TENTATIVE USE OF SEQUENTIAL POPULATION ANALYSIS TO ANALYSE THE STATUS OF INDIAN OCEAN BIGEYE STOCK

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SUMMARY

This document is trying to evaluate the present status of Indian Ocean bigeye stock using sequential population analysis. A first step was to estimate the catch at size of the two major gears catching bigeye tuna, namely longliners and purse seiners. The yearly catches at age are estimated using this catch at size table, assuming a growth curve identical to the growth estimated in the Western Pacific (as bigeye growth in the Indian Ocean is poorly known) and a simple slicing method. This catch at age is later analysed using the Murphy equation and hypothesis of natural mortality at age and of recruitments/terminal F. The results obtained are the trend in biomass and the fishing mortality by age of each of the two gears. This analysis indicates a fast increase of fishing mortality by each of the two gears during recent years. The present catches appear to be at levels which are probably much higher than the equilibrium productivity of the stock and which are not sustainable. Although these results are still highly provisional, because of multiple uncertainties in the data and method used, many of its results are probab ly realistic ones which can be useful to understand better the present status of the stock and its uncertainties.

INTRODUCTION

Bigeye tuna stock status in the Indian Ocean has never been thoroughly analysed by the IOTC scientific committee, for instance using production or analytical models, primarily because of the weakness of the available statistical and biological data concerning this stock. However, recent improvement in the IOTTC data base may allow now, despite of the same remaining pending uncertainties, to initiate some stock assessment analysis. The goal of this paper is to try to estimate the catch at size and catch at age of each gear, longline and purse seiners. Concerning bigeye, the positive factor is that these two gears are contributing to nearly all the catches (when other gears, often poorly followed, are catching large quantities of other species). The goal of this paper is to extrapolate the size data available yearly for each gear, purse seine and longline, to the total yearly catches of each fishery. This figure of total catches by size can be used to estimate the yearly catches at age of each gear (and the yearly total) based on an hypothetical growth assumed for the species. This catch at age table can then be analysed using SPA techniques, using two sets of additional hypothesis concerning (1) natural mortality as a function of age and (2) exploitation rates or/and recruitment. The first VPA done in this paper are tentative ones which could be improved by the IOTC working group (improving the estimates of the catch at size and catch at age tables, and the SPA hypothesis and method used.

ESTIMATING CATCH AT SIZE AND CATCH AT AGE TABLES

Yearly catches

The total yearly catches by gear used in this hypothesis are taken from the OTC data base available on the 15th of June 2001 (table 1). It can be noticed that a wide majority of bigeye catches are taken only by two gears, longliners and purse seiners, the catches by other gears being negligible (this characteristics will be a positive factor to handle data and to run the analysis).

Catch at size

The size distribution of the yearly catches of each gear have been estimated independently for each of the two gears.

Purse seiners

The size data available for purse seiners can be considered as quite good, as a systematic size sampling has been conducted on this fishery since its beginning, a great care being given to a good species identification of the species (using the Atlantic ICCAT sampling). The size data used have been obtained on a majority of the purse seine fleets which were active in the Indian Ocean since the beginning of the eighties. These size distribution are already widely extrapolated by scientists to nearly 100 % of the catches by each fleet. Then the available size data was simply extrapolated yearly by the ratio of the present weight of sampled fishes to the yearly total catch by purse seiners (independently of the season or of the area). All the available size distribution from Japanese purse seiners until 1990 were not used in this analysis because they appear to be questionable. The catch at size estimated for the two gears by this method are given in figure 1 b; the corresponding average sizes during recent years on figure 2 and the average yearly weight is shown on figure 3.

Longliners

The size data available on bigeye taken by longliners were obtained on the major longline fisheries: Japan, Taiwan and Korea and they were obtained from the IOTC data base. An analysis of this size data indicates that the validity of Taiwanese and Korean size data bases is still questionable.

Waiting for a validation of these two size data bases, only the longline Japanese sizes data were used and extrapolated to the total of bigeye catches by longliners. This raising was done using a stratification of the Indian Ocean in 4 sub areas: NE, SE, SW and NW, with a latitudinal limit at 20° south and an east west limit at 80°E. The goal of this geographical stratification was to take into account the spatial (and indirectly seasonal) heterogeneity of sizes taken by longliners. The Japanese size samples available yearly in each of these four sub areas were extrapolated in two successive steps: first to the total catches of each country as they were submitted to the IOTC by 5° and month, and (2) to the total catches by longliners independently of their flag (table 1). When size data were not available in the year and area strata, a strata substitution was done with the same area in adjacent years (see table 2). The catch at size estimated by this method are given in figure 1b ; the corresponding average sizes during recent years on figure 2 and the average yearly weight is shown on figure 3.

It is quite clear that this method may be questionable, but the statistical uncertainties in its results are impossible to estimate. However, it is quite clear that the size of bigeye taken by longliners have been quite stable in the range 80 cm to 160 cm from one year to another (the differences between areas being well taken into account by the method). Another pending question is the extrapolation of size taken on Japanese longliners to other fleets such as the Taiwanese and Korean fleets. Knowing that Japan was catching between only 10 and 20% of bigeye catch during recent years, often in specific proper fishing zones (figure 4), this extrapolation may introduce unknown bias in the estimate of the total sizes taken.

A major result which is probably a very strong one is the general pattern and levels of sizes taken by longliners and purse seiners during recent years (for instance the period 1990-1999). This result, shown by figures 1, 2 and 3 is that:

- Sizes of bigeye taken by purse seiners and longliners are quite independent and show very little overlap: purse seiners catching bigeye between 30 and 80 cm when longliners catch bigeye significantly only between 80 and 180 cm.

- Subsequently the average weight of PS catches is of 6.2 kg (fluctuating between 5.9 and 7.6 kg), when the long line average weight reach 46 kg .

- The size taken yearly by each gear during the entire period do show little variability and no clear trend; this stability is quite interesting to note, as it is seldom observed with such constancy of the size pattern of each gear and during such a long period.

- The increased number of large bigeye caught during recent years by Japanese longliners (see figure 1a) is probably a real and general tendency which is due to the very large value of these large bigeye on the sashimi market (as such fishes are often sold at prices per kilo which are 3 times larger than small bigeye, the longliners can easily have low level of cpues in numbers of fishes, but still make more money.

- Numbers of bigeye taken by purse seiners during recent years are higher than numbers taken by longliners: in a ratio of about 2 to 4 since 1994.

Catch at age

The catch at size table by gear can be transformed into catch at age tables when the growth pattern of the species is known or estimated. The best way to estimate catch at age would to do an age decomposition of the monthly or quarterly size distribution using an *ad hoc* statistical method, allowing to estimate the real proportion of each age at each size. However due to time constraint and to the weakness of the size data, a rought estimates of catch at age was obtained by a simple slicing of the yearly catch at size following a given growth curve. The first attempt to estimate the catch at age was done using the growth curve proposed by Stequert et al in 1999 for the Indian Ocean bigeye (see figure 5). However it appears that this growth curve and its L infinity of 304 cm, well above any observed size of bigeye, correspond to a very fast growth of the adult bigeye: following this growth, the duration of life between 90 cm, size at recruitment in the longline fishery, and 180 cm the largest sizes commonly caught by longliners, is a life duration of less than 4 years. Such short duration appears to be very unlikely for a species like bigeye based on the knowledge obtained in other oceans (SPC works and their tagging). An alternative growth model estimated to be more realistic was then used to estimate the catch at age. This model is the Von Bertalanffy growth given by Lehodey et al 1999 for the central and western Pacific bigeye combining results from tagging, hard part reading and fishery data. This model is the following:

L infinity= 166.3cm

k= 0.349

t_0= -0.389

Based on these growth parameters a slicing table of the yearly size distribution, given on table 3,was built and used to estimate the catch at age. The weight at age corresponding to this growth pattern are given in the same table 3 and the catch at age of longliners and purse seiners are shown on figure 6 .

SPA method and hypothesis used

The SPA used was simply a forward cohort analysis of the catch at age matrix (Murphy 1965) combining catches of longliners and of purse seiners.

Natural mortality assumed

A sensitive hypothesis in any SPA is the natural mortality as a function of age used in the model. Unfortunately this natural mortality remains unknown for the Indian Ocean bigeye (in the absence of tagging results) and unfortunately this fundamental parameter remains highly speculative in other oceans such as the Pacific and the Atlantic. It appears from all tagging results that M of juveniles, class 0 and 1, is higher, or much higher, than M of adults which appears to be quite low. This high level of juvenile M appears to be difficult to estimate and it has been highly variable from an analysis to the other, even for analysis done by the same team and when using the same data set (SPC yearly analysis). There is also a potential increase of M for the large adult bigeye or a differential M between males and females (An. IATTC 2001), but this higher M remains questionable. Based on SPC work, a longevity of at least 10 years of exploited life appears to be quite likely for bigeye.

In this context, the following vector of M at age has been used as the basic guess of the present SPAs:

Age	0	1	2	3	4	5	6	7	8	9+
M	1.2	.8	.4	.4	.4	.4	.4	.4	.4	.4

It is quite clear that this vector of M is be of prime importance in any SPA analysis. Alternate hypothesis of M at age should then be also tested to evaluate better the potential effects on the results of this critical major uncertainty.

Estimation of "minimal" recruitments

A first run of SPA was conducted using a backward solution of the SPAs assuming a high rate of fishing mortality at the oldest exploited age. Such run provides estimates of the minimal recruitment of each cohort which can "explain" the observed catches (assuming that the catch at age and natural mortality at age were correct). This vector of yearly "minimal" recruitment (figure 7) has nothing to do with the real biological recruitment, unless when the stock is heavily exploited. In such a case, each cohort would be exploited close to the convergency solutions of the ASP, and the estimated levels of recruitment tend to converge towards the real level of recruitment. This high exploitation rate appears to be quite realistic during recent years following the spectacular increase of adults and of juveniles by purse seiners and longliners. This high exploitation rate hypothesis will be kept later as being the more realistic one.

H70: SPA at constant recruitment of 70 million

None of the present SPA was done with an ad hoc tuning of cpue indices, due to the lack of available index for any of the fishery (purse seiners or longliners). It is estimated that the trends of published cpue is quite unrealistic and can hardly be used as an index of the adult biomass because of the jump of cpue in 1978. This large and suddeent increase of cpue cannot be explained by a corresponding increase of biomass, but more probably by unknown technological changes producing a more efficient targeting of bigeye tunas (it can be noticed that the bigeye prices in the sashimi market dramatically increased during the same period);

This first ASP was done in the hypothesis that the stock has never been heavily exploited and then correspondingly that recruitment was high and stable at a level of 70 million yearly during the period. This hypothesis of constant recruitment may appear to be quite strong and false for many fish stocks, but it may be a quite realistic one for bigeye tuna, a species showing in the Indian Ocean (and in the Atlantic) a remarkable stability of its catch rates and of its apparent biomass (the short term yearly variability of the adult cpue being probably due to fishery and environmental factors, not to a real variability of biomass) . The adult biomasses and corresponding fishing mortality of each gear obtained in this hypothesis are shown by figure 8 and 9. In this hypothesis, the average total fishing mortality was at moderate levels of less than 0.06 until 1992, and is showing a fast increase since 1993, reaching a plateau at 0.2 since 1996.

The corresponding adult biomass is showing a slow decline between 850,000 tons for the virgin stock and a present biomass of 500,000 t.

H50: SPA at recruitment of 50 & of 70 million for cohorts 1986-1990

This hypothesis of lower recruitment corresponds to a stock which would have been more heavily exploited during the entire period. The higher levels of recruitment for the years 1986 to 1990 are "necessary" as minimum recruitments explaining the large catches taken by longliners on these 5 cohorts. It should be noticed that these cohorts have not been significantly exploited by the purse seine fisheries, as they were still at age zero before the development of the FAD fisheries and of the subsequent increase of bigeye catches.

The adult biomasses and corresponding fishing mortality of each gear obtained in this hypothesis are shown by figure 8 and 9. The trends of fishing mortality on age 0 by purse seiners and on age 2 to 9 by longliners is given on figure 10. In this hypothesis, the average total fishing mortality was higher than in the previous hypothesis, but still at moderate levels of less than 0.10 until 1992; the average F is showing a fast increase since 1993, and steadily increasing since to reach a level of 0.3 in 1999. In terms of yield per recruit, this level of fishing mortality corresponds to a full exploitation. The corresponding adult biomass is showing a slow decline between 160 and 1988 (from 600,000 tons to 440,000), followed until 1993 by an increase of biomass due to the 5 large year classes assumed (reaching 600,000t in 1993), and a severe decline since 1993 reaching 300.000t in 1999 (e.g. half of the virgin biomass). The average age specific fishing mortality estimated during recent years (95-99) for each gear, purse seiners and longliners, is shown by figure 11. This figure indicate:

(1) that fishing mortality exerted by purse seiners are significant only at age 0 and
(2) that there is very little overlap in the age fished by the two gears (this was already an obvious result comparing catches at size taken by the two gears),
(3) that under the combination of hypothesis and methods used in the present analysis, the purse seine fishing mortality exerted by purse seiners at age zero appears to be lower than the levels estimated for longliners at older ages.

Relationship between total yearly catches and average fishing mortality

This relationship is always quite interesting to show because of its quite efficient power to synthesize the results of ASPs and the potential stock status. This relationship is shown by figure 11. This figure shows well the recent fast increase of catches in relationship with the recent increase of average fishing mortality. This typically a situation of non equilibrium of the stock and fisheries in which the observed catches tend to be higher, or much higher, than the equilibrium catches. This desequilibrium is easily shown running a production model on the catches and mortality data of hypothesis H50 (using a PRODFIT model with k=10 years and m=1.0) which is estimating the MSY at a level of 97,000t (well under recent levels of catches) and an optimal fishing mortality estimated to be at 0.21 (e.g. well under recent levels of F).

Discussion of results

It is quite obvious that the present analysis is only a very first and provisional step towards future comprehensive stock assessment of the Indian Ocean bigeye. This first analysis suffers of various major uncertainties because of various weaknesses concerning:

(1) the **statistical data** available, especially in the longline fisheries for which both the level of total catches and the size taken remain poorly known,

(2) the **stock structure** which is still unknown (the present assumption being a full mixing within a single Indian ocean stock)

(3) the **growth**: average pattern and variability (inter individual and as a function of sex) which are still unknown

(4) **natural mortality as a function of age**, a key parameter in stock assessment and interaction between fisheries, which is still unknown

(5) the **slicing method** used to estimate catches at age from catches at size is clearly not the best one.

(6) The **SPA method** used should be diversified using a wide range of alternate hypothesis in the data and parameters.

Despite of these various serious limitations, most of the present results may still be very significant and representative of the present stock status. This is for instance the case for the catch at size and catch at age tables of the two gears, longliners and purse seiners, which are speaking by themselves. The results of the ASP, even if they are still provisional and speculative, seem to be quite consistent with the advice provided by any good expert in stock assessment analysing the trends of catch at size: this advice could be summarized as following.

The bigeye stock has been suffering during recent years a fast increase of fishing mortality on both its juvenile (purse seiners) and on its adults (by longliners) fraction of stock. It is difficult to conclude that the stock is overfished (because it is difficult to evaluate if the present fishing effort are below or above the optimal effort which icorresponds to the MSY), but there is a high probability that the present high catches of bigeye are not sustainable, and that present fisheries are probably operating well above the MSY level. This potentially dangerous disequilibrium is due to the too fast increase of fishing mortality.

The management advice in such a situation would be that it is necessary in the context of the precautionary approach, to reduce the risk of stock collapse with a strict limitation of fishing mortality of bigeye at its present level. A significant reduction of effort could also be reasonably envisaged, as the present level of fishing mortality may already be overfishing the stock. This limitation of fishing mortality should target both the purse seine fishery and the long line fishery, because the fishing mortality of the two gears have shown a similar dramatic increase. The negative impact of purse seine fisheries on the adult stock is likely, but is highly dependent of the natural mortality at age zero. If this natural mortality is high, the purse seine fishery would have very little impact on the stock size and on the yield per recruit of the fishery, if this M is moderate, the large catches of juvenile bigeye by purse seiners may be in the long term very negative for the yield per recruit of the bigeye fishery and may be for the conservation of the stock. In fact, bigeye stock may be facing a situation similar to the situation faced by southern bluefin tuna in the eighties, where a large purse seine fishery targeting juvenile was developed on a stock which was already fully exploited by longliners.

CITED LITERATURE

AN IATTC 2001. Status of bigeye tuna in the Eastern Pacific ocean. Document A4 submitted to the IATTC scientific working group, La Jolla, May 2001.76p.

LEHODEY P., J. HAMPTON AND B. LEROY, 1999. Preliminary results on age and growth of bigeye tuna (*Thunnus obesus*) from the western and central Pacific Ocean as indicated by daily growth increments and tagging data. Standing committee on tuna and billfishes, Tahiti, June 1999.

MURPHY G.I. 1965. A solution of the catch equation. J. Fish. Res. Bd Can.,17:33-40

STEQUERT B. AND F. CONAND. 2000. preliminary studies of age and growth of bigeye tuna (*Thunnus obesus*) in the Western Indian Ocean. IOTC document submitted to the Working group on tropical species, Victoria, September 2000.

ACKNOWLEDGEMENT

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	LL	PS	other	Total
1950	0	0	0	0
1951	0	0	0	0
1952	702	0	0	702
1953	1778	0	0	1778
1954	4627	0	0	4627
1955	5860	0	0	5860
1956	9482	0	0	9482
1957	7271	0	0	7271
1958	6407	0	0	6407
1959	5706	0	0	5706
1960	9754	0	0	9754
1961	9146	0	0	9146
1962	14169	0	0	14169
1963	9064	0	0	9064
1964	14000	0	0	14000
1965	15600	0	0	15600
1966	17527	0	0	17527
1967	23310	0	0	23310
1968	34551	0	0	34551
1969	27757	0	0	27757
1970	24832	0	81	24913
1971	20381	0	51	20432
1972	18759	0	58	18817
1973	15667	0	130	15797
1974	26163	0	124	26287
1975	35654	0	100	35754
1976	27297	0	142	27439
1977	33785	0	160	33945
1978	48146	5	119	48270
1979	32793	1	132	32926
1980	33704	20	105	33829
1981	34276	11	230	34517
1982	43019	115	105	43239
1983	47293	586	194	48073
1984	36493	4017	378	40888
1985	41685	7145	335	49165
1986	45194	10620	529	56343
1987	49149	13396	472	63017
1988	54428	15053	2280	71761
1989	49412	11975	910	62297
1990	54775	12643	590	68008
1991	51841	15567	648	68056
1992	52662	11197	465	64324
1993	76051	15863	559	92473
1994	75943	18795	702	95440
1995	85273	28438	1764	115475
1996	97443	24493	998	122934
1997	96941	33758	994	131693
1998	110590	27329	1115	139034
1999	104389	38253	781	143423

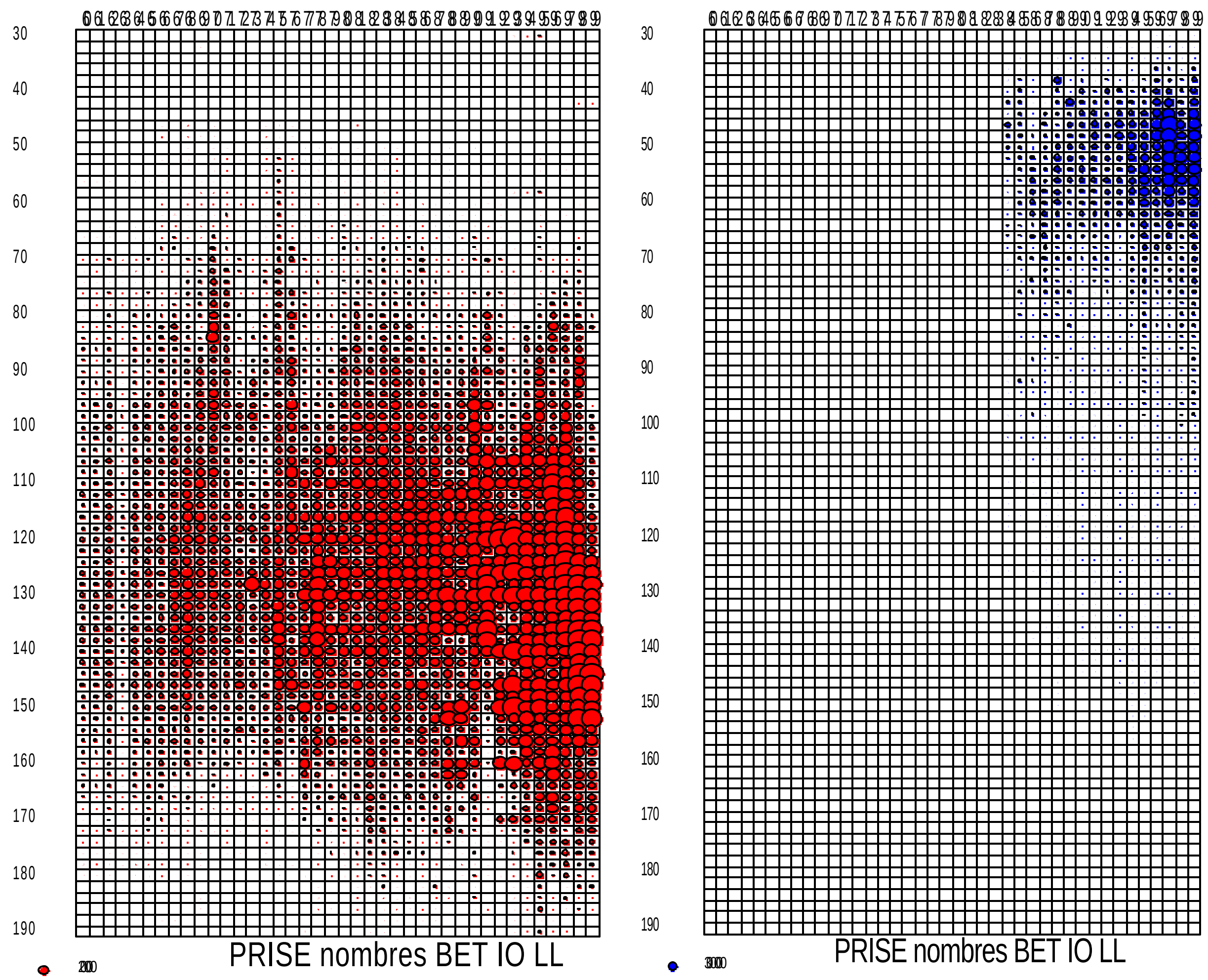
Figure 1;: Total yearly catches of bigeye by gear used in theAnalysis (IOTC data, June 2001)

Year fished	Area fished	Year sampled	Area sampled
1960	**1**	**1965**	**1**
1960	**2**	**1965**	**2**
1960	**3**	**1965**	**3**
1960	**4**	**1965**	**4**
1961	**1**	**1965**	**1**
1961	**2**	**1965**	**2**
1961	**3**	**1965**	**3**
1961	**4**	**1965**	**4**
1962	**1**	**1965**	**1**
1962	**2**	**1965**	**2**
1962	**3**	**1965**	**3**
1962	**4**	**1965**	**4**
1963	**1**	**1965**	**1**
1963	**2**	**1965**	**2**
1963	**3**	**1965**	**3**
1963	**4**	**1965**	**4**
1964	**1**	**1965**	**1**
1964	**2**	**1965**	**2**
1964	**3**	**1965**	**3**
1964	**4**	**1965**	**4**
1967	**3**	**1966**	**3**
1969	**3**	**1968**	**3**
1970	**3**	**1968**	**3**
1971	**3**	**1970**	**3**
1973	**4**	**1972**	**4**
1975	**2**	**1974**	**2**
1980	**2**	**1979**	**2**
1981	**2**	**1979**	**2**
1984	**2**	**1983**	**2**
1985	**2**	**1983**	**2**
1986	**2**	**1983**	**2**
1990	**2**	**1989**	**2**
1993	**4**	**1992**	**4**
1994	**2**	**1993**	**2**
1995	**2**	**1994**	**2**
1997	**2**	**1996**	**2**
1999	**1**	**1998**	**1**
1999	**2**	**1998**	**2**
1999	**3**	**1998**	**3**
1999	**4**	**1998**	**4**

Figure 2: table of strata substitutions used for the unsampled areas in the longline fishery in the extrapolation of size data

Age	Upper limit	Lower limit	Average weight
0	30	64	2
1	66	94	9
2	96	114	22
3	116	130	38
4	132	140	52
5	142	148	62
6	150	154	73
7	156	160	80
8	162	166	100
9+	168	200	120

Figure 3: table of the size limits between ages used to slice the size distribution and to buyild the estimated matrix of catches at age



Longline Purse seine

Figure 1: Total catches at size estimated for purse seine and longline fleets between 1960 & 1999

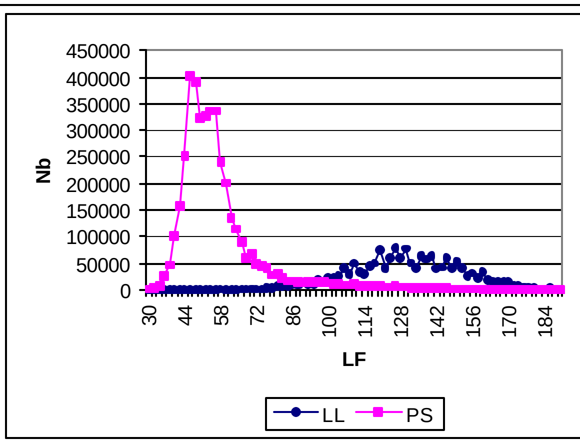


Figure 2: Total catches at size of Indian Ocean bigeye, average period 1990-1999, estimated for purse seiners and for longliners

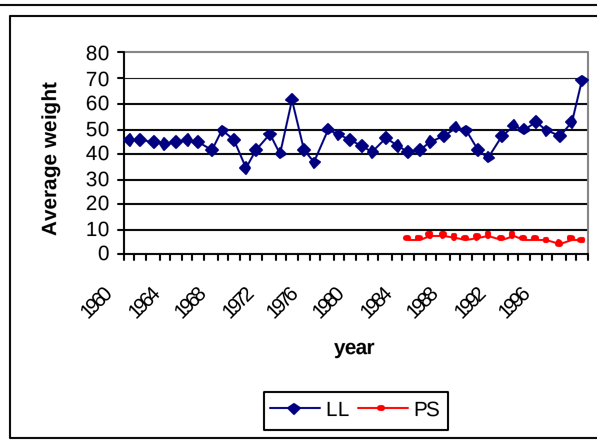


Figure 3: Average weight of bigeye tunas taken in the Indian Ocean by purse seiners and longliners

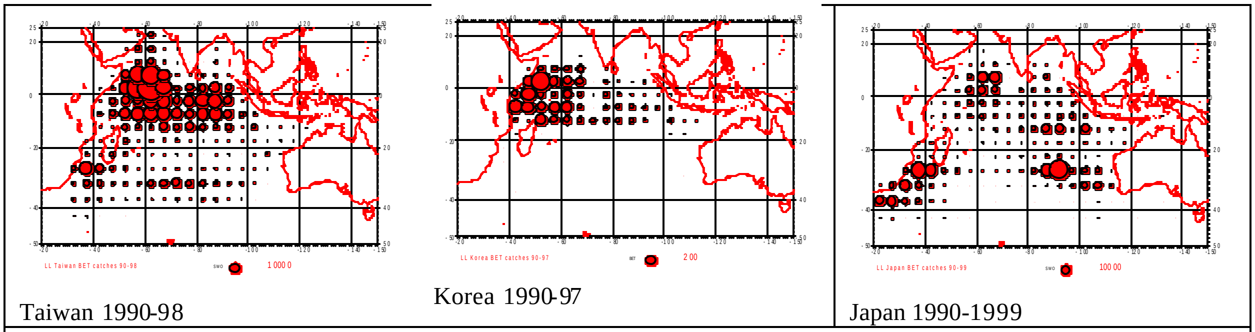


Figure 4: Average fishing maps of bigeye by Japanese, Taiwanese and Korean longliners (this figure indicates that the fishing zones of the 3 countries tend to be quite different)

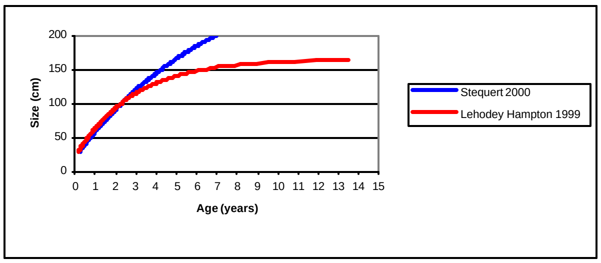


Figure 5 : Comparison of the bigeye growth curves proposed by Stequert et al 1999 for the Indian ocean bigeye (using otoliths) and for the central and western Pacific bigeye by Lehodey et al 1999 (using otoliths and tagging results)

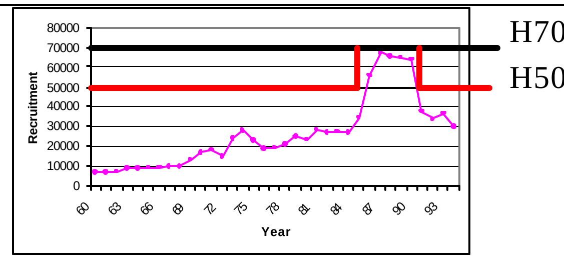


Figure 7: Minimal recruitment of Indian Ocean bigeye (under an hypothesis of M at age of 1.2 for age 0,m=0.8 for age 1, and M=.4 betwen age 2 and 9+); this minimal level was estimated in the hypothesis that each cohort was fully exploited during its life (high terminal F). H70 and H50 describe the 2 hypothetical recruitment vectors used in the SPA

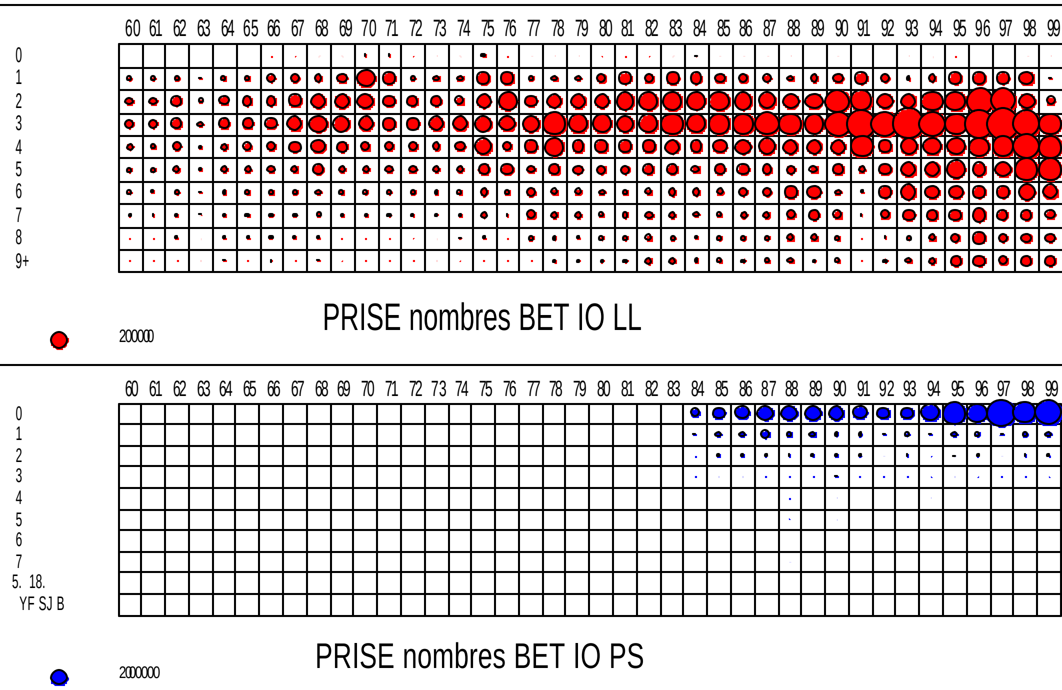


Figure 6: Total catches at age estimated for purse seine and longline fleets between 1960 & 1999 in the hypothesis of Ledodey & al growth curve (& using slicing)(the scale of the 2 figures is different)

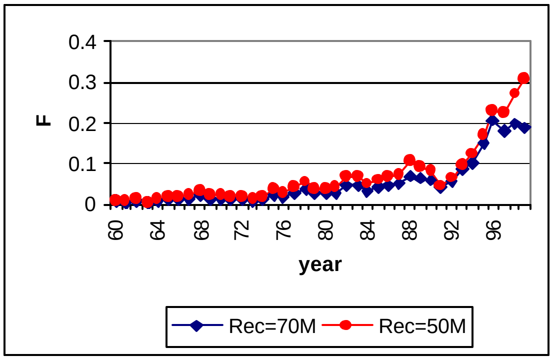


Figure 8: Average fishing mortality (age 0 to 9+) estimated For bigeye in the two hypothesis H70 and H50 concerning the levels of recruitment

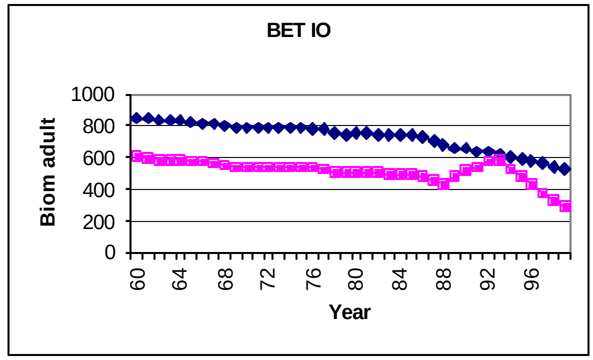


Figure 9: Spawning biomass (age 3 to 9+) estimated For bigeye in the two hypothesis H70 and H50 concerning the levels of recruitment

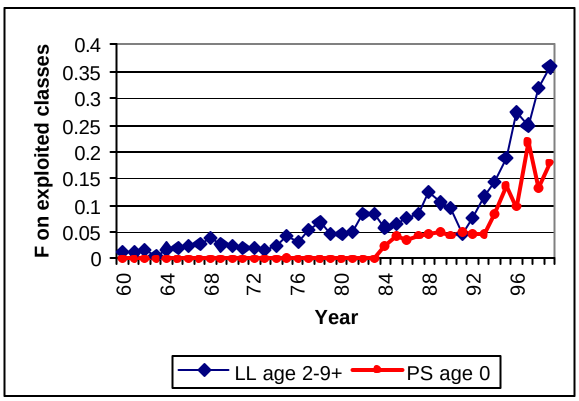


Figure 10: Levels of average fishing mortality estimated for purrse seiners (age 0) and for longliners (age 2 to 9) in the H50 hypothesis

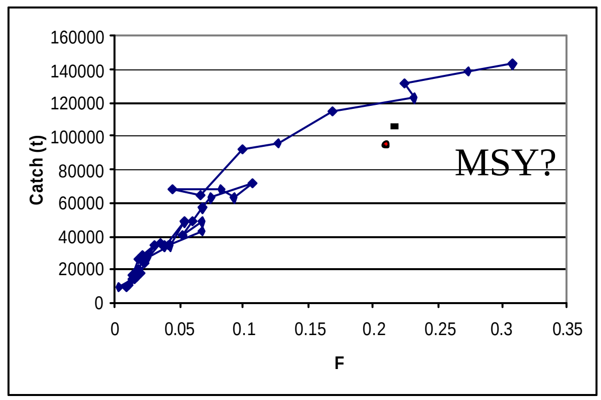


Figure 11: Apparent relationship between the total yearly catches of bigeye and the average fishing mortality (age 0 to 9) Estimated under the H50 hypothesis)