# A COMPARISON OF BIGEYE STOCKS AND FISHERIES IN THE ATLANTIC, INDIAN AND PACIFIC OCEANS

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*SUMMARY*

*This paper presents a comparison of fisheries exploiting. First, a comparison of the bigeye catch trends by ocean is done; it shows in all areas a fast and quite synchronous increase of the bigeye catches since the early eighties, followed by a stable or slowly declining catch trend. Worldwide catches are due to a combination of low value bigeye taken by purse seiners (mainly at small sizes under FADs), and of valuable large bigeye targeted by longliners for the sashimi market. Sizes taken by the various gears in the three oceans are compared. Historical changes of fishing zones are analysed. Relationship between catches of longliners and sea surface temperatures is reviewed in each ocean. The main biological characteristics of bigeye tuna such as growth, sex ratio at size and natural mortality, estimated in the various oceans are compared. Bigeye stock status and the recent changes in the stock assessment diagnosis done by the different tuna agencies, following the recent increases of catches, are examined and discussed. Present limitations and uncertainties on the real stock status of bigeye worldwide are discussed. It is concluded that despite of a more active research developed worldwide during recent years on bigeye tunas, the assessment and prospects for management of these heavily exploited stocks remain widely uncertain and an increasing source of concern.*

*KEYWORDS*

*Bigeye, fisheries, catches, migration, stock status,biology*

*Résumé*

*Cet article présente une comparaison des pêcheries qui exploitent le patudo .Une comparaison des tendances des prises de patudos dans chaque océan est réalisée.. Elle montre partout un accroissement rapidement marqué des captures depuis les années 1980, suivi par plateau ou une légère décroissance des captures. Les prises mondiales de patudos sont constituées d'une combinaison de patudos de faible valeurs marchande capturés à la senne (principalement à de petites tailles et sous des objets flottants artificiels)et de gros patudos de forte valeur capturés à la palangre pour le marché du sashimi. Les tailles capturées par les divers engions dans les tois océans sont comparées. Les changements historiques dans la surface des zones exploitées sont analysés. Les relations entre les prises des palangriers et les températures de surface sont analysées dans chaque océan. Les principales caractéristiques biologiques du patudo, telles que sa croissance, le sex ratio par taille et la mortalité naturelle estimées dans les divers océans sont comparées. L'état des divers stocks de patudos et les évaluations récentes réalisées par les diverses agences des thonières, suite aux accroissements récents des prises, sont examinés et discutés. Les limitations et les incertitudes actuelles de l'état réel de ces stocks sont discutées. Il est conclu que malgré une recherche mondiale accrue sur la patudo durant les années récentes, les évaluations et les perspectives de gestion de ces stocks fortement exploités demeurent largement incertaines. Ces incertitudes constituent une source croissante de préoccupation.*

*Mots clef*

*Patudo, pêcheries,prises, migration, état des stocks, biologie*

## 1 Overall

Bigeye stocks and fisheries have, until recently, been under very little scrutiny by scientists, at least compared with other major tuna species such as yellowfin or skipjack. A more active research programme and efforts targeting an improvement of fishery statistics (better species identification, improved size sampling, better follow up of catches by illegal unreported and unregulated fleets or IUU, etc) has been developed world wide during the late nineties targeting bigeye, and their first results were reviewed in 1996 by the La Jolla first world meeting on bigeye tuna (Anon. IATTC 1998). However, still relatively little is presently known world wide on this species in comparison with other tuna species such as yellowfin tuna, despite of its great economical value.

Until the early nineties, all the bigeye stocks in the Atlantic, Indian and Pacific Oceans were still moderately fished, and each of them was in reasonably good condition (this conclusion being based on the most recent stock assessments done on these stocks). However, a steadily increasing trend of bigeye fishing efforts and catches has since been observed in all three oceans: this trend was observed for both the purse seine fisheries, in relation to an increasing use of Fish Aggregating Devices -or FADs- under which bigeye are often associated and caught (Fonteneau and al. 2000), and for the longline fisheries that are increasingly targeting bigeye tuna because of its high value on the sashimi market (many of these vessels being Illegal, Unregistered and Unregulated or IUU). This increase of catches has raised serious concerns upon a possible overexploitation of the bigeye stocks world wide, especially in the Atlantic, the Indian Ocean and the Eastern Pacific, and to lesser degree in the western Pacific. This paper presents a comparative overview of bigeye tuna stocks and fisheries worldwide as well as the main biological characteristics of this species, and discusses the major problems in the assessment of bigeye stocks.

## 2 Fisheries

### *2.1 Introduction*

This review will be done using a world wide stratification between four fishing zones later called “oceans”, dividing the Pacific Ocean into its “historical” division at 150°W between the eastern Pacific Ocean (later called EPO) and the western Pacific (later called WPO), although this division may not be a valid one for the Pacific bigeye stock (as this frontier is based on “historical administrative” factors, and not at all on the bigeye movement patterns). Figure 1 shows the average fishing zones of bigeye by the various fisheries during recent years. Data and analysis concerning the Pacific Ocean were obtained from the Inter American Tropical Tuna Commission (or IATTC) in the EPO, and from the Secretariat of the Pacific Community (or SPC) in the WPO. Data and analysis concerning the Atlantic bigeye were obtained from the International Commission for the Conservation of Atlantic Tunas (or ICCAT) and from the Indian Ocean Tuna Commission (or IOTC) for the Indian Ocean.

### *2.2 Bigeye tuna: the most valuable tuna fisheries*

There are very few comprehensive economical analyses comparing the landing values of the main tuna species at a worldwide scale. However, all these data tend to indicate that nowadays bigeye tuna is probably the first tuna species in terms of the value of its landings (followed by yellowfin and skipjack, see Figure 2): this high value is simply due to the large quantities of large bigeye tunas (about 300,000 t yearly) that are sold at variable but high prices (over 10$ per kg) on the Japanese sashimi market. This high price of large bigeye in the Japanese market is a quite recent phenomenon that is related to the development of ultra freezing in the longline fleets and cargo vessels during the mid seventies, and to the increase of air transportation of tunas. In contrast, it can be noted that small and large bigeye taken by purse seiners and sold to canneries have been stagnant and always paid at low prices under 1$/kg.

### *2.3 Catch trends*

*Introduction*

The trend of total catches taken on each stock is a very important parameter because is, *per se* and alone, often highly indicative of the stock status. For instance, these total catches can be indicative of changes in the effective fishing effort, even when they are not visible in the statistics of nominal effort. Thus the trend of total catches associated with a simple qualitative knowledge of trends in the fishing effort may also indicate when the stocks are being overfished.

*Trends in each ocean*

Total catches of bigeye taken by ocean are shown in figure 3 (cumulative catches) and figure 4 (for each ocean). A slow but constant increase of world bigeye catches has been observed until the early nineties, followed by a spectacular increase in recent years and a peak of total catches during the mid nineties (especially in the Atlantic and Pacific Oceans). Figure 5 shows the total yearly catches taken by the two main gears catching bigeye, longliners and purse seiners[1]. It can also be noted that catch trends by purse seiners (figure 6) and by longliners (figure 7) in each ocean are quite similar to the trend of total catches by each gear. In the western Pacific, a regular increase of total catches has been observed until 1997, followed by a plateau during recent years. The Eastern Pacific is the first area where a stagnation of total catches has been observed since 1985, while a serious decline of total catches has been observed in both the Indian and Atlantic Oceans during more recent years (since 1998) despite continuous pressure exerted by increasing numbers of fisheries (Indian Ocean and Western Pacific catches being sustained at high levels over 100,000 t yearly). It can also be noted that total bigeye catches in the Indian Ocean was the lowest world wide until the mid eighties, but became and remain now the most important world wide since the mid nineties.

### *2.4 Overview of gears catching bigeye*

*Longline*

This gear has always been the major gear targeting large bigeye tuna worldwide, and the bigeye catches by longliners have been permanently increasing during the last 20 years (figure 5 and 7). The analysis of the longline fishery data shows that since the mid seventies many longline fleets have changed their target species from yellowfin and albacore to bigeye, targeting (most often in given time and area strata). It has also been noted that this targeting of bigeye by longliners has most often been associated with a deeper setting of the lines, trying to set the longline in deep waters at depth greater than 200 m (figure 8) (Suzuki 1999, Nishida 2000 and Miyabe 1994).

*Purse seine*

Purse seiners are also increasingly catching large quantities of small bigeye (figure 5 and 6), but always a secondary species, this fishery targeting mainly skipjack and yellowfin. However, catches of small bigeye by purse seiners have been widely increasing during recent years in relation with the development of artificial FADs, under which bigeye tuna tend to aggregate (Fonteneau and al. 2000). Nowadays, most bigeye tunas are taken worldwide by purse seiners in association with FADs (figure 9).

Several bait boat fisheries are also catching significant amount of small bigeye, mainly in the Atlantic Ocean (Ghanaian fishery, where bigeye is a by-catch of the skipjack fishery). The Atlantic is the only ocean where various specialized bait boat fleets are targeting medium and large sizes bigeye in temperate waters (Senegal, Madeira, Azores, Canary islands) (Pereira 1995).

It can also be noted that these three gears are catching the majority of bigeye world wide, bigeye tuna being very seldom caught by any other fishing gear.

### *2.5 Bigeye statistical uncertainties*

Bigeye tuna is among all the other tunas, the species facing worldwide the worse statistical uncertainties for all the major fisheries catching bigeye. These statistical uncertainties observed in the various oceans by each gear are compared and discussed hereafter.

*Purse seiners*

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[1] Bigeye catches given for the Eastern Pacific are the corrected figures, where catches by purse seiners have been corrected since 1993 by the IATTC multispecies sampling, and where catches declared in the Taiwanese and Korean log books have been raised by a factor of 1.5 in order to estimate their total catches.

Increasing quantities of bigeye have been taken worldwide by these fleets (figure 5), primarily in association with an increasing use of FADs, but it appears that the real amounts and trends of bigeye taken by purse seine fisheries are still difficult to estimate. In the Atlantic, the problem of potential misidentification between bigeye and yellowfin in the landings of small tunas has been fully identified since the mid seventies (Fonteneau 1976), while the full recognition of this problem has been slow and partial in many fisheries elsewhere. It is quite easy for an experienced scientist or a trained technician to distinguish a small bigeye from a small yellowfin, immediately and without error, based on their external characteristics (ICCAT field manual, Schaefer 1999). This conclusion is always a valid one, even on very small sizes and on frozen fishes. However, all skippers (log books) and canneries (landing statistics) tend to record these small tunas, not as a function of their biological species, but as a function of their sizes and commercial value. Therefore, small bigeye tuna tend to be mis-registered in many landing statistics as yellowfin or often as skipjack (Small yellowfin being also often classified as skipjack). This bias in the species identification tend to be observed in both log books and cannery statistics. In the Atlantic and Indian Oceans, based on these observations, it has been concluded that a systematic species and size sampling of the landings of small tunas is the only way to correct this type of bias (an. ICCAT 1985). It was also concluded in these two oceans that the species sampling should target all the tuna species landed, not only the landings of yellowfin. Such multispecies sampling schemes have been routinely managed in the Atlantic since 1979, and very similar sampling schemes have been also developed by European scientists in the Indian Ocean since the beginning of the purse seine fishery in 1982 (Pianet et al. 2001). The typical effects of this multi species sampling are given on an example taken from the Indian Ocean, and show the yearly species composition shown in the logbooks and after the multi-species sampling data processing (figure 10). In the Western Pacific, this multi-species sampling has been done since the mid eighties, but only on the US purse seine fleet; sampling on other fleets has been developed quite recently, and only on some fleets. In various circumstances trained observers have also conducted this species sampling. This species sampling has been conducted on the declared yellowfin, assuming that there was no yellowfin or bigeye misclassified as skipjack. This point would possibly need further verification. In the IATTC, the problem of BET misidentification has been recognized recently (Schaefer 1999) and a systematic species sampling has been conducted only since 1999 (Tomlinson 2002); the results obtained by this sampling are now used for the stock assessment. The present historical catch series of bigeye by purse seiners have not yet been corrected by the IATTC, assuming that the non-corrected series of historical bigeye catches are not significantly biased.

There is of course a potential time heterogeneity in most historical statistical series of bigeye catches by purse seiners, especially in the Pacific Ocean but also in the Atlantic Ocean before 1980, catches during the initial years being possibly underestimated to an unknown degree.

*Longliners*

Bigeye catches by longliners are also facing various severe potential uncertainties, especially since the early nineties, due to the increasing catches by various fleets. This serious statistical problem is linked with the declining role of Japan in the world bigeye fisheries, knowing that most stock assessment are based upon the Japanese CPUE and sizes of fishes taken by this fleet. The major longline fleet presently active worldwide is the Taiwanese one, but unfortunately the statistical follow-up of this large and heterogeneous fleet remains quite slow and poor world wide. Furthermore, there are also increasing numbers of so called IUU (Illegal, Unreported and Unregulated) longliners that are increasingly catching world wide unreported quantities of large bigeye (these fishes being sold at high values on the sashimi market). Among these fleets of longliners that are poorly followed by statistics, there is world wide an increasing number of small coastal vessels, that are often changing their flags and working under variable joint ventures. These catches remain difficult to estimate (for instance through import certificates to Japan); in the Atlantic, these catches have been estimated to be in a range between 10,000 to 25,000 t during the last 10 years. There is an apparent decline of the IUU catches during recent years, but this decline may not correspond to a decline of total catches by IUU fleets, but only to an increasing lack of reporting (for instance part of these IUU fleets carrying now the flags of coastal countries such as Indonesia, still without reporting their catches). The problem of IUU catches has been tentatively corrected in the Atlantic and Indian Oceans, but it remains less visible in the Pacific, especially in the Eastern Pacific. There is a serious potential risk that large numbers of IUU longliners are still catching world wide unreported catches of bigeye tunas, thus introducing an increasingly dangerous bias in the stock assessment done by the various tuna commissions. This statistical problem increasingly faced during recent years by bigeye fisheries, may introduce serious bias in recent stock assessments as all bigeye stocks are now possibly overfished (see chapter 4).

### *2.6 Changes in bigeye fishing zones by ocean and gear, and changes in average catches by area fished*

*Longline*

After the rapid increases of the exploited areas observed during the fifties, the areas fished in the three oceans by longliners do show a quite stable size since the early sixties, well shown by the maps showing the 10 years average maps of bigeye catches by longliners during the last half century (figure 11). Another map, figure 12 shows what could be called the “bigeye hotspot” for the longline fisheries with all the 5°-month strata fished by longliners during the period 1952-2001 within which a monthly high catch of bigeye (more than 250 tons) has been taken. Major increases of the catches per fished area have been observed during the period 1952-2001 (figure 13a) in relation with the increase of total catches in each area. It can also be noticed that these yearly catches per fished area observed in each ocean are very similar at least during the period 1960 to 1992, the Pacific Ocean showing since the early nineties some decline (figure 13b).

*Purse Seiners*

The areas fished in the three oceans (figure 14) show an increasing size, especially during the last 20 years (figure 15a). This trend may be partly linked to a better species identification of bigeye catches (for instance in the EPO since 2000), but also to the expansion of FAD fisheries catching bigeye in areas where this species was not available previously. Increases of the catches per fished area have been observed during the same period in all areas (figure 15b). Bigeye catches taken by unit area by purse seiners have been highly variable (especially in the Eastern Pacific) and they tend to be widely different between oceans. Some convergence of the levels of yearly catches taken by unit area during recent years by purse seiners can be noticed in the Atlantic, Indian and Eastern Pacific Oceans, while the Western Pacific levels remain by far the lowest. It is difficult to conclude how much of these changes in the levels of bigeye productivity are due to real time and space heterogeneity of bigeye catches and/or to the heterogeneity in the species identification of small bigeye.

***2.7 Nominal and effective CPUE***

*Purse seiners*

Tuna scientists tend to consider that bigeye nominal CPUE care most often not indicative of relative changes in bigeye biomass, as it is a by-catch by purse seine fisheries. However nominal bigeye CPUE (bigeye catches divided by numbers of days at sea) by these fisheries are easy to calculate, and these CPUE are interesting to analyse and to compare. These nominal CPUEs of bigeye (figure 16) have been showing large increases worldwide. The high values observed during recent years were probably due to a combination of factors such as (1) a better species identification during recent years, (2) a fast and major increase of fishing power of purse seiners (deeper nets, sonars, etc) and the increasing use of FADs under which bigeye are often associated. It can be noted that the CPUE has been showing, in most areas, a low variability from one year to another, this low variability remains quite surprising, knowing that most purse fisheries are exploiting only one year class of bigeye (between 0.5 and 1.5 years). The only but major exception to this rule remains the Eastern Pacific sinve the mid nineties, an area showing a high variability of catch rates (as well as of sizes taken, see paragraph 2.7).

*Longliners*

The bigeye CPUE of the longline fleets can be calculated, either as a nominal CPUE in the main fishing zones (for instance in the equatorial areas) or as a CPUE index that is trying to estimate the trend of stock biomass (using Generalized Linear Models or GLM and taking into account various factors, such as the changes in time and area strata, the hook depth and various environmental factors). These CPUE are most often calculated mainly from the Japanese fleet, because this fleet shows a wide geographical coverage worldwide, a long duration of permanent activities (half a century) and a very good quality of its catch and effort series.

Nominal CPUEs of longliners tend to show very little decline in each ocean during the entire history of the fisheries (figure 17a), and their recent absolute levels are very similar in each ocean (6 to 10 fishes /1000 hooks). This means that the nominal catches of bigeye per 1000 hooks in the equatorial area have been quite homogeneous over time (during half a century) and worldwide. It can also be noticed that the initial bigeye CPUE do not show the fast and major decline often observed for other tuna stocks (such as yellowfin or albacore). The stability of these nominal CPUE tend to be interpreted by an increasing efficiency of Japanese longliners to target bigeye, the results being that the nominal catches tend to stay quite constant, despite of an adult biomass that has been declining in relation with increasing catches.

The decline of bigeye stocks is better shown by standardized indices calculated using GLM (such CPUE are shown by figure 17b; taken from ICCAT 2003 and IOTC 2003 annual reports). These CPUE patterns are quite similar for each stock, with a slow decline until the early eighties, and a fast and major decline during recent years. Scientists working in the various tuna commissions consider that these CPUE are probably quite indicative of the adult stocks trends.

A limiting factor in the interpretation of these GLM results is that the fishing power of each hook is assumed to be constant world wide since 1950, an hypothesis that is difficult to believe knowing the multiple improvement of efficiency developed by all tuna fleets, and especially for the highly efficient and mobile Japanese fleets. At this stage, it should be kept in mind that if significant increases of fishing power have been developed on the longline fleets, then the real decline of biomass during recent years would be more severe than the decline presently estimated by standardized CPUEs.

### *2.8 Sizes taken in each ocean by the various fisheries*

*Purse seiners*

Bigeye tunas taken by purse seiners are predominantly juvenile fishes in a very stable range between 35 and 70 cm. These sizes are very similar in the Atlantic and Indian Oceans and are very stable from one year to another (figure 18 and 19) with an average weight between 5 to 10 kg. A major exception to this observation has been noticed in the Pacific, especially in the Eastern Pacific where the size distribution of bigeye tunas taken by purse seiners has been widely variable during recent years (between 5 and 20 kg, figure 20) , small bigeye being absent from the FAD fishery during some years, a fact never seen in the Atlantic and Indian Oceans.

*Longliners*

In contrast, the relative stability of average weights and of the size distributions observed in the longline fisheries, between oceans and over time, are well shown by figure 18 and 21.

*Whole combined fleet*

As a whole, it is then interesting to show the estimated catch at size taken world wide on bigeye by each of the two gears (figure 22), as this figure (given in numbers and in weight of fishes) well shows the potential of competition and interaction between the purse seine and the longline fisheries.

### *2.9 Bigeye tuna and the recent increase of fishing by purse seiners on FADs*

One of the major changes introduced during recent years by purse seiners in the bigeye fishery has been the generalized use of artificial aggregating devices or FADs that have been massively and increasingly seeded at sea by purse seiners since the late eighties and produce a large percentage of the total purse seine catches (figure 23). Furthermore, the effects of these FADs has been increased by the frequent deployment of supply vessels in charge of following and managing these FADs. The goal of these FADs was to increase skipjack catches (the species always largely dominant under FADs), but there is no doubt that these FADs have been widely increasing bigeye catches, a species most often present and caught under these FADs, mostly at small sizes (under 80 cm). The percentage of bigeye tuna found under FADs in the various oceans is given in figure 24, showing that bigeye is always a quite minor species in the FAD associated catches. Before the development of these FAD fisheries, small bigeye were probably too scattered to be efficiently caught by purse seiners in great numbers. This is no more the case nowadays, as small bigeye tend to be often associated under FADs: after 10 years of multispecies sampling done in the Atlantic and Indian Oceans, it can be concluded that bigeye tuna was caught under 90 % of FAD sets in association with the other tuna species (cf Fonteneau and Pallares this symposium).

It should also be noted that FADs used worldwide are more and more efficient for catching large quantities of tunas, including bigeye, with an improved technology which seems to be quite similar world wide: improved systems to locate FADs (including bird radars), use of underwater nets, use of echo sounders, assistance from supply vessels, satellite positioning of FADs, use of underwater light, computer analysis of FAD movement patterns, use of bait under FADs, etc. All these changes as well as their direct effects on the efficiency are poorly known, but there is no doubt that they increase the efficiency of the purse seine fleets to catch bigeye tuna associated with FADs. In the Atlantic and Indian Oceans, it is considered by scientists that supply vessels are significantly increasing the efficiency of purse seine efforts on FADs (and also helping to optimize the purse seiners operational costs), but unfortunately their activities are poorly followed by scientists (even the number of these supply vessels remains poorly estimated and followed by the various tuna agencies). These supply vessels possibly add serious uncertainty to stock assessment, especially in relation with fishing mortality associated with FADs.

### *2.10 Conclusion on bigeye fisheries*

This comparative overview of the bigeye fisheries active during the last 50 years has shown the major similarities, and minor differences, in their levels and trends. The similarities are widely linked to the fact that most tuna fleets are identical worldwide, targeting the same mixture of tuna species, and selling their product to the same markets. The conclusion at this stage is that if the differences observed between each ocean (for instance due to environmental heterogeneities) are sometimes real ones, the similarities are widely dominant over the differences. Furthermore, it remains quite interesting to identify the real differences in the behavior of the various fisheries, and to try to understand the basic reasons of these observed differences.

## 3 Biology

### *3.1 Introduction*

The goal of this section is to compare the main biological characteristics estimated for bigeye tunas by scientists working in different oceans, and to discuss how much these differences are real or artificial ones (for instance, due to lack of data).

### *3.2 Bigeye and sea surface temperature: biological movements between spawning zones, nurseries and feeding zones.*

All the small bigeye taken by purse seiners are caught in equatorial warm surface waters. It has been shown that these small bigeye tend to stay in these shallow warm waters as they still have limited thermoregulation facilities and thus a limited biological capacity to efficiently feed in deep waters.

In contrast, a wide majority of adult bigeye catches taken by longliners in each ocean are caught in association with warm surface waters, close to the equatorial zones (as shown by figure 25; sea surface temperature data taken from Levitus and Boyer 1984). Only a small fraction of the  bigeye catch are taken associated with cold surface waters (keeping in mind that these large bigeye are always feeding and living in deep cold deep waters, in equatorial or in temperate areas), at least during the day.

The geographical distribution of the fishing zones of the various age classes of bigeye by surface and longline fisheries, as well as the seasonal concentration of large bigeye in areas potentially suitable for spawning, is interesting to show, as it may indicate the bigeye migration patterns in each ocean. Such a figure, taken as an example from the Atlantic, shows the main characteristics of the distribution of the fisheries; the hypothetical migration patterns that can be deduced from this distribution are shown for the Atlantic Ocean (figure 26, showing the hypothetical nurseries, spawning and feeding grounds and potential hypothetical movements between these areas).  Similar movement patterns of bigeye tunas between equatorial and temperate areas are also observed in the Indian Ocean (An. IOTC 2003) and in the Pacific Ocean  (Miyabe 1994, Hampton et al. 1998)

### *3.3 Growth and longevity*

Many studies have been conducted upon bigeye growth in the various oceans, using a wide range of methods such as results from tagging, modal progressions and hard part readings (vertebrae, otoliths, dorsal spines). The comparison between the “best” growth curves selected and used by the various tuna agencies in each ocean show that the growth patterns of bigeye estimated worldwide (Delgado de Molina and Santana  1985, Lehodey and Hampton  1999, Stequert and Conand 2003, Suda and Kume  1967) are very similar (figure 27). Bigeye recruitment takes places at a size of 30 cm (e.g. at an age of about 6 months), and the largest sizes of bigeye taken by the longline fisheries being close to most values of estimated L infinity. There is still a potential two stanza growth for juvenile bigeye in the Pacific Ocean, but the apparent slowing down of growth at preadult stages does not appear to be very significant (for instance compared to the two stanza phenomenon observed for Atlantic yellowfin).

One of the major pending questions concerning bigeye growth remains the poor knowledge of the real age and longevity of large fishes: the average growth of the population seems to be well described by the Von Bertalanffy model and parameters presently used, but very little is known concerning the variability of growth between individuals and between males and females. As a result, the real longevity of the exploited population remains widely uncertain in all bigeye stock assessment: if there is a large intra cohort growth variability, then large fractions of the bigeye stocks (the individuals with low L infinity) would be much older than the longevity of 8 or 10 years, based on the average growth presently used by most analytical stock assessment. The recent recoveries of tagged bigeye after more than 10 years at liberty (Hampton, this symposium) would confirm this conclusion that a significant fraction of the bigeye catches would be older than expected by the average growth models. This serious uncertainty should be solved by large number of age reading done on large fishes, or tagging large numbers of bigeye tunas and being patient, waiting to recover them at large sizes, 10 years later or more.

### *3.4 Natural mortality as a function of age: Mi*

This parameter is fundamental in all analytical stock assessment (this point being discussed by Fonteneau and Pallares, this symposium). The vectors of M at age presently used by the various tuna bodies in their assessments are shown in figure 29. These values were obtained either as estimated model parameters (such as the MULTIFAN-CL results) or simply as a working hypothesis done by scientists based on various information (ICCAT and IOTC, same values of M used). In the Pacific Ocean, the M at age is estimated each year by the statistical model MULTIFAN-CL (Fournier et al. 1998) based on a wide range of information (tagging and recovery data, fishery data). The comparison of M vectors used shows that similar levels of M are used worldwide in the stock assessments done by the various tuna bodies.

However, these similar patterns and levels of M at age should not be considered as a proof that M at age is presently well estimated by the scientists: the biological analysis of changes of natural mortality as a function of age (and sizes) (Fonteneau and Pallares, this symposium) tends to indicate that these values of M are probably still widely uncertain; one of the major uncertainty concerns small bigeye that are fished in mixed schools, in equatorial waters, in association with small yellowfin and skipjack. It has been assumed by scientists in the Atlantic Ocean that these three species should have the same natural mortality when they are in mixed schools, while natural mortality estimated on small size tunas and independently on the three species by MULTIFAN-CL, do show very different levels (low for bigeye, high for yellowfin, very high for skipjack). Wide uncertainties also remain concerning the increase of natural mortality for males and females due to sexual activities and later in their life to a potential senescence.

In conclusion, if the vectors of M used by scientists for bigeye are quite similar world wide, there is no doubt that both the absolute levels and the relationship with age remains widely uncertain, especially for juvenile and oldest fishes.

### *3.5 Optimal sizes of bigeye cohorts as a function of growth and $M_i$*

Figure 28 shows at what size and age the maximum weight of a cohort should be observed (in an unfished stock, assuming that Mi, longevity and growth are well estimated). Such optimal size is often used as an indicative reference point, as it indicates if a given fishery is exploiting the stock at a too low or a too large size . This optimal size tends to be estimated for bigeye at about 40 kg and 4.25 years (which implies that sizes of bigeye taken under FADs are always much smaller than these optimal sizes).

However, it should be kept in mind that such a theoretically optimal size remains widely uncertain when natural mortality or/and growth are poorly estimated and of little interest when the stock is heavily exploited by fisheries and showing a much younger age structure of its underlying population.

### *3.6 Sex ratio at size*

The information concerning sex ratio at size of bigeye has been collected to variable degrees in the three oceans: this information is abundant in the Atlantic (Miyabe 2002) and Pacific Oceans (SPC and Miyabe com. pers.), and primarily comes from samples taken on large bigeye fished by Japanese longliners (figure 30). This information is not available for the Indian Ocean. The patterns of sex ratio at size are quite similar in the Atlantic and Pacific Oceans: sex ratio are quite equal until 130 cm (50/50 for males and females), while males tend to be slightly dominant for larger bigeye after spawning (>135cm). This quite linear increase of the percentage of males in the catches reaches levels of 70 % in the Pacific at the largest sizes commonly taken by longliners, but much less in the Atlantic Ocean. This dominance of males at large sizes is also commonly observed world wide for yellowfin (figure 31), but the 100% levels of males that are often observed for large yellowfin are never seen for bigeye.

This inversion of sex ratio is clearly significant, but it should be considered as being a quite moderate one: as an example, if the catch at size figure of longliners is multiplied by the average sex ratio at size, the result is that 55% of bigeye catches in weight would have been males, and 45% females. These percentages of male and female in the catches are in fact quite similar and close to an equal sex ratio for most sizes of bigeye taken. Such quite minor difference in the catches by sex would hardly justify stratifying between males and females the bigeye stock assessment analysis (as it is done for the swordfish stock in the Atlantic, a stock showing a wide dominance of females at large sizes).

The biological uncertainty remains high concerning the interpretation of this increasingly differential sex ratio at large sizes: such phenomenon can be interpreted by a differential growth, a differential natural mortality or/and a differential catchability linked to sex, but this interesting question remains poorly studied for bigeye.

### *3.7 Size at first maturity*

The bigeye size at first maturity has been analyzed in the Atlantic and Western Pacific Oceans. In the western Pacific, 50% of the bigeye females spawn at a size of 135 cm (Schaefer and Fuller 2004), while in the Atlantic the level is reached at a size of 110 cm (Pereira 1987).

### *3.8 Behavior and environment*

The various peculiarities of bigeye behaviour observed in the different oceans have been widely described by various authors (such as Sharp 1978, Miyabe 1994, Brill 1994, Holland 1990, Itano 2000, Musyl et al. 2003), as well as in some papers presented during this symposium (Brill this symposium). It is quite difficult to compare in detail these heterogeneous results, but there is no doubt that the age specific behavior of bigeye tuna is very consistent between oceans. Bigeye tuna always shows at small sizes (for instance fishes smaller than 70 or 80 cm), a tendency to school with small yellowfin and skipjack in shallow warm equatorial waters, and often to aggregate under FADs. This schooling and shallow behavior of juvenile bigeye is modified for the preadult and adult bigeye when these fishes tend to disperse and to feed in deep cold waters and to seasonally migrate to temperate areas. There is good hope that it will be possible in the near future to model these changes of the bigeye behaviour as a function of their size and of the spatial and vertical heterogeneity of the environment (Maury, this symposium).

These spectacular behavior changes between juvenile and adult bigeye are observed worldwide. They are easily explained by major changes in the physiology and anatomy between small and large bigeye tuna (swimming bladder, thermoregulation, etc). These changes between the juvenile and the adult bigeye are extreme and quite unique among the other tuna species.

### *3.9 Conclusion on bigeye biology*

The comparative review of the main biological parameters and characteristics of bigeye tuna worldwide has shown that very significant progress has been obtained in this biological field. These data confirm that the biological characteristics of the bigeye tuna stocks appear to be very similar worldwide.

## 4 Stock assessment

### *4.1 Assessment methods used in the various oceans*

Stock assessment done on bigeye tunas by the tuna bodies have been using a wide range of models such as various types of production models, sequential population analysis (ICCAT, IATTC, IOTC), and statistical models (IATTC and SPC). These models uses a variable set of information (statistical models such as

MULTIFAN-CL try to integrate multiple types of information when they are available) and the results do provide some estimates of the recent stock status. The details of these methods and results presently obtained are given by various authors in this symposium. The goal of this chapter will be limited to develop a global comparative overview between the methods used in the various areas and between the apparent uncertainties faced by these stock assessments done independently in each area for each bigeye stock. This discussion will be separated into the Indian and Atlantic Oceans on one side, as the stock status and methods used in the two oceans are very similar, and on the other side in the Pacific Ocean.

***4.2 Stock status in the Atlantic and Indian Oceans***

*Atlantic Ocean*

In the Atlantic Ocean, the bigeye stock assessment has been done periodically by ICCAT since the mid eighties using both production models and tentative sequential population analysis. The results of these assessments were quite stable over time until the mid nineties, the MSY of the stock being then estimated at levels of about 80,000 t. The large and fast increase of catches observed since the early nineties (by purse seiners on juvenile bigeye, as well as by longliners on the adults, see figures 6 and 7) has produced a major change in the fishery and in the stock assessment. When these increased catches were first observed during the early nineties, there was nearly an unanimous opinion expressed then by scientists that these high catches, that were well above any previously estimated MSY, would be unsustainable (for instance during the SCRS 1995, figure 32; An. ICCAT 1996). These deep concerns were reinforced by the expected decline of yield per recruit following the wide increase of juvenile catches and they were at the origin of the bigeye year program (or BETYP) then recommended by SCRS (Fonteneau and Pallares 1997). However, and very surprisingly, the present MSY of bigeye stock is now estimated at about 100,000t (An ICCAT 2003), e.g. at a level much higher than the MSY estimated until the early nineties (and despite the unknown reduction in the yield per recruit due to the large increase of catches at very small sizes). This situation of a new higher stock productivity remains widely unexplained: it is not clear if the MSY and optimal effort of the bigeye stock were underestimated by the historical SCRS analysis (a bias often faced by many tuna stock assessment, see Fonteneau et al. 1996). Such problem could for instance be due to the fact that significant fractions of the bigeye stock, that were previously "cryptic"[2] and unavailable to fisheries (being too scattered or too deep), are now increasingly available and caught, thus increasing the MSY of the stock in the same way as a geographical expansion of the fishery. The other hypothesis is that there has been during recent years, an increase in the biological productivity of the bigeye stock (for instance due to higher recruitment, faster growth or lower natural mortality), although this hypothesis may seem to be quite unlikely.

*Indian Ocean*

In the Indian Ocean, the bigeye stock assessment has been done only very recently by the IOTC, since 2000, and using both production models and various sequential population analysis (An IOTC 2003). The major increase of catches observed during the nineties (by purse seiners increasingly catching small bigeye, as well as by longliners catching more adults, cf figures 5 and 6) was the main factor driving these IOTC analysis. It was concluded by IOTC that the bigeye stock is not yet overfished, but that all the recent catches over 120,000 t since 1995 were well above the estimated MSY at about 100,000 t. These analyses remain widely uncertain due to the lack of biological data (absence of tagging results in the Indian Ocean) and to the serious deficiency in the database used (the Indian Ocean bigeye fishery by longliners being widely dominated by Taiwanese vessels, a fishery providing to the IOTC very few and not very reliable data upon its activities).

*Yield per recruit*

In both oceans, the yield per recruit interaction between the purse seine and longline fisheries is estimated to be quite low, simply because the high fishing mortalities exerted on juveniles by purse seiners are exerted at a quite moderate average yearly levels, and only during a short period of time (about 1 year), while the longline fishing

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- [2] such "cryptic biomass" can be described as the fraction of the total biomass which will survive at the equilibrium if a very high (or infinite) fishing effort was exerted by the existing gears, under their present fishing patterns and in given exploited fishing zones working in an area smaller than the total stock distribution.

mortality tends to be exerted upon the adult bigeye during several years (about 10 years) and probably at a higher average level of F.

### *4.3 Stock status in the Pacific Ocean*

Fishing pressure on bigeye tuna has been increasing during recent years in the Pacific, but probably much less than in the Indian and Atlantic Oceans, as shown by the catch trend observed in both the Eastern and Western Pacific (figure 4). Most analyses are done on a two stocks basis, these two stocks being separated by a stock assessment frontier at 150° West: an Eastern stock by the IATTC (using its statistical model A-SCALA, Maunder and Watters 2003) and a western stock by SPC scientists (although some of the analyses done with MULTIFAN-CL by SPC scientists also cover the entire Pacific Ocean). Detailed information upon the method used and the results obtained in each area are given by S. Harley and J. Hampton (this symposium). The present analyses conclude that in both areas, the bigeye stocks during recent years have been reaching their levels of full exploitation, the context of the two analyses being quite different:

*Eastern Pacific*

Recent catches have been above the estimated MSY (Harley this symposium), but the measures taken by the IATTC and the serious decline of Japanese longline effort and catches have reduced the pressure on the adult stock (this tendency being counter balanced, to a still unknown degree, by a recent increase of catches by Taiwanese longliners in the area). The FAD fishery targeting small bigeye has been very active during some years (mainly between 1996 and 1999), but has been catching few small bigeye since then. The major source of uncertainty and of worry is due to the recent lack of small bigeye in the purse seine FAD fishery, as it could be interpreted as a biological lack of recruitment for the stock.

*Western Pacific*

The conclusion of the most recent analysis (Hampton, this symposium) is that the MSY of the bigeye stock should be estimated at about 40,000 tonnes, e.g. at levels well under the total bigeye catches observed since 1972. However it is recognized by his authors that this assessment should be considered as being highly uncertain because of statistical uncertainties in the purse seine catches, in the effective longline efforts and to the lack of catch, effort and size data from the major purse seine fisheries that are active in Philippines and Eastern Indonesia. This apparent low MSY is also the consequence of the stock recruitment relationship assumed in the model and to the fact that in the present MULTIFAN-CL analysis, recent recruitment levels are estimated to be “too high”, and well above the real average productivity of the bigeye stock. It is hard to understand how bigeye catches could have been permanently increasing and being multiplied by a factor of two during the last 30 years, each of these yearly catches being well above the presently estimated MSY. The western Pacific stock would have been the first and only tropical tuna stock showing such a phenomenon of sustained catches well above the MSY, and of a long term positive trends of its recruitment[3]. Such “natural” variability of tuna stock productivity and of MSY has been simulated by Fromentin and Fonteneau 2001. Furthermore, it should also be noted that the estimate of MSY given in 2002 by the same MULTIFAN-CL was at a higher level of 80,000 tons (probably more realistic?). The comparison between MSY of the various bigeye stocks fished world wide and the sizes of the corresponding areas fished, also raised some doubt upon the validity of the low MSY estimated for the Western Pacific, as the western Pacific would show by far the lowest MSY, when the area is by far the largest (figure 33) (keeping in mind that this area is highly productive for all other tuna stocks), and when both catch rates and the level of total bigeye catches between the various fishing zones are nearly identical.

*Yield per recruit*

The potential yield per recruit interaction between the purse seine and longline fisheries are estimated to be quite high in both the eastern and western Pacific (Hampton, Harley this symposium). Surprisingly this result is widely different from the conclusion obtained in the Atlantic and Indian Oceans (An ICCAT 2003, an IOTC 2003), two areas where this potential interaction is estimated to be quite moderate. The reasons explaining these rather strange differences should be analyzed and explained (this should be easily done, as these calculations are simply based on fishing mortality at age exerted by purse seiners and longliners, growth, and natural mortality at age).

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[3] Such an apparent increase of the estimated recruitment has often been found in many stock assessments, but careful reanalysis of these results often show that these trends were artificial and *de facto* biologically misleading, being linked with increased catches, increased size of the fishing zone or depth, and/or increased efficiency by the fisheries (see Fonteneau and al. 1996).

*Stock structure*

All the stock assessment analysis conducted in the Pacific Ocean have also faced the difficult issue of stock structure. The Pacific Ocean is a very large area, and there is a high biological probability of low mixing rate, if any, for instance between tunas fished in remote areas such as the South American coast and in the Coral Sea, at a great distance of about 7000 nautical miles (this lack of mixing being confirmed by the Coral Sea tagging; Hampton this symposium). On the other hand, when a single stock analysis is done in the Eastern Pacific, this analysis is assuming a frontier (without any net movements at all ages) in the middle of major fishing and spawning zone of the Central Pacific area where the adult bigeye are heavily fished by longliners. It can be noted that there is no apparent East-West frontier between two «visible » stocks, see figure 11, as for the yellowfin fisheries in the Pacific, nor any environmental barrier at 150° West. More tagging data would probably be the best way to estimate these long term and ocean wide age specific mixing rates, knowing that the results of such tagging would need many years before being fully usable in the context of long distance movements.

### *4.4 Conclusion about stock assessment*

Bigeye stock assessments have been conducted in the various oceans by independent teams of scientists and using various independent methods. Most of these stock assessments are very recent and still quite experimental in their methods and results. There is a converging general tendency to conclude that each bigeye stock has been fully fished during recent years, with recent catches often above the estimated MSY, but unfortunately it could easily be considered that the real status and prospects of most (or all?) bigeye stocks probably remain highly uncertain. One of the major problems and dangers faced world wide by these bigeye stocks is probably due to the additive effects of the increasing catches of juvenile bigeye taken under FADs by purse seiners, and of the also increasing catches of adult bigeye that are taken by longliners and sold at a very high price on the Japanese sashimi market. Unfortunately, it is probably realistic to recognize that the real biological danger faced by most or all bigeye stocks are still widely uncertain, as these prospects are highly dependent of the levels and shape of natural mortality at age as well as of recruitment trends, both factors that are still very poorly estimated by scientists.

On the other hand, there is no doubt that there are now various positive prospects to improve the present stock assessment. The new tagging programmes recently conducted and planned on bigeye should widely improve the biological knowledge on the species. In term of models, the recent development of an operational model for bigeye under the FEMS project (Pallares this symposium) should help (in the Atlantic and Indian Oceans) to estimate the sensitivity of the assessments to its various uncertainties (structural ones or linked with its parameters). On the other side the implementation of statistical models such as FAST (Maury this symposium) and MULTIFAN-CL models (Fournier et al., 1998, Miyabe and al., this symposium) together with the recent major improvements in the biological parameters used in these models should produce a much more realistic stock assessment. It is also quite clear that a better exchange of information, hypotheses and methods between the various teams working on bigeye stock assessments could probably improve the validity of these results.

## 5 Conclusion on world bigeye prospects: research, fisheries & management

Bigeye tuna is the most valuable tuna species fished world wide, but surprisingly this species has been quite poorly and quite recently studied and assessed by the scientists. The positive factor is that scientific efforts have been widely increased world wide on bigeye, for instance since the last world meeting on bigeye tuna in 1996. In this context of developing research and of increasing fisheries, there is still serious conservation uncertainties faced by most bigeye stocks. The good news are that scientific research upon bigeye are now very active, when there is not yet any proven overfishing of any bigeye stock world-wide, but on the other hand, the negative prospects of overfishing are increasingly faced by all bigeye stocks. Although there is still very little clear interaction between purse seine and longline fisheries, there is no doubt that this potential risk has been increasing during recent years, in relation with the increased catches of small bigeye associated with FADs, and this constitutes an increasing source of concern. Bigeye tuna is typically a long living species showing a quite late spawning and a quite low biological productivity: these biological characteristics (similar to bluefin tuna) should be taken into account in order to promote a precautionary management of these stocks, as these resources may be more easily overfished than tropical tunas (Fromentin and Fonteneau 2001), the risks being increased by the high value of large bigeye which allows the longline fishery to operate at very low levels of the adult stocks

(although this factor may be counter balanced by potential increases in the oil cost, a factor that could be limiting fishing operation targeting low densities of bigeye).
More active cooperation between the tuna agencies and their scientists working on bigeye would improve the assessment and management of bigeye tuna: an in depth comparative analysis of the various bigeye stocks fished world wide (their habitat, fishing patterns developed by the various fisheries, behaviour of fishes, their exploitation rates, etc..) would help to reduce the present uncertainties in the stock assessment, as bigeye stocks and fisheries are very similar world wide. The comparison between the "answers" of the various bigeye stocks to the recent increased fishing pressure observed at variable degrees in the various oceans would also be highly positive.

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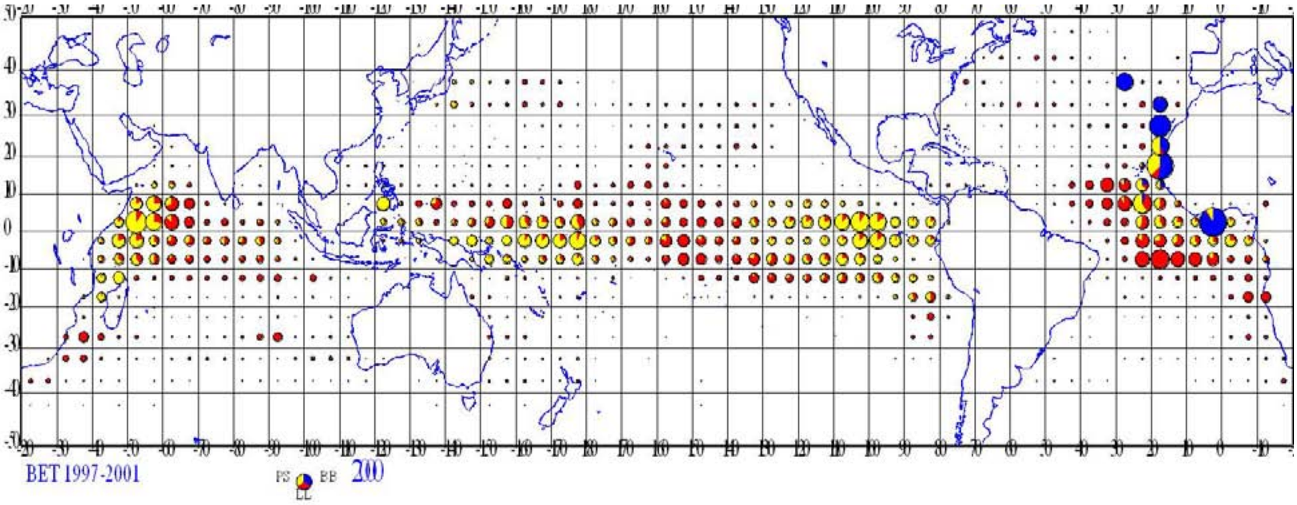



**Figure 1**. Fishing zones of bigeye taken by various tuna fleets during recent years (average 1997-2001): by longliners (in white, LL), by purse seiners (in grey,PS) and by pole and line baitboat vessels (in dark, BB).

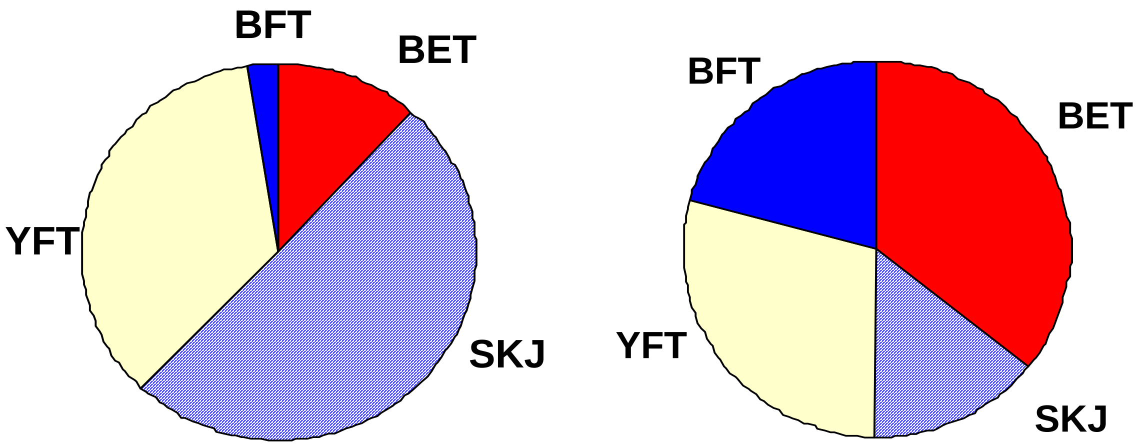



**Figure 2.** Landed quantities in percentage of the major tuna species during recent years (average 1990-2000) in term of weight (left) and in terms of their estimated landing value (BET: bigeye, SKJ: skipjack, YFT: yellowfin and BFT: northern and southern bluefin).

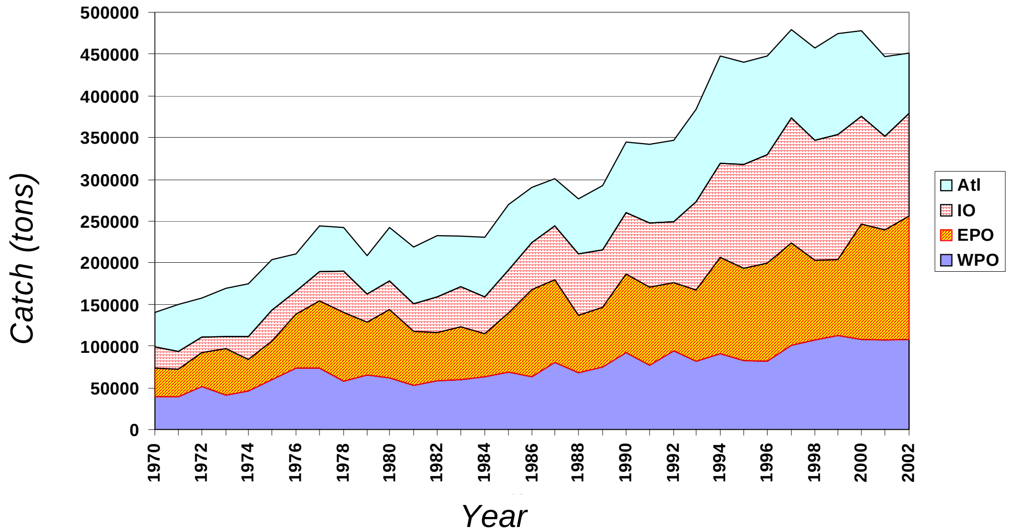



**Figure 3.** Cumulative yearly catches of bigeye tuna taken by ocean (Atl:Atlantic, IO: Indian ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).

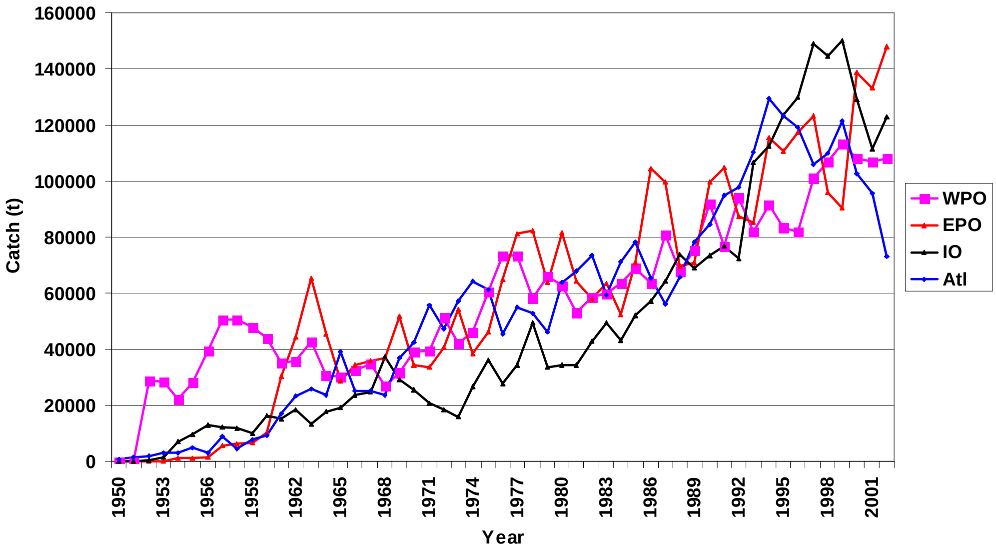



**Figure 4.** Yearly catches of bigeye tuna taken by ocean (Atl:Atlantic, IO: Indian ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).

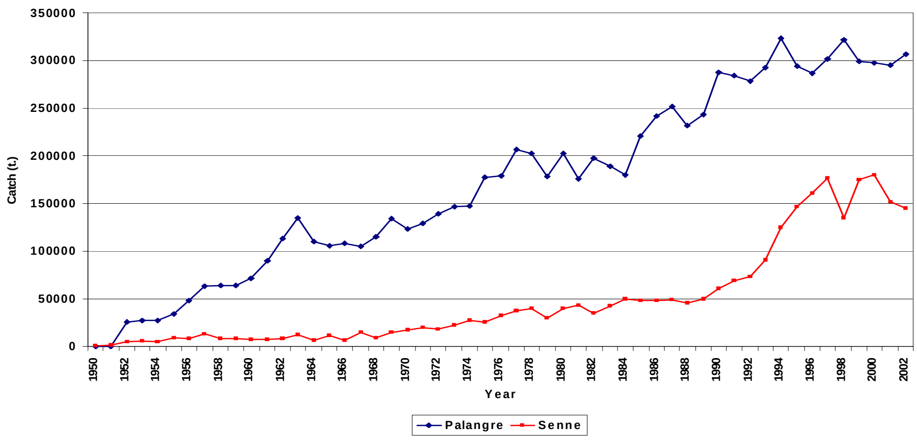



**Figure 5.** Yearly catches of bigeye tunas taken world wide by purse seiners and by longliners.

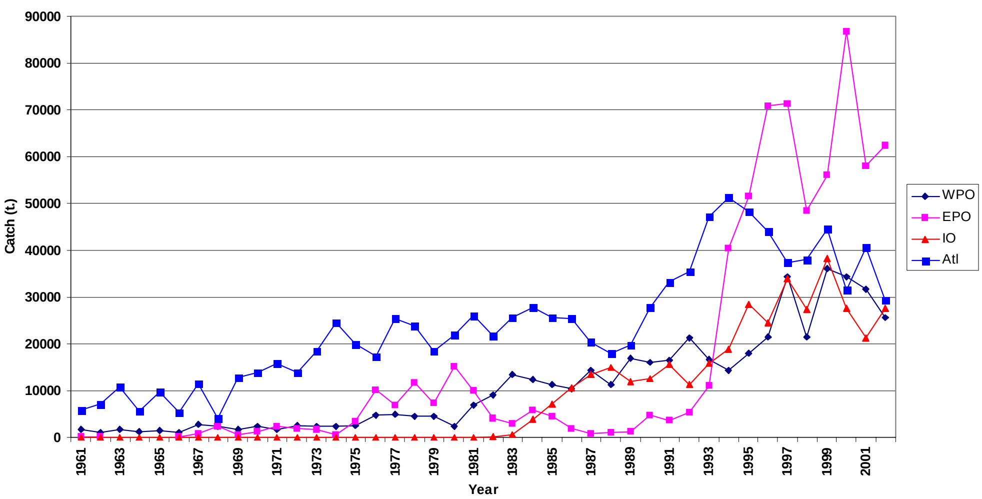



**Figure 6.** Yearly catches of bigeye tuna taken by surface fleets in each ocean (Atl:Atlantic, IO: Indian Ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).

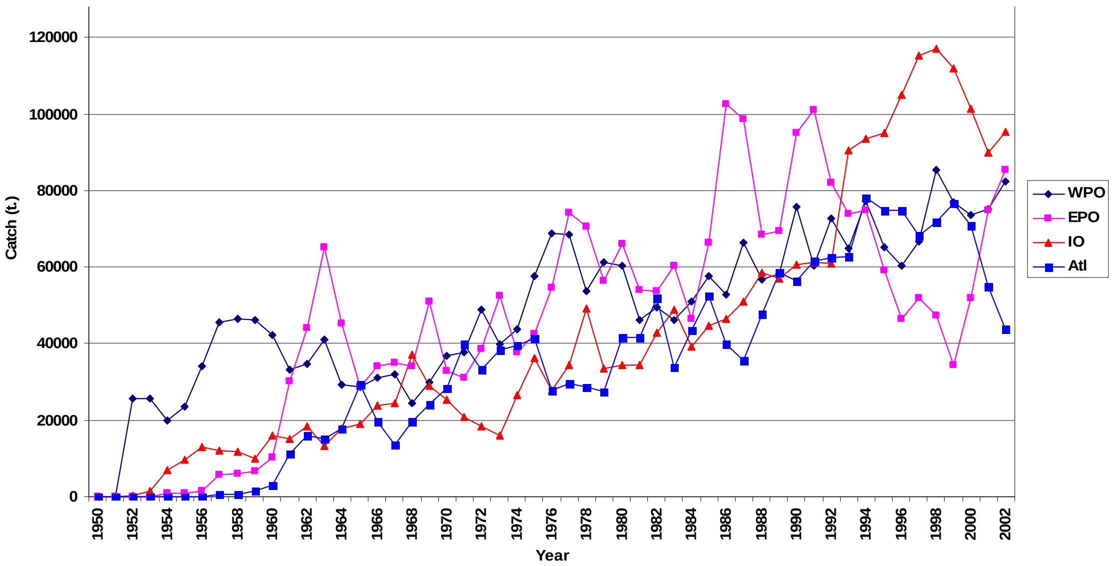



**Figure 7.** Yearly catches of bigeye tuna taken by longliners in each ocean (Atl:Atlantic, IO: Indian Ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).

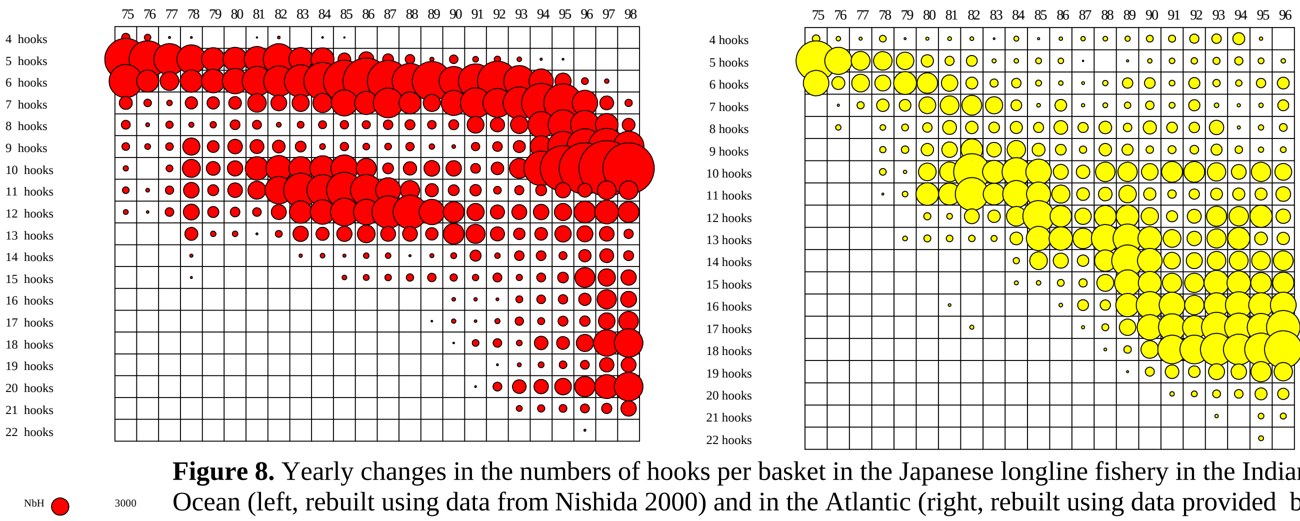



**Figure 8.** Yearly changes in the numbers of hooks per basket in the Japanese longline fishery in the Indian Ocean (left, rebuilt using data from Nishida 2000) and in the Atlantic (right, rebuilt using data provided by Suzuki).

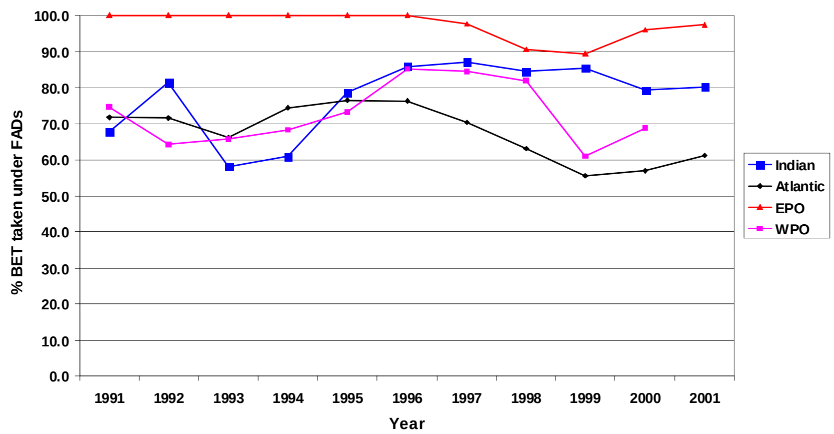
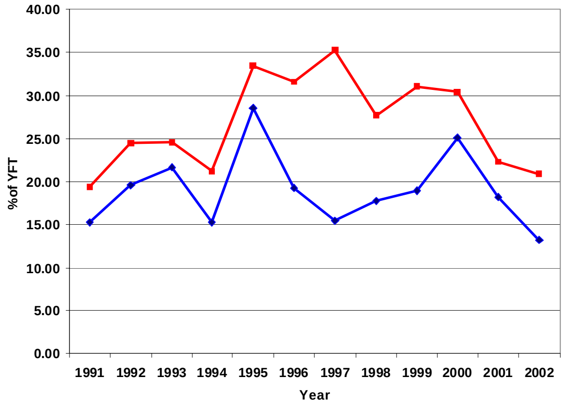
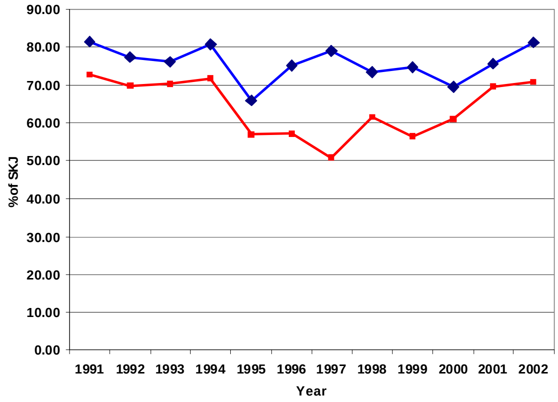



**Figure 9.** Estimated percentage of bigeye in the FAD associated catches taken in each ocean (Atl:Atlantic, IO: Indian Ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).



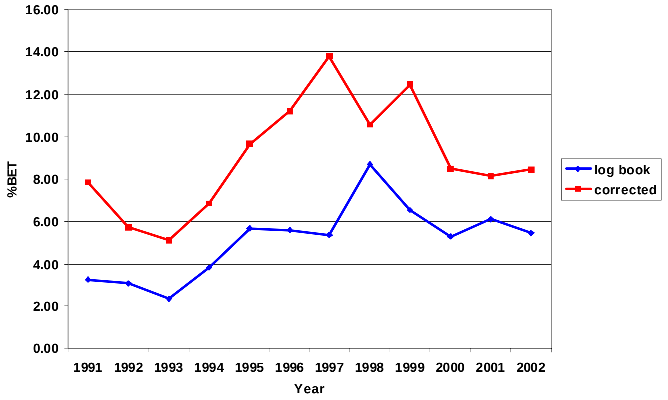
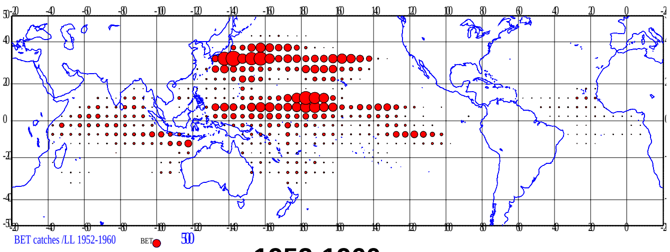
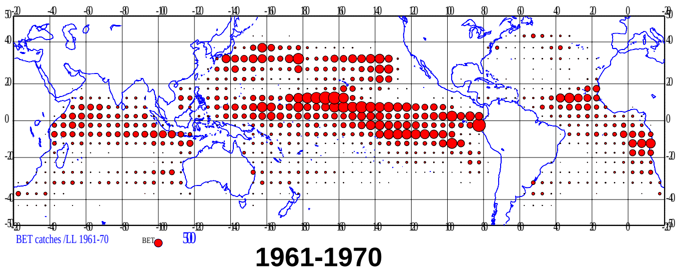



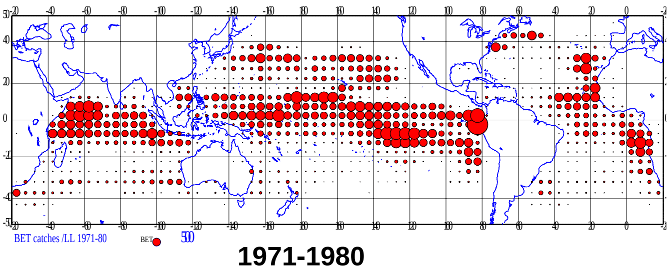

**Figure 10.** Species composition of the purse seine catches in the Indian Ocean during the period 1991 to 2002, shown for yellowfin (top left), skipjack (above) and bigeye (lower left), in percentage, as taken from the log books, and best species composition estimated after a systematic sampling of the species composition of these landings. This figure shows the typical changes of species composition of FAD associated catches by purse seiners, after a multispecies sampling, e.g. a systematic moderate increase of yellowfin catches, a decline of skipjack catches (moderate in % but large in quantities), and a systematic large increase of bigeye catches.



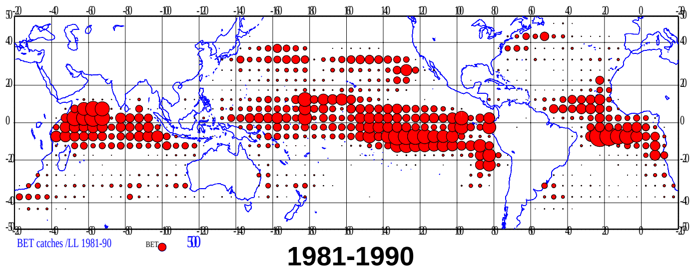

1952-1960



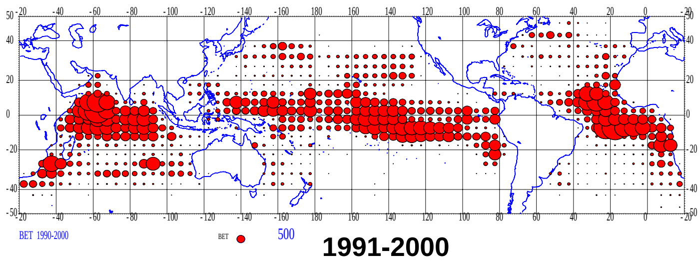

1961-1970




1971-1980




1981-1990




1991-2000

**Figure 11.** Fishing maps showing the estimated geographical distribution of total bigeye catches by longliners during 5 periods of 10 years (period 1952-2000).

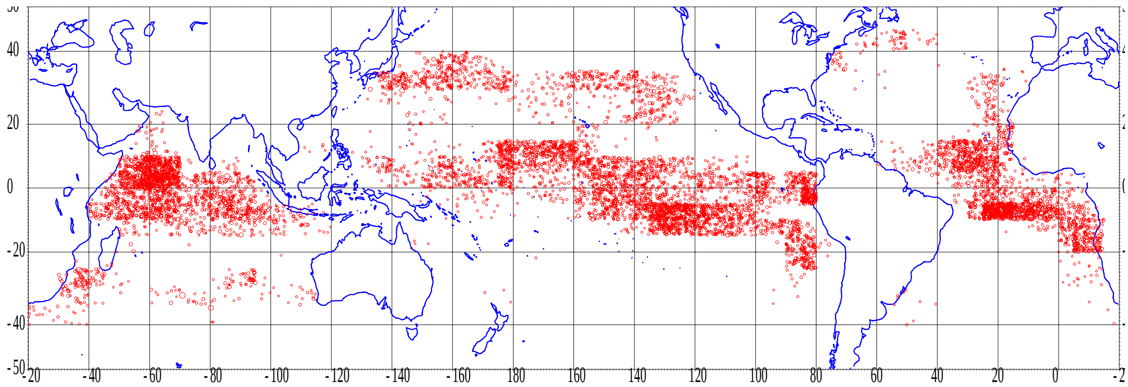



**Figure 12.** Map showing the « **hot spot** » of bigeye catches: each circle shows, in proportion to the estimated catch, each of the large catches of bigeye (>200 tons) taken during any month in each 5° square during the period 1952-2000 by the combined fleets of longliners (each cirche being randomly positioned within each 5° square).

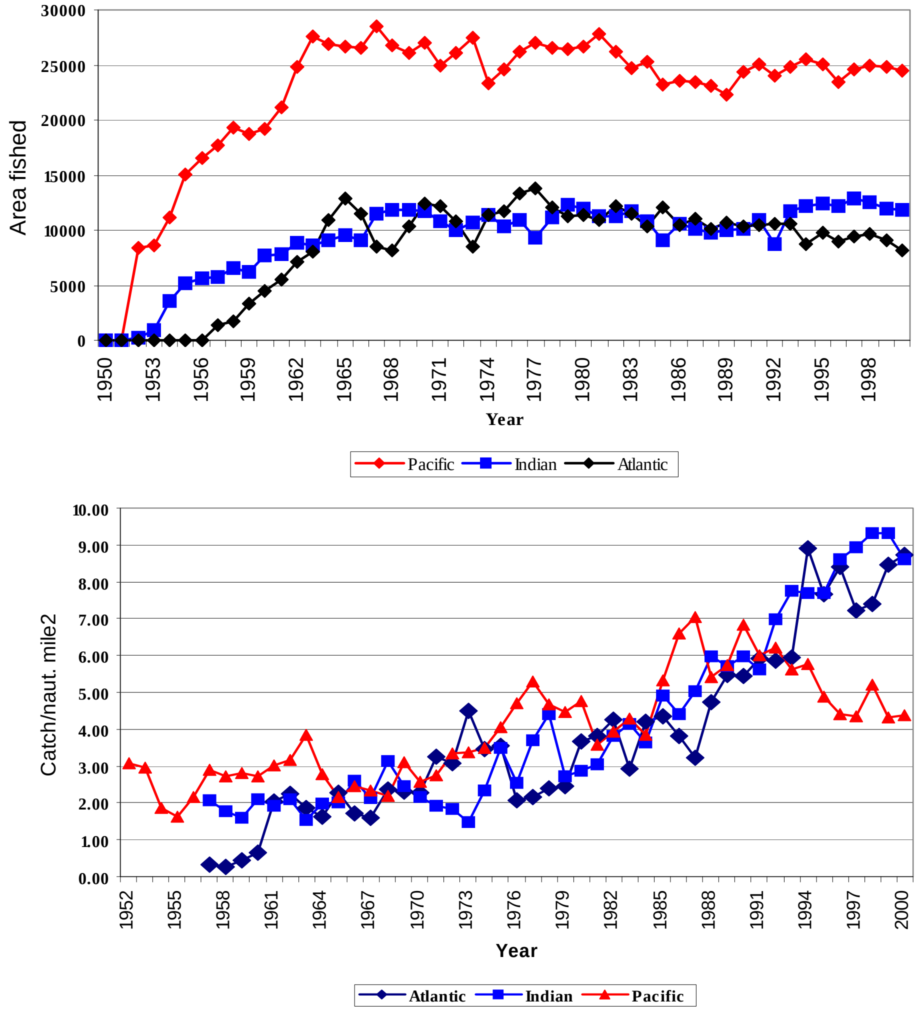



**Figure 13.** Size of the fishing zones where bigeye tunas have been caught significantly by longliners in each ocean (a total greater than 10 tons of bigeye by 5° square during each year), upper figure, and corresponding catches of bigeye tuna taken yearly by longliners in each unit of area (tons/ sq. naut. mile$^2$), lower figure.

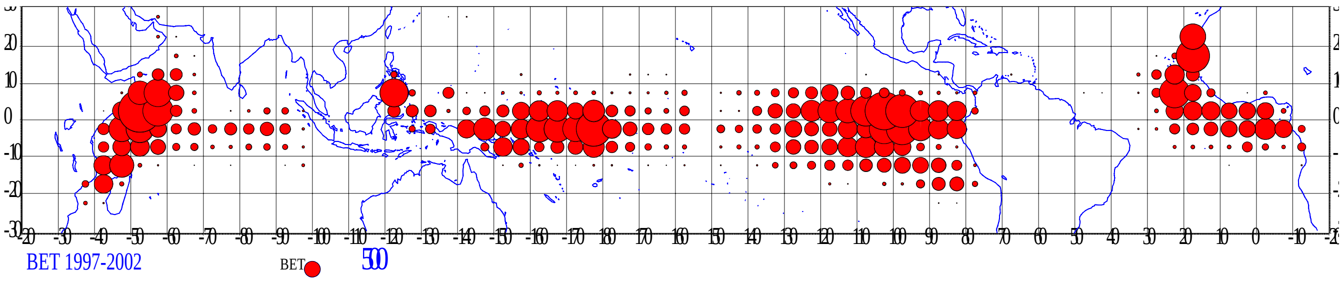



**Figure 14.** Average catches of bigeye by purse seine fisheries during recent years (average period 1997 to 2002).

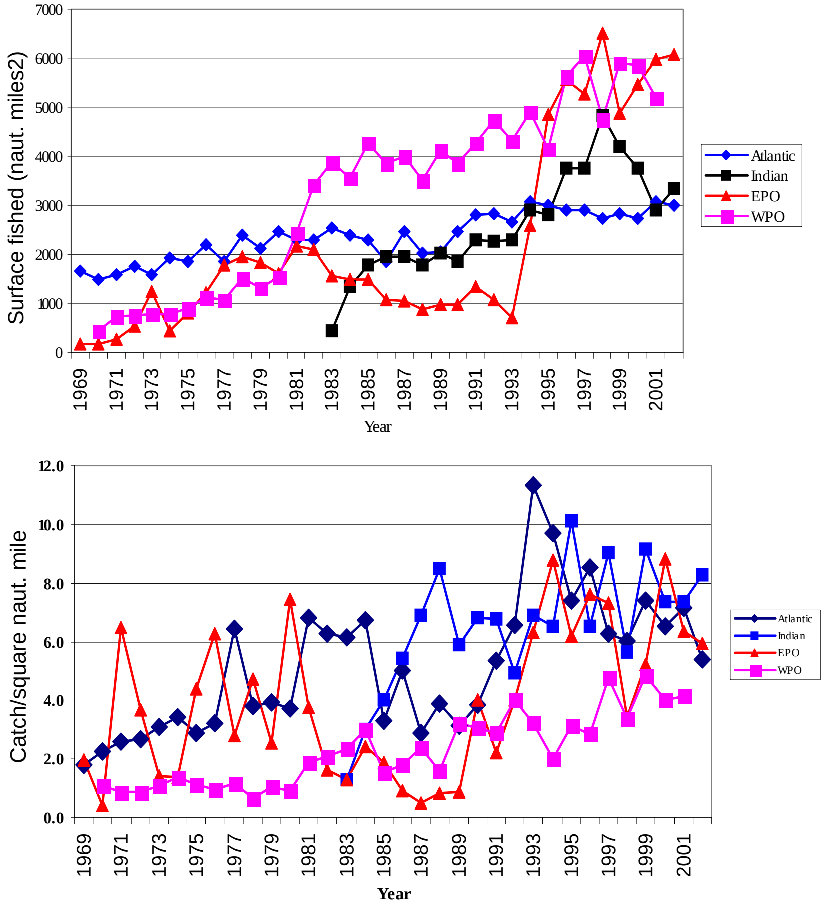



**Figure 15.** Size of the fishing zones where bigeye tunas have been caught significantly by purse seiners in each ocean (a total greater than 10 tons of bigeye by 5° square during each year), upper figure, and corresponding catches of bigeye tuna taken yearly by purse seiners in each unit of area (tons/ sq. naut. mile2), lower figure.

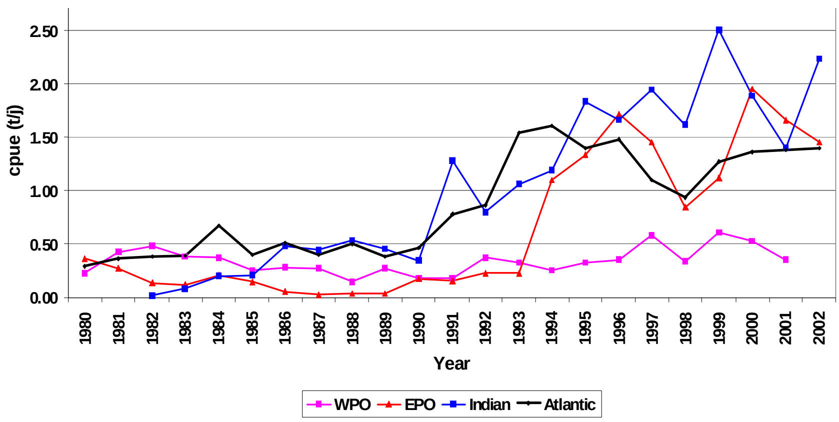



**Figure 16.** Nominal CPUE of bigeye for the various purse seine fisheries (bigeye catches/days at sea) in each ocean.

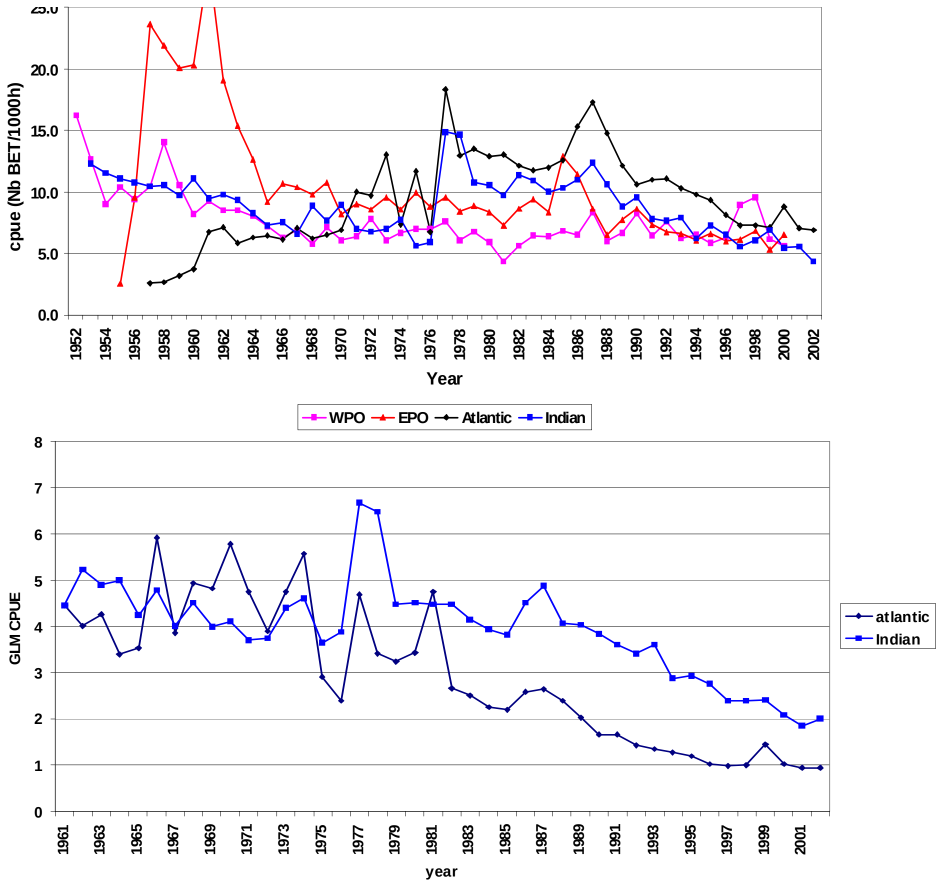



**Figure 17.** Nominal CPUE of bigeye tuna calculated for Japanese longliners in the equatorial areas of the 4 oceans (Indian and Eastern Pacific oceans, 5°N to 15°S, Western Pacific and Atlantic: 15°-10°S; upper figure 17 a) and typical GLM CPUE calculated in the Atlantic and Indian oceans for the same fisheries, as an estimate of biomass levels (lower figure 17 b).

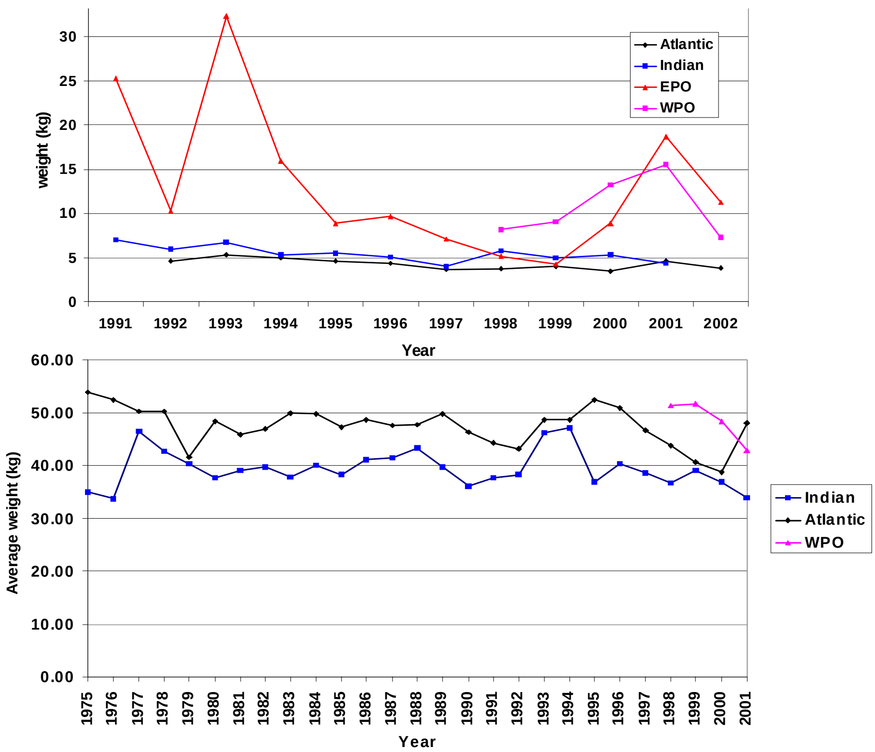



**Figure 18.** Average yearly weight of bigeye taken by purse seiners (upper figure) and by longliners (lower figure) in various oceans during recent years.

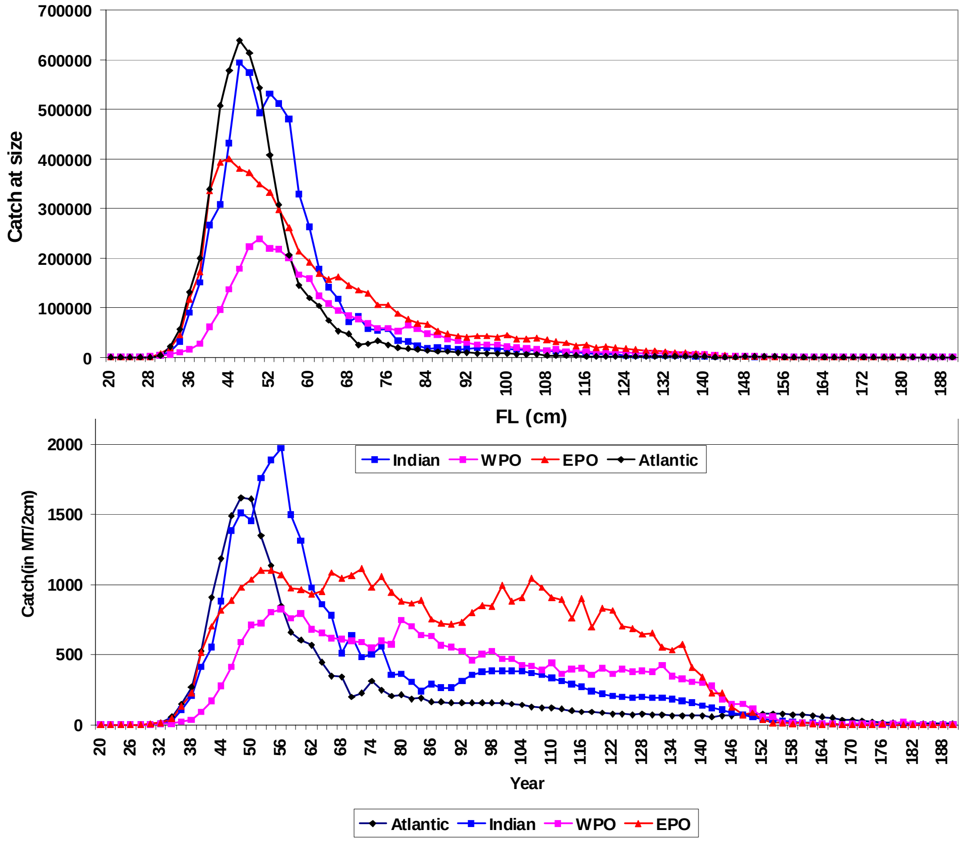



**Figure 19.** Average size distribution of bigeye taken in each ocean by purse seiners during recent years shown in numbers (upper figure), and in weight (lower figure).

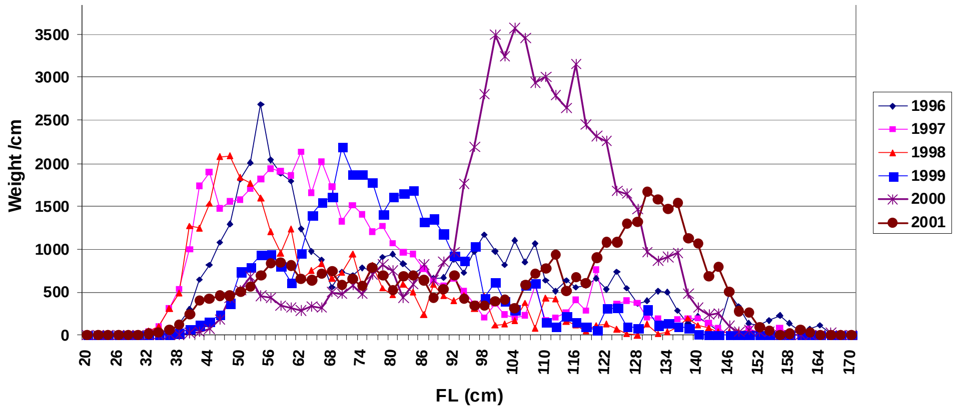



**Figure 20.** Yearly distribution of bigeye sizes taken by purse seiners in the Eastern Pacific.

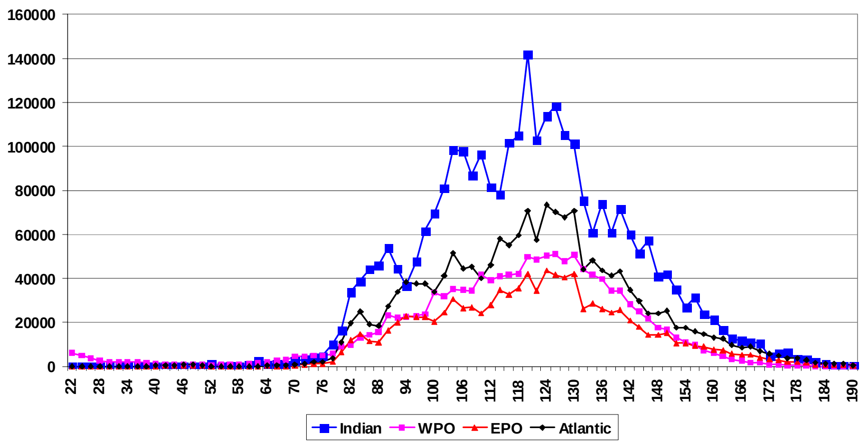



**Figure 21.** Average size distribution of bigeye ta in the various oceans.

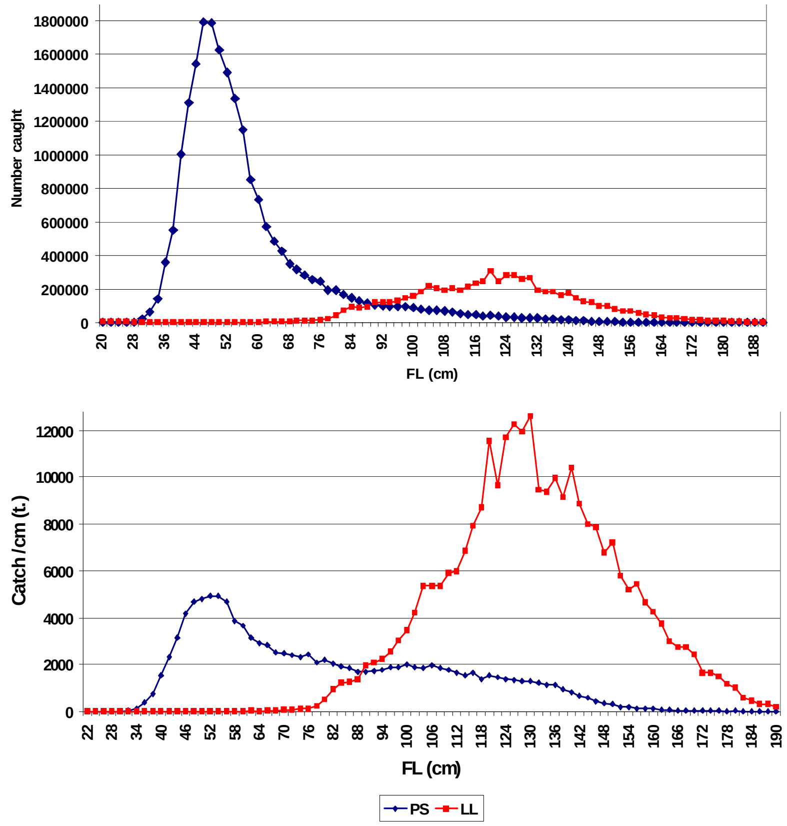



**Figure 22.** Total catches by size of bigeye taken world wide by longliners and by purse seiners during recent years (period 1997-2000), in numbers of fishes (upper figure) and in weight (lower figure).

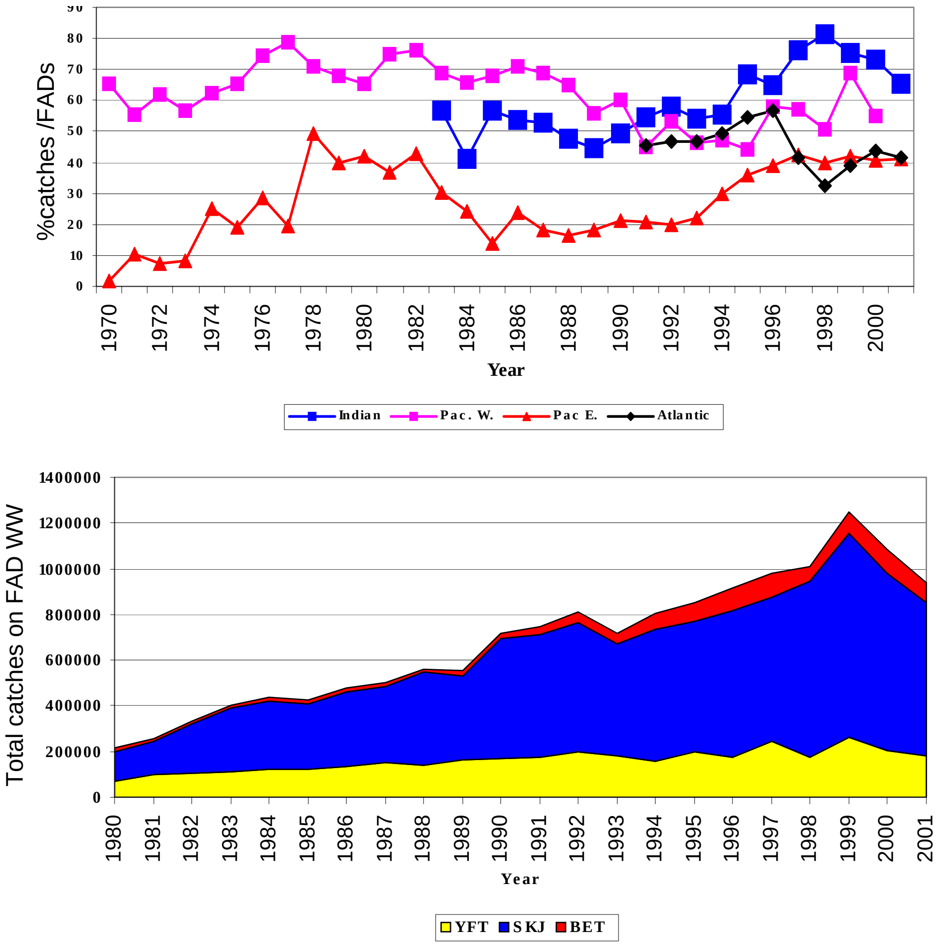



**Figure 23.** Estimated amount of catches taken by purse seiners associated to floating objects (natural or artificial): figure 23 a (upper) shows the estimated percentage of FAD associated yearly catches in each ocean, and figure 23b, lower figure, shows an estimate of total catches taken yearly by purse seiners under floating objects

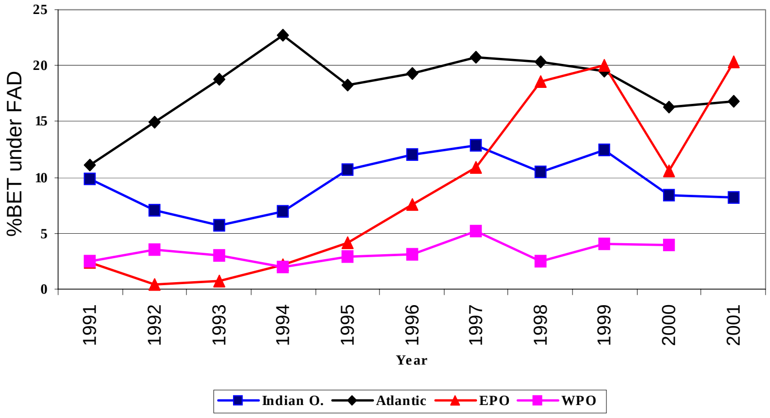



**Figure 24.** Estimated yearly percentage of bigeye tuna taken by purse seiners under floating objects in each ocean (showing the quantity of bigeye against total tuna catches under FADs).

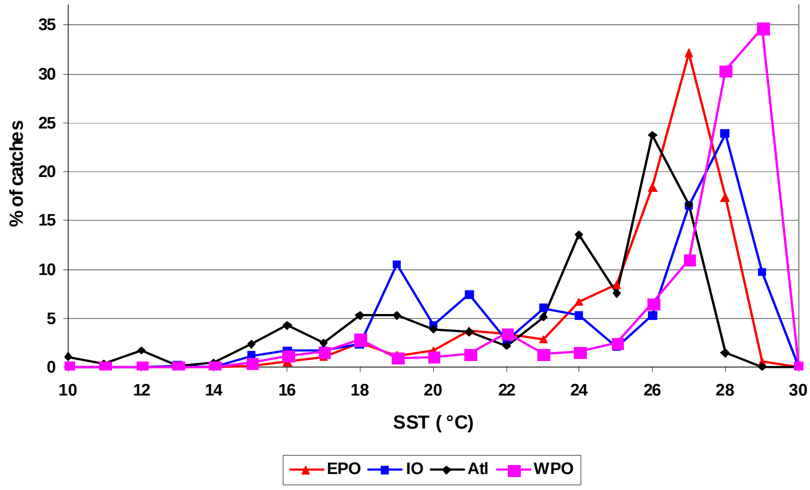



**Figure 25.** Percentage of bigeye catches taken during the period 1991-2000 as a function of the average sea surface temperature in each 5° square and quarter where these tunas were taken (Atl:Atlantic, IO: Indian Ocean, EPO: Eastern Pacific Ocean and WPO: Western Pacific Ocean).

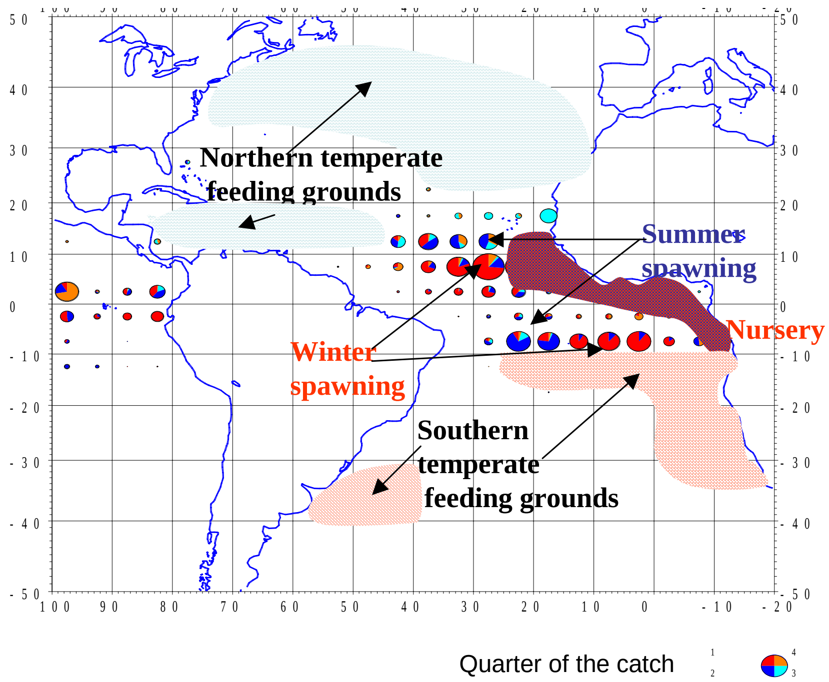



**Figure 26.** Fishing maps showing in the Atlantic the quarter and 5° strata where large bigeye were caught during recent years (1997-2001) by longliners under with a sea surface temperature greater than 25°C (potential spawning strata), nursery area based on the areas where small bigeye are taken by purse seiners, feeding grounds of adult bigeye, and hypothetical movement patterns between these strata.

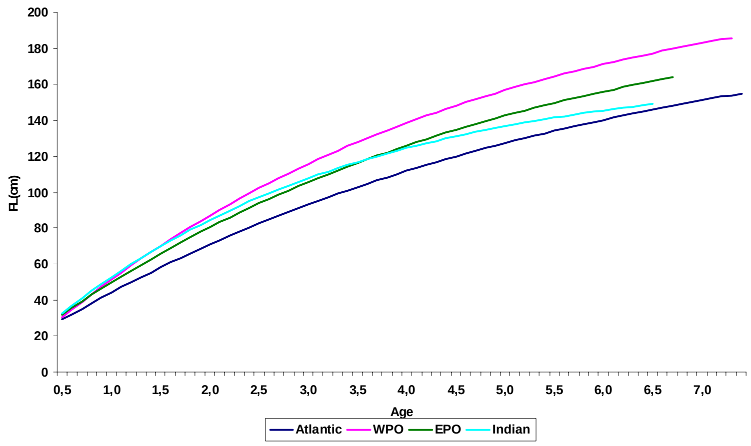



**Figure 27.** Examples of growth curves estimated world wide for bigeye tuna by various authors in various oceans (Atlantic: Delgado de Molina and Santana 1985, Western Pacific: Lehodey et al 1999, Eastern Pacific: Suda and Kume 1967, Indian Ocean: Stequert and Conand 2003).

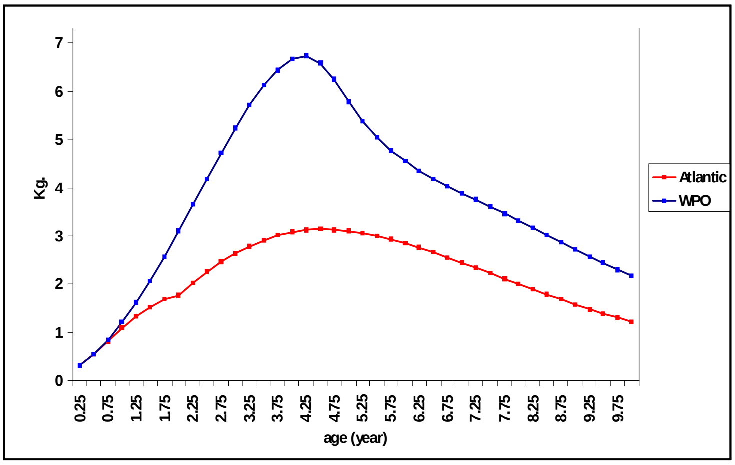



**Figure 28.** Weight of an unexploited cohort of bigeye assuming two typical patterns of growth and natural mortality used for this species (Atlantic and Western Pacific).

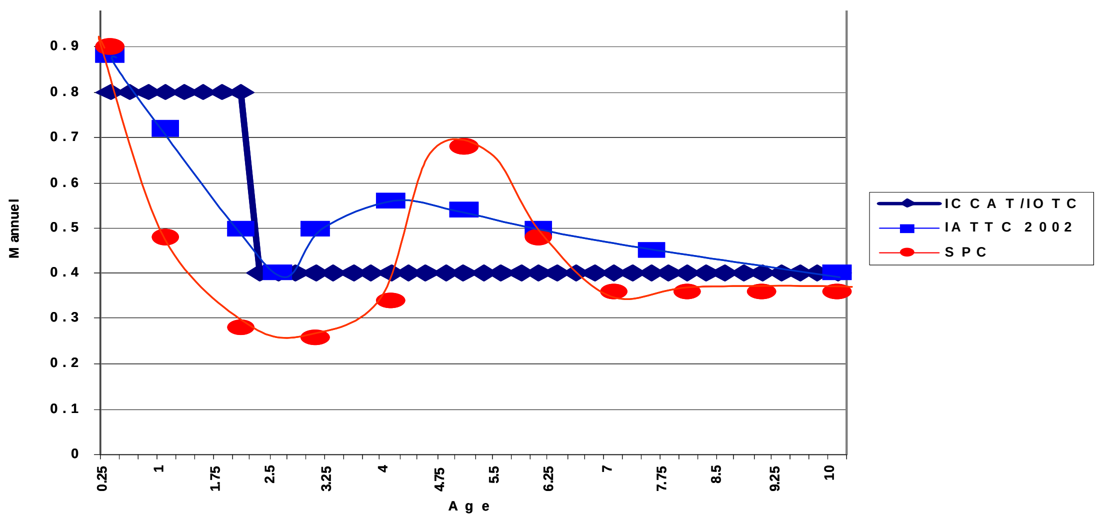



**Figure 29.** Yearly rates of natural mortality as a function of age used by the various tuna bodies in their assessment.

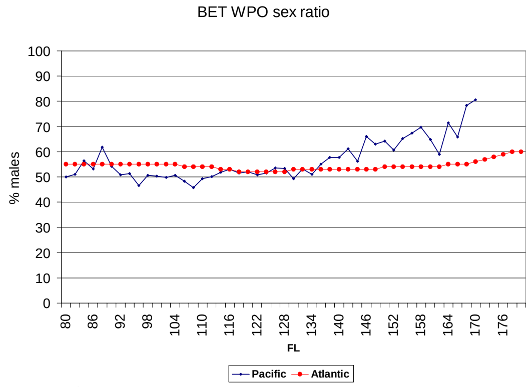



**Figure 30.** Sex ratio at size estimated for large bigeye tuna in the Japanese longline fisheries of the Atlantic and Pacific oceans (given as the percentage of males)(data taken from Miyabe 2002 for the Atlantic and obtain from SPC for the Pacific Ocean).

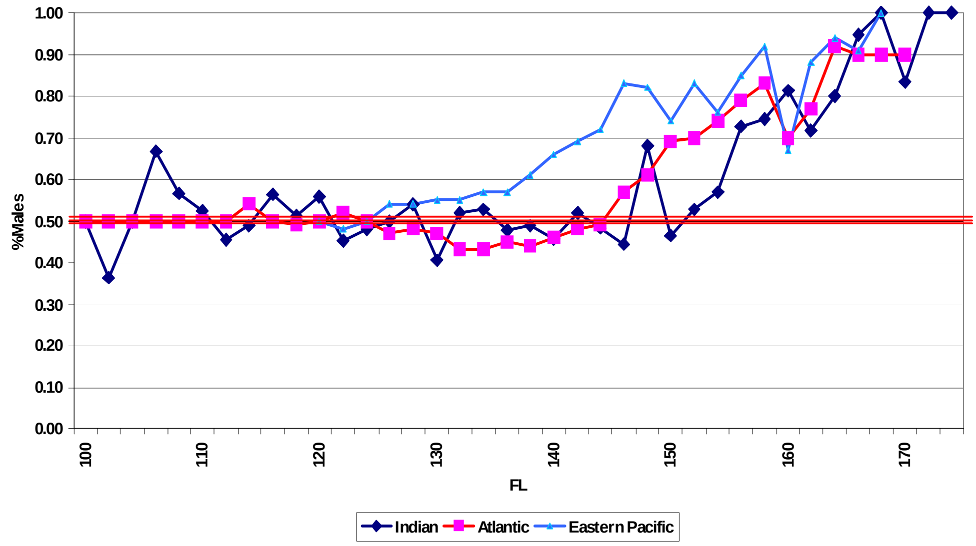



**Figure 31.** Sex ratio at size observed for adult yellowfin in various oceans (Taken from Fonteneau 2002).

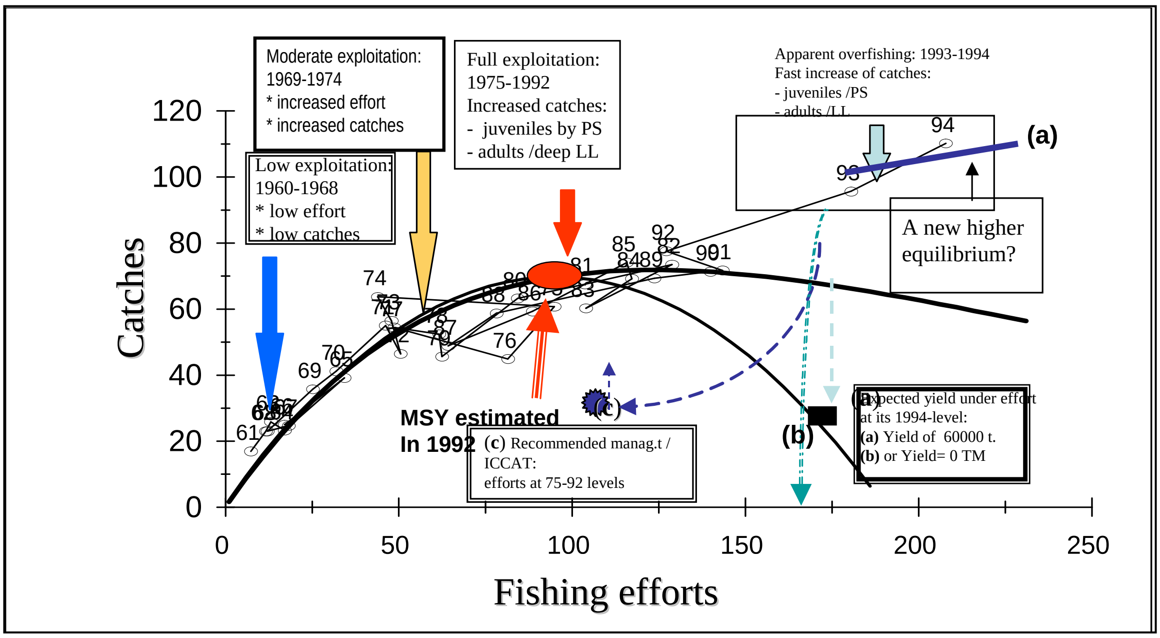



**Figure 32.** Overview figure prepared by scientists during the SRCS 1995 meeting (presented to the Commission meeting) and showing, based on a production model, the uncertain prospects of the Atlantic bigeye tuna stock, following the very fast increase of effort and catches since 1993. At this time, the (a) hypothesis of a « new higher equilibrium productivity » was then estimated to be the less realistic one, and most scientists thought that catches and CPUE would severely decline in the near future (hypothesis b or c).

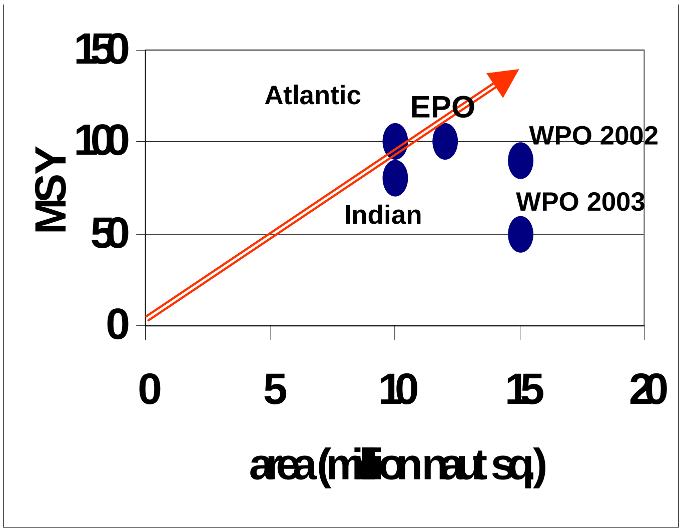



**Figure 33.** Sizes of the bigeye fished area in each ocean and estimated MSY in each of these areas.