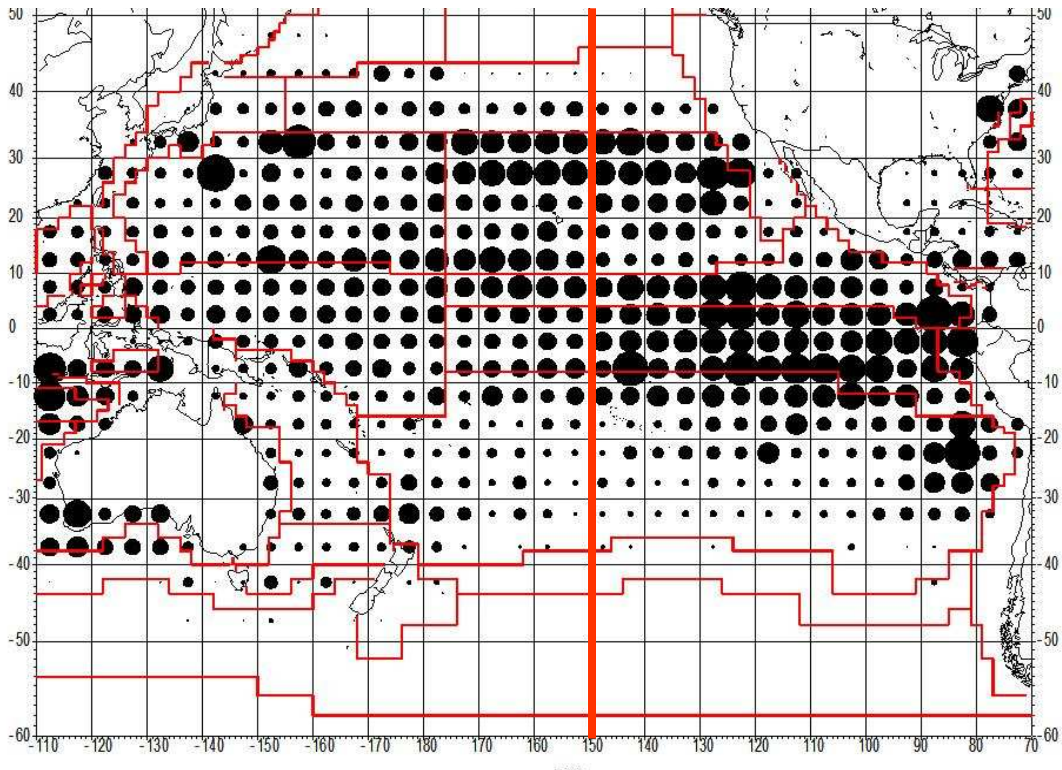


Figure 15: Map showing the highest 5°-month CPUEs observ ed during the 1952-2004 period in the Japanese longline fishery and Longhurst 1998 areas.

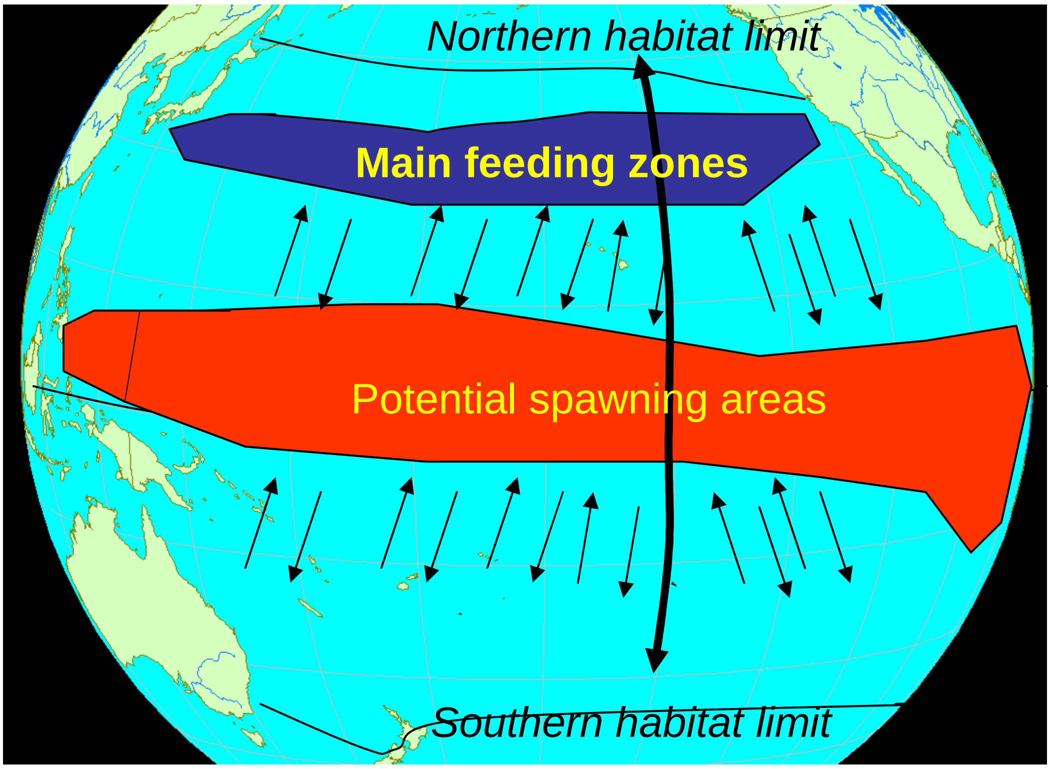


Figure 16: A conceptual overview of the main potential spawning and feeding zones of bigeye tuna in the Pacific Ocean, and the logical movement patterns of this species between these areas.

KURO: ***Kuro Shio Current***
NPST.W and E: ***North Pacific Subtropical Gyre West and east***
OCAL ***Offshore California Current***
SPSG: ***South Pacific Subtropical Gyre***
SSTC: ***South Subtropical Convergence***
CAMR ***Central American Coastal***
SUND ***Sunda-Arafura Seas Coastal***
NPTG: ***North Pacific Tropical Gyre***
PNEC: ***North Pacific Equatorial Countercurrent*****.**
PEQD ***Pacific Equatorial Divergence***
WARM ***Western Pacific Warm Pool***
ARCH ***Western Pacific Archipelagic Deep Basins***

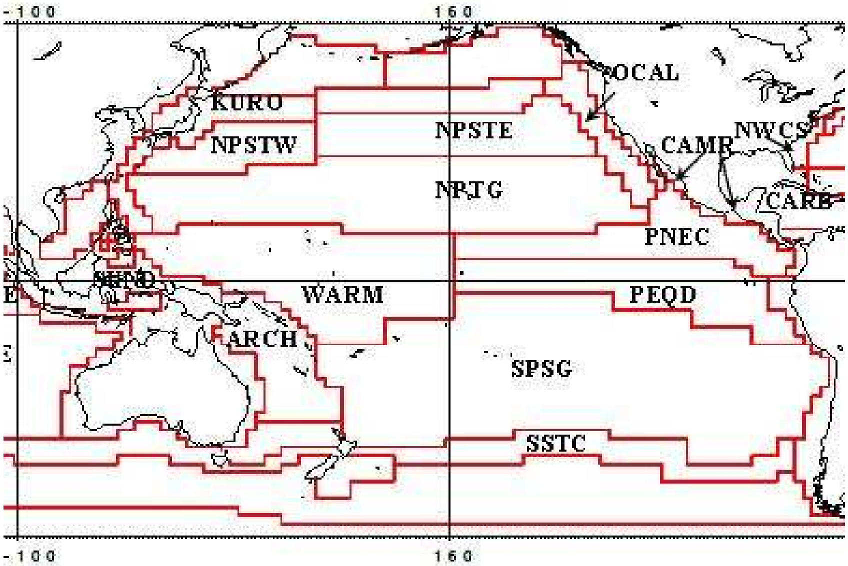


Figure 17: Map of the Longhurst 1998 areas in the Pacific Ocean

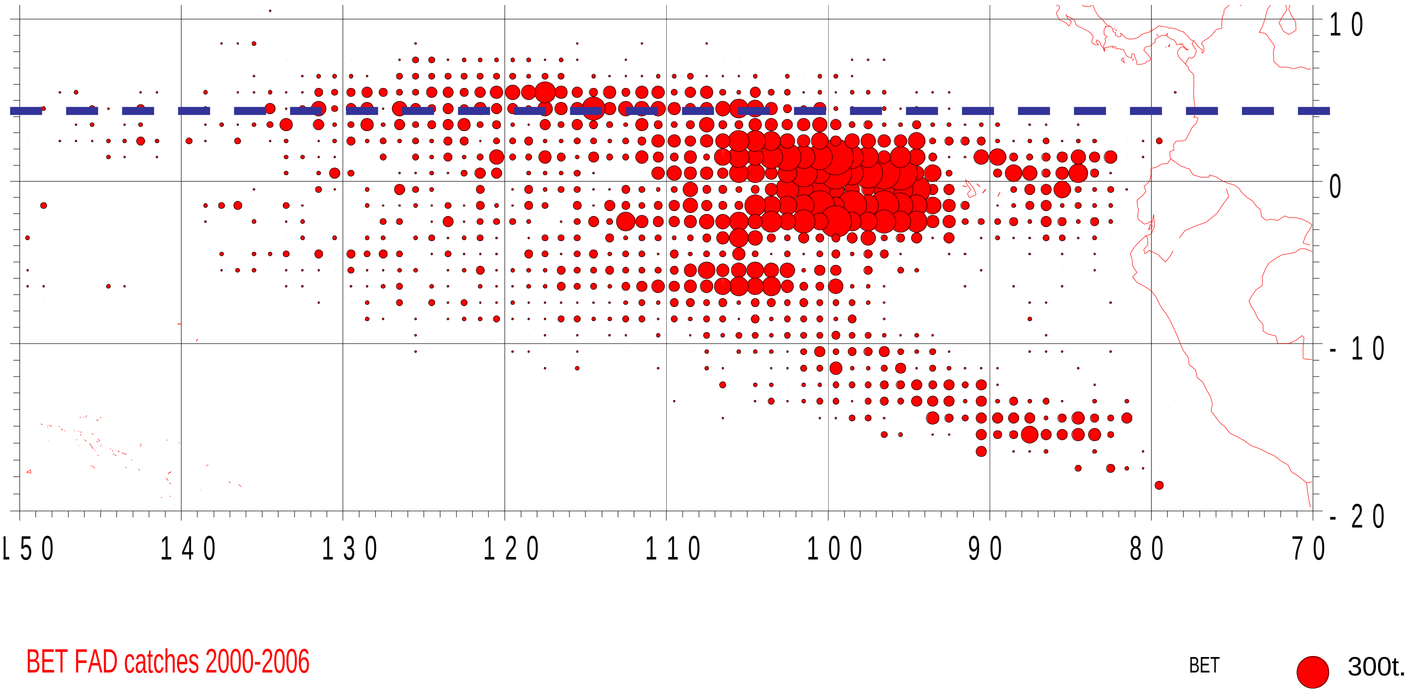


Figure 18: Average bigeye catches taken under FAD, by 1° squares, during the 2000-2006 period and 4°N approximate environmental limit *(surface current below this latitude being permanently dominated by a Westward flow: in the hypothesis that small bigeye are consistently associated with drifting FADs, such potential westward drift of FADs could produce a westward flow of the juvenile fraction of the bigeye fraction of stock).*

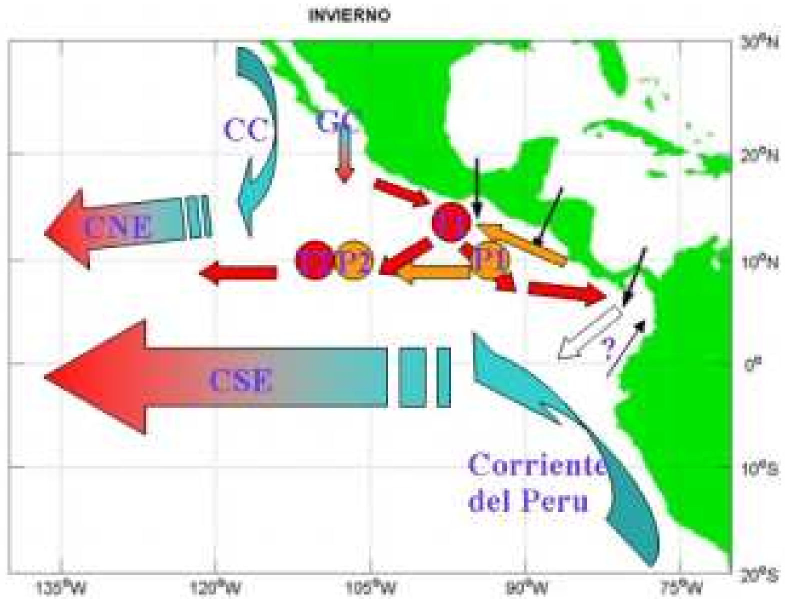


Figure 19: Surface current in the EPO (figure modified from Wirtki and taken from Trasvina Castro 2007). *It can well be assumed that drift of FADs is predominantly following this westward water flow.*

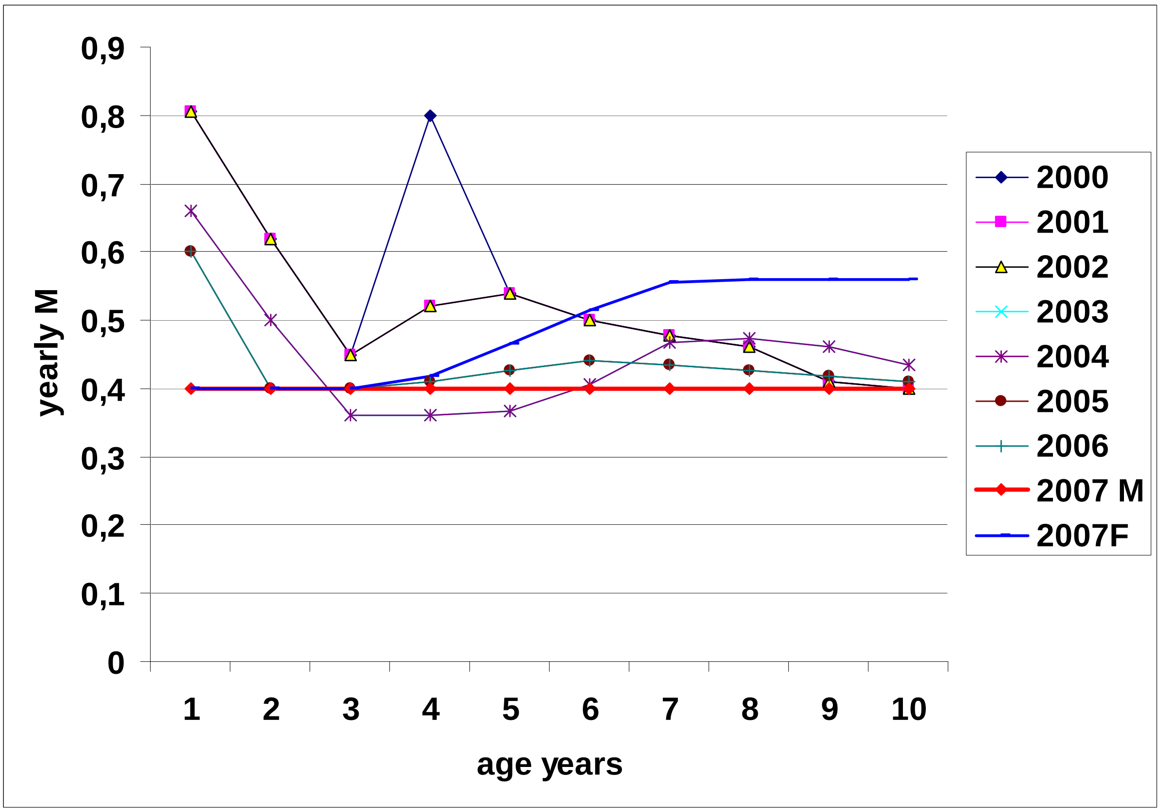


Figure 20: Natural mortality of bigeye as a function of age used in recent IATTC stock assessments

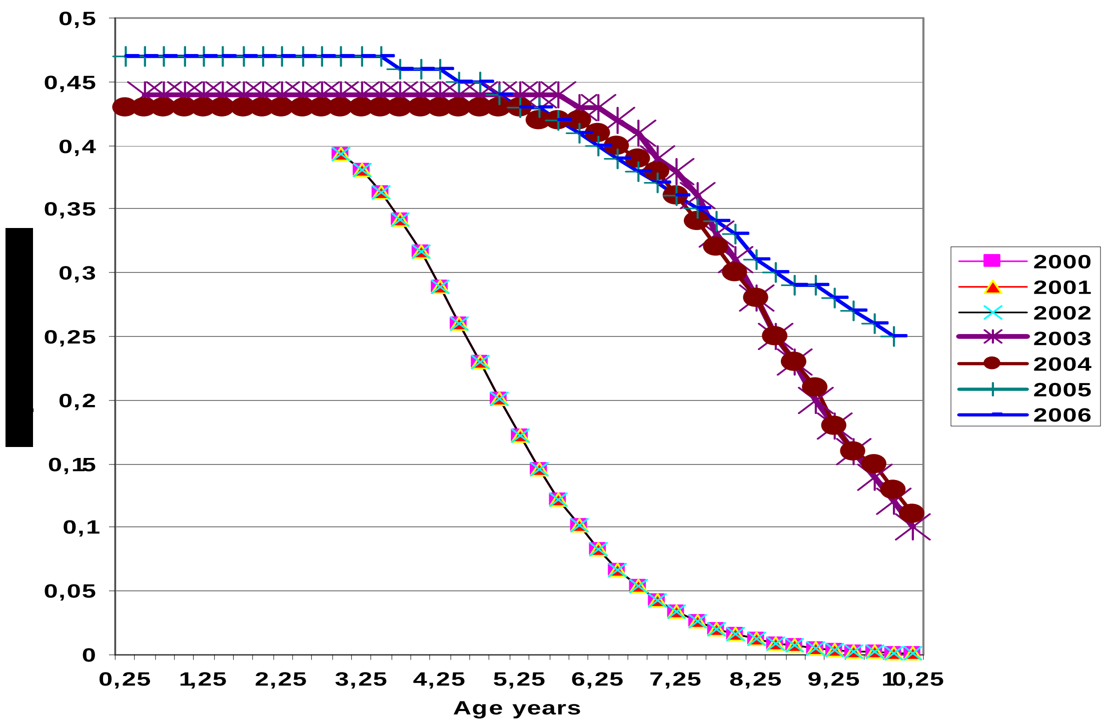


Figure 21: Sex ratio at size of bigeye tuna used in the yearly IATTC stock assessment (the lower curves were used during the years 2000 to 2002)

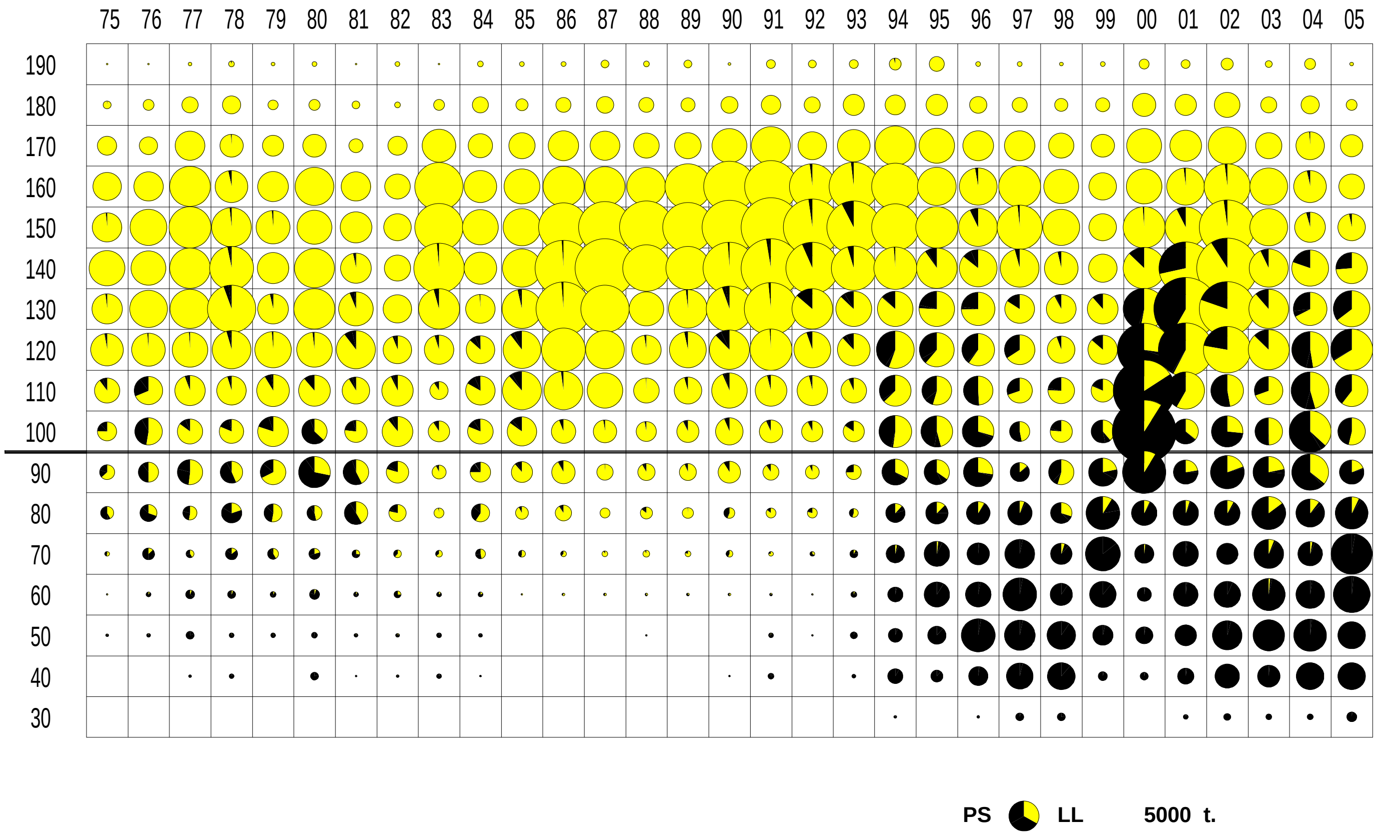


Figure 22: Pie diagram showing the total yearly catches at size (in weight , by 10 cm intervals of fork lenght) by gear, of bigeye tuna in the EPO

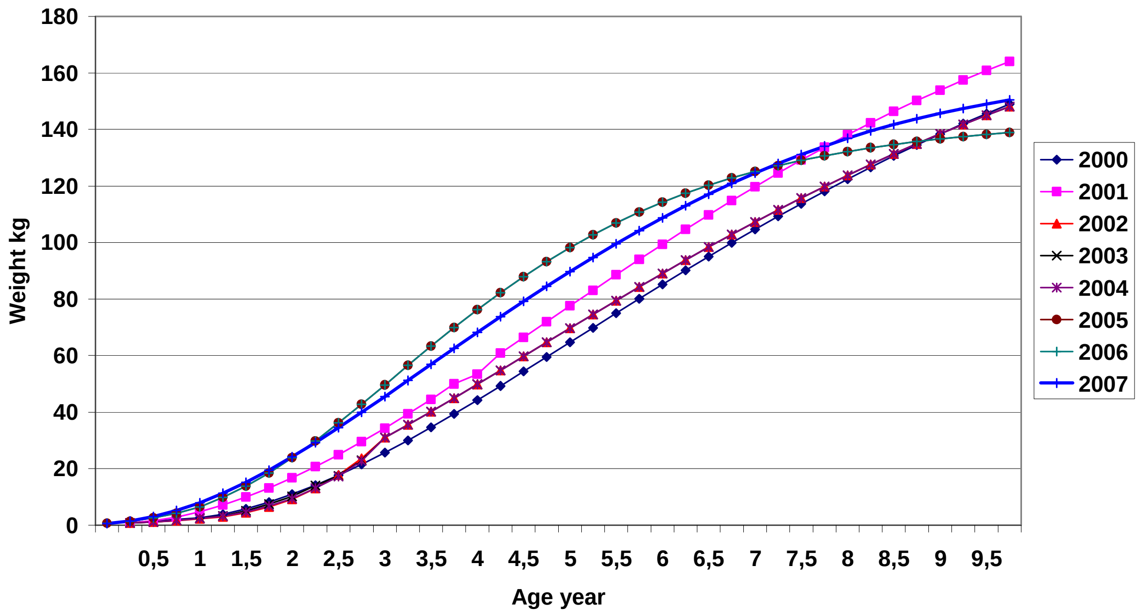


Figure 23: Growth pattern (in weight) estimated by the IATTC assessment models during the 2000-2007 period, given in average weight on a quarterly scale

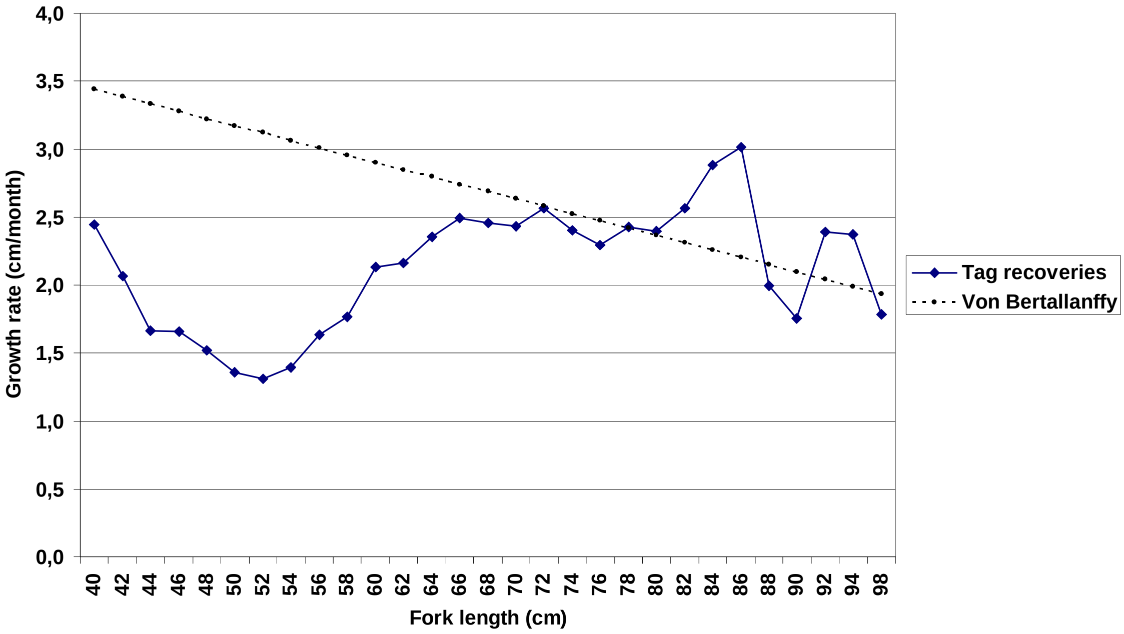


Figure 24:Apparent growth rate (in cm/month) presently estimated for juvenile bigeye tunas recovered in the Indian Ocean and growth rates estimated by age readings of otoliths and following a Von Bertalanffy law. *A figure showing (1) a decline in growth rates between 40 and 55 cm, followed by (2) an increasing growth rate in a range between 55 and 70 cm, followed by (3) a slowly declining growth rate over 70 cm. This pattern is typically observed in a 2 stanza growth curve. Such growth pattern may well be also observed in the EPO. This growth rates estimated from tagging is similar to the previously estimated Von Bertalannfy growth curve at sizes over 70cm, but widely different in the 40-70 cm.*

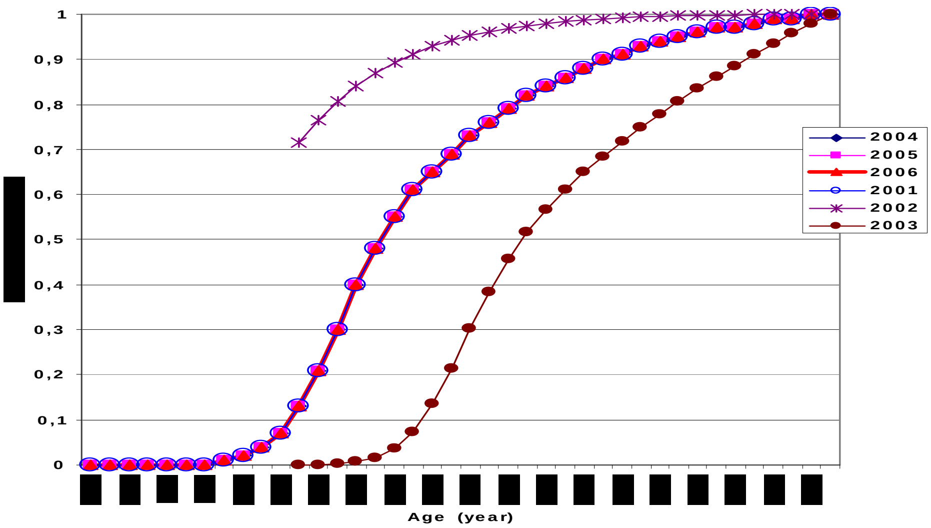


Figure 25: Patterns of relative fecundity at age used by the IATTC in its recent stock assessments estimated for bigeye (left curve: years 2000 and 2001 , central curves 2004-2007, curve on the right: 2002)

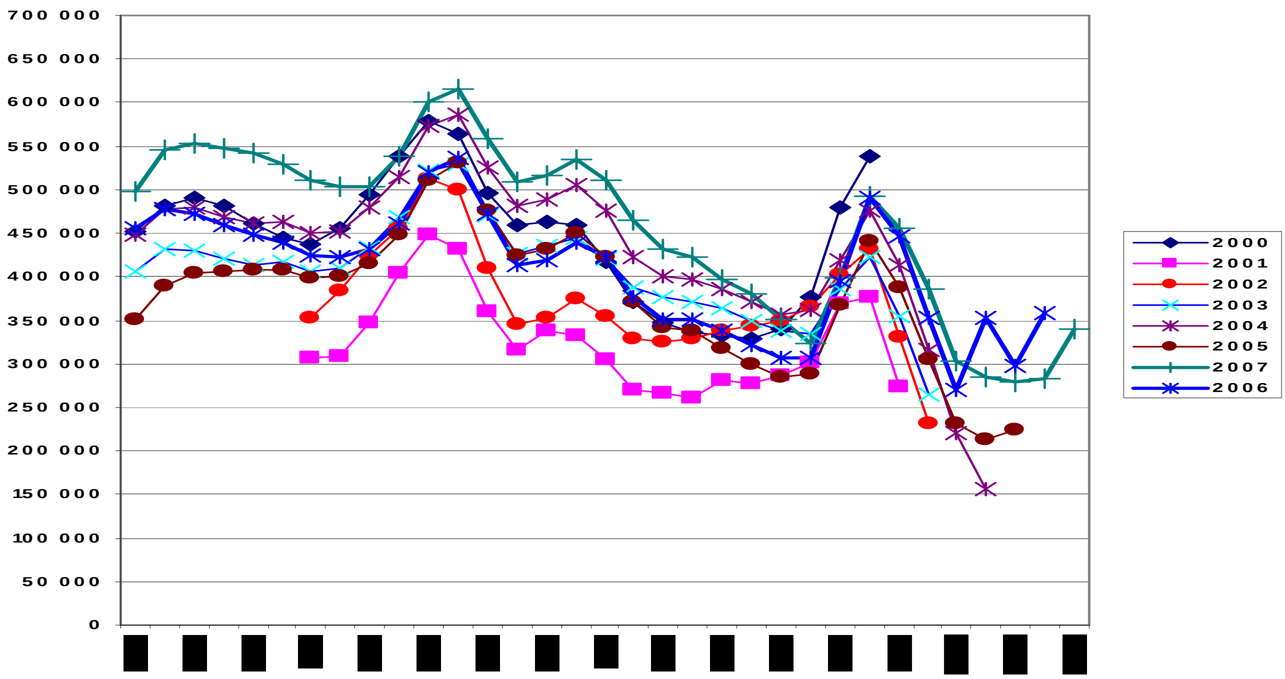


Figure 26: Yearly levels of bigeye stock biomass estimated by the IATTC assessments

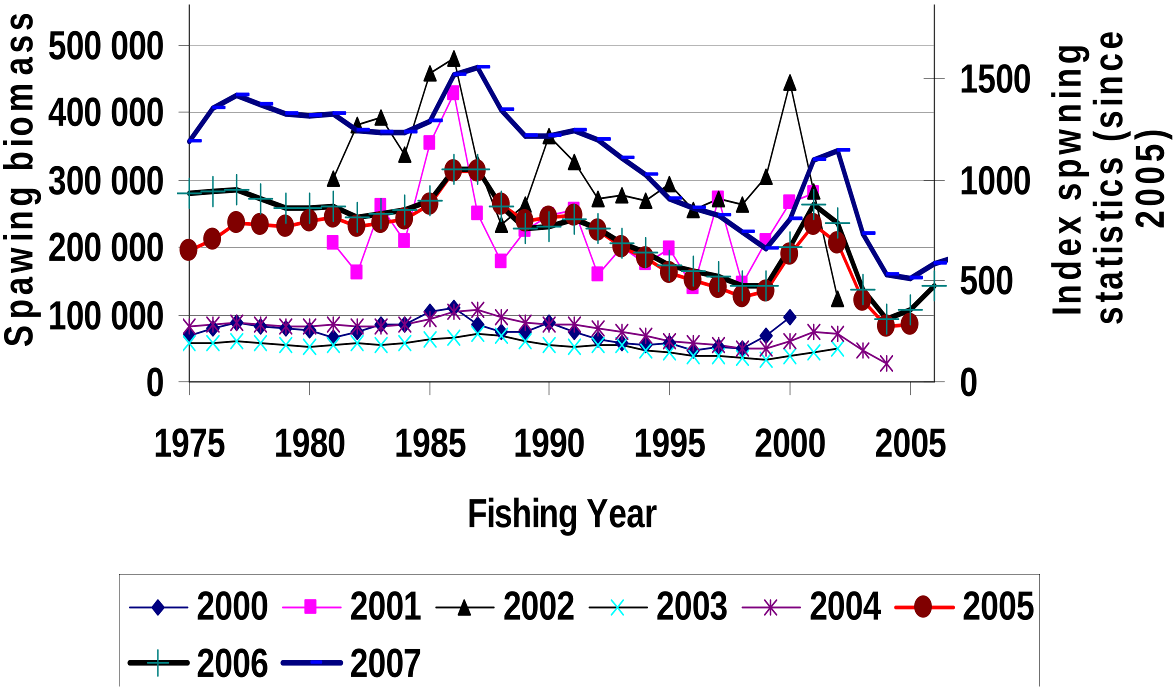


Figure 27: Levels of the bigeye spawning biomass estimated by the IATTC during the 1975-2004 period (*period 2005-2007 « Spawning stock » was estimated as a relative index that is difficult to compare with previous series)*

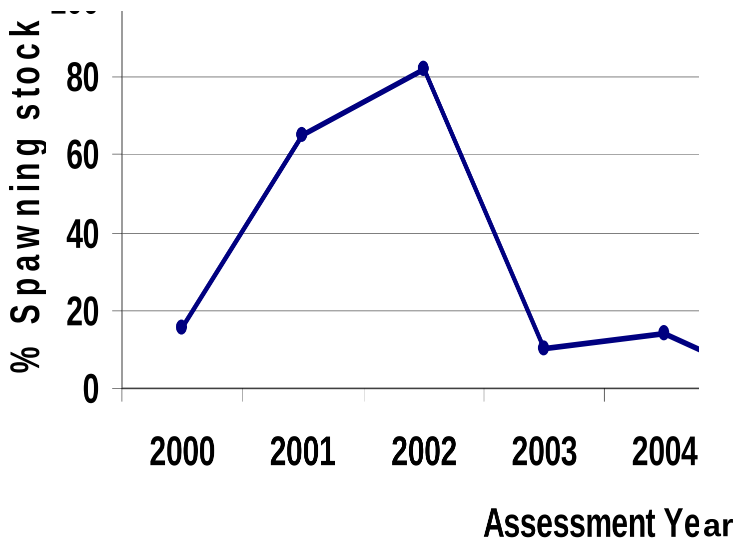


Figure 28: Average percentage of the spawning biomass vs total biomass of BET during the average period 1996-2000, at age 1+, as estimated in the recent BET stock assessments.
NB:
@ During the assessment years 2001 & 2002, the spawning stock is necessarily an estimated biomass of mature BET, males + females
@ During the assessment years 2000, and 2003-2004, -2002, the « spawning stock » is probably an estimated biomass of mature females
@ During the assessment period 2005-2007 « Spawning stock » was estimated as a relative index that cannot be compared to previous ones

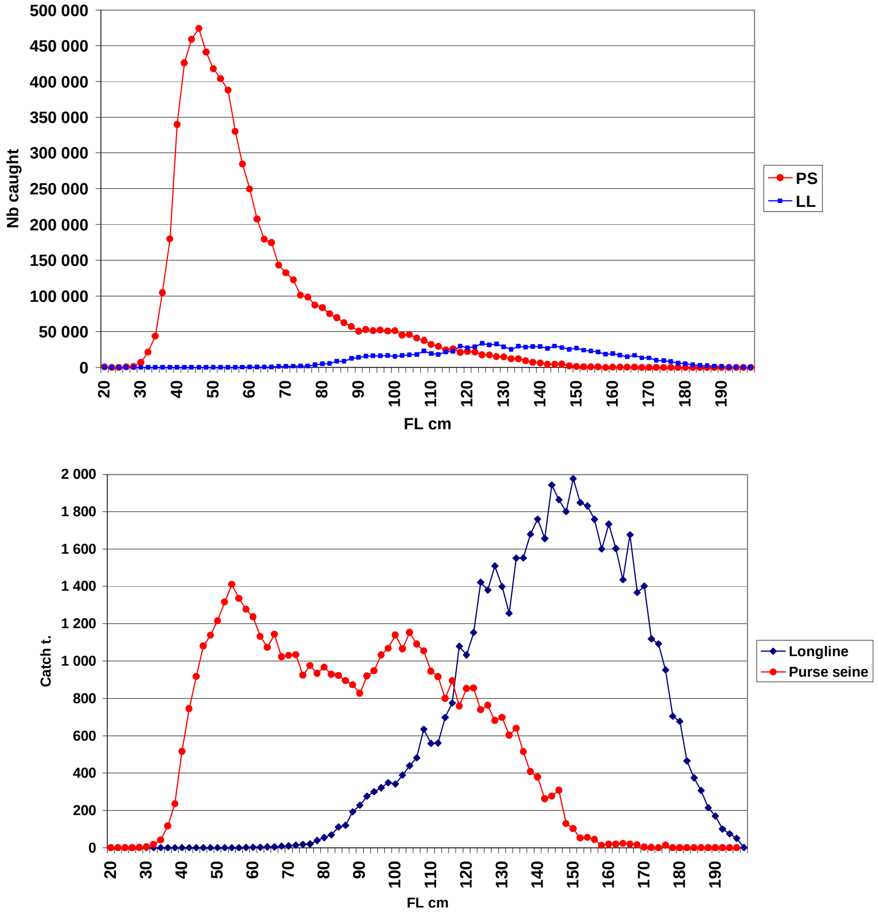


Figure 29: Total catches by size of bigeye taken in the EPO by longliners and by purse seiners during recent years (period 1996-2005), expressed in numbers of fishes caught (upper figure) and in weight (lower figure)