PRELIMINARY YIELD PER RECRUIT ANALYSIS OF THE INDIAN OCEAN YELLOWFIN AND BIGEYE FISHERIES.

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RESUME

Ce document presente des estimations de F par age et par engin sur l'albacore et le patudo par les diverses pecheries thonieres de l'Ocean Indien et tente d'analyser l'interaction theor ique, en termes de production par recrue, entre engins de surface et palangre sur le stock d'albacore au moyen de simulations. Cette premiere etude menee dans l'Ocean Indien est basee sur un certain nombre d'hypotheses faites lors d'etudes similaires des stocks de thons de l'Atlantique. A partir des donnees palangrieres asiatiques (Japon, Coree, Taiwan), des donnees sur la peche artisanale (Maldives, Sri Lanka) et de celles des senneurs (France, Espagne, Cote d'Ivoire), des analyses de cohortes et des calculs de production par recrue (modele de RICKER multi-engins) sont realisees. Il apparait que la peche artisanale, axee sur les petits individus, provoque un effet tres defavorable sur la production par recrue de l'albacore, alors que la peche a la senne, beaucoup moins selective, peut accroitre rapidement la production par recrue en augmentant la mortalite par peche. Cet accroissement de production par recrue n'est observe que pour des niveaux moderes de mortalite par peche palangrieres. Les simulations sur les pecheries d'albacore tendraient a montrer que pour un niveau de recrutement eleve, l'accroissement des prises des senneurs ait un effet negatif modere sur les prises palangriere et nul sur les pecheries artisanales. Le patudo montre peu de changement de sa production par recrue lors de l'introduction de la peche a la senne. Il semblerait que l'effort de peche des palangriers puisse se traduire par une elevation de la production de patudo, a condition que la capturabilite reste constante. Ces conclusions sont toutefois discutees a la lumiere des hypotheses de base.

SUMMARY

This document presents estimates of age specific F by gear on the yellowfin and bigeye tuna fisheries of the Indian Ocean and try to simulate the theoretical interactions in terms of yield per recruit between surface and longline gears fishing on yellowfin stock. As the first study of this kind in the Indian Ocean, it is based on several assumptions made on similar studies on the tuna stocks of the Atlantic Ocean. By using Asian longline data (Japan, Korea, Taiwan), artisanal fishery data (Maldives, Sri Lanka) and purse seine data (France, Spain, Ivory Coast), cohort analysis yield per recruit analysis according to the RICKER multigear model are performed. Artisanal fisheries as they are catching mainly small fish, induce very unfavorable values of yellowfin yield per recruit. On the other hand, purse seining, a less selective purse seining method, can enlarge the yield per recruit by increasing the fishing mortality on a wide range of fish lengths. This increase of the yield per recruit is noted when longline mortality remains at moderate levels. Interactions between yellowfin fisheries tend to prove, for a high recruitment level, that increasing purse seine catches would generate a moderate negative effect on the longline catches and no effect on the artisanal catches. For bigeye, very little change in its yield per recruit was noted when purse seining is introduced. It would seem that an increase of the longline fishing effort would generate a larger bigeye production, if the catchability coefficient remains constant. However all these conclusions are discussed in regard with the initial assumptions.

1. INTRODUCTION

Before 1983, only the smaller and the larger yellowfin of the Indian Ocean were exploited by artisanal and longline fisheries. The artisanal fisheries of Maldives and Sri Lanka are mainly catching juvenile yellowfin : on average between 0.5 and 7.0 kg with some fish up to 20kg.

The longline fisheries of Japan, Taiwan and Korea operating in the Indian Ocean are mainly catching adult yellowfin over 20 kg. With the introduction of the purse seine fishery in 1983, other middle year classes started to be exploited on a large scale. Yellowfin caught with this gear have fork lengths between 35 and 160cm but most of the fish are below 140cm. Today all yellowfin year classes between half year and seven years and over are more or less exploited.

Regarding bigeye tuna, adults are highly exploited by longline and juveniles represent a small proportion of the purse seine catches. They also seem present among yellowfin caught by the artisanal fishery but this has not yet been assessed.

Therefore stock assessment, interactions between fisheries, migration patterns, etc... are becoming a priority in Indian Ocean tuna research. So, all available catch, effort and size frequency data for these two species were gathered in order to conduct some preliminary cohort analysis, which give estimates of age specific F by gear. Of course, several key parameters on the biology of the Indian Ocean yellowfin and bigeye are not yet known, they will be set to values found in the Atlantic Ocean. The analysis is conducted for the 1962 to 1985 period.

The production models which are commonly used to assess the status of yellowfin stocks in other oceans cannot be employed in the Indian Ocean because of a lack of reliable abundance index. The only longtime series cpue available are from the longline fishery which are considered as a biased measure of the overall abundance of the total stock. Production models can however be used for bigeye with longline cpue (FAO, 1980) which have to be adjusted for deep longlining introduced in recent years.

The present work is limited to the analytical stock assessment and some theoretical interactions on yellowfin between surface and longline fisheries are analysed.

2. SOURCES OF DATA

2.1 Catch statistics

2.1.1 Artisanal fishery

Only the statistics from the pole and line and trolling fisheries of Maldives were received from IPTP with the agreement of the Ministry of Fisheries of the Republic of Maldives. These statistics cover the period 1970 to 1982 on a monhly basis and the species concerned are skipjack and yellowfin, in number of fish. No detailed statistics were obtained for Sri Lanka tuna fishery. Bigeye, although present in the artisanal tuna catches, are probably misreported with yellowfin catches as the juveniles of these two species are very similar.

2.1.2 Purse seine fishery

French and Ivorian catch and effort statistics are from the ORSTOM data base (1982-1985). The 1984 and 1985 Spanish data were respectively obtained from the Instituto Espanol de Oceanografia of Santander and the Seychelles Fishing Authority Tuna Fishery Bulletin, First quarter 1986. These statistics cover the purse seine fishery since its beginning in the Indian Ocean. No data was provided for the Mauritian purse seiner operating in the area since 1979.

2.1.3 Longline fishery

Longline data (catch in number of fish) were gathered from the IPTP tuna data base for:

- Japanese tuna catch statistics from 1962-1980 on a monthly basis;
- Taiwanese tuna catch statistics from 1967-1977 on a monthly basis;
- Taiwanese tuna catch statistics from 1978-1982 on a quarterly basis;
- Korean tuna catch statistics from 1975-1980 on a monthly basis;

Japanese tuna catch statistics from 1981 to 1984 on a monthly basis, were provided by the Far Seas Fisheries Research Laboratory of Shimizu, Japan.

2.2 Size frequency distributions

2.2.1 Artisanal fishery

Size frequencies for yellowfin were given by IPTP for the pole and line fishery of Maldives for 1983 and 1984:

- in 1983, measurements are based on 44 samples with a total of 1935 yellowfin measured during the months of January, February, June, July, August and September.
- in 1984, measurements are from 19 samples with a total of 1151 yellowfin measured during the months of January, February and April through August.

2.2.2 Purse seine fishery

Yellowfin and bigeye size frequencies are available from 1983 to 1985 for the French purse seiners. During this period, 32510 yellowfin and 2443 bigeye were measured. All fishing trips were sampled When the vessels called in Victoria Harbour.

2.2.3 Longline fishery

A rough estimate of the yellowfin and bigeye size frequency distributions for all the different longline fisheries is the Japan 1982 size frequencies used by MIYABE and KOIDO (1985). This typical longline size distribution is assumed as constant during the complete history of the longline fisheries (all countries).

3. DATA STANDARDIZATION AND SUBSTITUTION

3.1 Catch statistics

3.1.1 Artisanal fishery

Sri Lanka tuna catch statistics were recorded from the IPTP Data Summary No 3 (1985) and No 5 (1986).

The 1983 and 1984 Maldives yellowfin catch is respectively taken from the IPTP Data Summary No 5 (op. cit) and ANDERSON (1985). When catches on a quarterly basis were not available the year catches were equally distributed in each quarter. Despite the fact that Maldivian tuna pole and line fishery is a traditional fishing method for centuries, catch statistics missing for 1962 to 1969 were not subsituted. In this analysis, artisanal fishery from Maldives was considered as having started in 1970. The same remark concerned also the Sri Lanka artisanal fishery.

3.1.2 Purse seine fishery

No standardization or substitution were performed as all necessary data are available.

3.1.3 Longline fishery

The detailed Taiwanese longline catches for 1962 to 1966 and Korean longline catches for 1966 to 1974 were taken from the literature (IPTP, 1986). Thence, the yearly yellowfin catches for these two countries were distributed on a quarterly basis according to the Japanese quarterly catches for the corresponding periods.

3.2 Size frequency distributions

3.2.1 Artisanal fishery

All missing size frequency distributions on a quarterly basis were substituted by using the quarterly size distributions of 1982 and 1983 obtained from Maldives.

3.2.2 Purse seine fishery

Data from French and Ivorian purse seiners were used to estimate the Spanish catch size distribution.

3.2.3 Longline fishery

The 1982 yellowfin and bigeye size frequency distribution of MIYABE and KOIDO (op. cit.) were substituted for all quarters.from 1962 to 1985. This hypothesis of a stable size distribution for longline catches is not satisfactory. Real size data should be preferred; however, longline catches show in general a stability of their sizes greater than all other fisheries.

4. ANALYSIS OF DATA

4.1 Catch distribution by age

4.1.1 Yellowfin (fig.1)

Yellowfin catches are distributed in six year classes called age group from 0 to 5 according to FONTENEAU length-age relationship (1980). The growth based on intensive tagging and on model progressions assumes a slow growth rate for juveniles up to 70 cm and a Von Bertalanffy growth model up to larger sizes. MARSAC and LABLACHE (1985) have found this same growth pattern in the Western Indian Ocean. The artisanal fisheries are catching fish of age groups 0 and 1 (0 to 2 years old). Most of the yellowfin caught by purse seiners are young fish (age group 0 and 1), however the total number of fish of these age groups remain much smaller than for the artisanal fishery. When compared with longline catch, significant amounts of larger fish, from age group 2 to 4, are present in the purse seine yellowfin catch. Longline and purse seine are consequently exploiting in common the same range of ages, i.e. yellowfin older than 3 years.

The trend of the artisanal fishery between 1970 and 1985 is characterized by an important increase of catches on age group 0 fish and a slower increase of age group 1 fish. No particular trend in the number of fish caught by the longline fishery is noted apart from a slight decrease of the number of age group 3 yellowfin from 1962 to 1985. It is remarkable that in 1985 the purse seiners are already catching more yellowfin of age group 4 and 5 than longliners. The validity of those observations depends on the very limited size distribution available for longline fisheries.

4.1.2 Bigeye (fig. 2)

Bigeye catches are distributed in eight year classes (age group 0 to 7) according to CAYRE et DIOUF growth curve (1984).

The sizes of bigeye captured by surface (purse seine) and longline fisheries are very different. There is no real overlap of the fractions of population exploited by each gear as for yellowfin. The purse seiners exploit the 3 first age groups, up to 3 years, while longliners start to catch bigeye, at a significant level, from age group 3 (fish older than 3 years). The maximum catch is achieved at age group 0 for purse seine fishery, and at age group 4 for longline fishery. The bigeye number of age group 0 caught by purse seiners is increasing rapidly, as well as age group 1 and 2.

The trend of the longline catch shows two levels of magnitude : a lower level before 1976-77 when the regular longline was performing, and a higher one from 1977-78 when the deep longline/has greatly increased the level of catch on all age groups. This greater efficiency of the deep longline has been tested and statistically demonstrated over the most productive fishing grounds for bigeye in the Indian Ocean (KOIDO, 1985) and in the Western and Central Pacific Ocean (SUZUKI et al, 1977).

/was introduced throughout the ocean. The introduction of the deep longline

4.2 Cohort analysis

We have used the PELLA and TOMLINSON (1969) method modified by FONTENEAU (1981) : instead of starting by an estimate of the initial or the final fishing mortality coefficient F, a direct calculation is made from an estimation of the initial recruitment of the cohort.

The data have been analysed on the following assumptions:

- constant recruitment for all cohorts,
- yellowfin and bigeye exploited in the Indian Ocean belong to single stocks,
- the length composition by species captured by the longliners does not differ between Japan, Korean, and Taiwanese catches.
- the length composition of fish captured by the Spanish fleet is the same as for the French and Ivorian fleets.
- the level of longline and artisanal catches are considered in 1985 as equal as in 1984.
- the natural mortality coefficient (M) of yellowfin is 0.8 during the 2 first years, then 0.6 (annual basis), for bigeye, it is set at 0.8 during the 2 first years, then 0.4. These are the values commonly used in the Atlantic Ocean. The high M used during the two first years of life is based on the hypothesis that M is much more higher at small sizes and is the same for the two species.
- the length-age and length-weight relationships are based on growth curves by FONTENEAU (1980) for yellowfin and by CAYRE et DIOUF (1984) for bigeye. These curves are based mainly on tagging results.

For yellowfin, different values of initial recruitment (R) have been tested, ranging from 40 to 100 millions, by 10 million step. The analysis made with R = 40.10^6 did not lead to a solution, because this recruitment is too low to explain the observed catches and the M hypothesis.

For bigeye, seven values of initial R have been introduced into the analysis : 35, 30, 27.5, 25, 22.5, 20 and 17.5 millions. They all provided a solution. Under those recruitment hypothesis, the high values of recruitments correspond to low exploitation rates; on the other hand, the low recruitment correspond to higher exploitation rates. The low exploitation rate of the stocks remains undefined as the available cpue data or the lack of tagging data do not allow the calibration of the cohort analysis.

4.2.1 Fishing mortalities

a) Yellowfin (fig. 3)

Estimates of fishing mortalities are given for an initial recruitment level of R = 100.10^6 . (corresponding to a moderate exploitation rate). This estimate of recruitment is quite arbitrary. Its level is 40% higher than the average recruitment accepted in the Atlantic Ocean (which seems to have a lower yellowfin MSY than the one of the Indian Ocean; FRANCIS, comm. pers). However, due to the convergency properties of cohort analysis on long living species, the general shape of the gear specific F is quite independent of the exact value of recruitment.

Two periods are considered :

- 1975-79 : longline and artisanal fisheries are performing at rather stable levels;

- 1983-85 : introduction and drastic increase of the purse seiner activities; the longline is stable; the artisanal fishery is increasing its catches by 57% when compared with the previous period.

According to the higher level of catches during the recent years, age specific F for the artisanal fishery increases from 1975-79 to 1983-85. This mortality is exerted on fish aged up to 1.5 year, with a maximum during the first year. The fishing mortality by longliners is concerning the ages 3 to 5. It increases during the recent period. The purse seine shows a wide range of exploited age classes. The F is slightly higher for fish older than 3. This latter F curve would suggest a well-balanced exploitation of the population by this gear.

b) Bigeye (fig. 4)

Quarterly estimates of F are given for 1965, 1975 and 1985 and for a recruitment of 35.10^6. This recruitment level is approximately set at the same level as in the Atlantic Ocean. The 1965 and 1975 curves follow the same trend; first, an increase of F from 2 to 4 year old fish, then seasonal variations due to lower catches during the third quarters. From 1965 to 1975 the increase of catch (19600 to 38700MT) and the increase of effort (83.10^6 to 208.10^6 hooks) result in higher fishing mortality coefficient ($2.75.10^{-2}$ to $5.52.10^{-2}$). In 1965 and 1975 bigeye is essentially captured by the regular longline.

In 1985, the purse seine is exploiting young fish (less than 2 years). The resultant trend of F is obviously different from the two previous situations, since the overall size composition of the catch is greatly changed. A seasonal cycle is still present, but the lower F are now displayed during the second quarters. No catch of bigeye by artisanal fishery has been reported in statistics. The catchability "q" is the ratio F against the effective effort; the latter is the nominal effort adjusted for deep longline and standardised by HONMA method (1974).

The catchability decreased continuously from 1962 to 1974 (fig. 5). Then an increase occured from 1975 on (before the extension of the deep longline gear in all longline fisheries) with a maximum reached in 1977-78 when deep longline was becoming the main gear. However the catchability, then, started again to decrease. It is likely that greater depths should be exploited in order obtain another significant increase of "q" on bigeye tuna.

4.2.2 Recruitment to the adult fishery

a) Yellowfin (fig. 6)

It appears that the numbers of fish aged 3, i.e. starting to be vulnerable to the longline, has decreased moderately since 1962. It can be noted that after the first decrease (1972-73), which may be attributed to the significant catches of the artisanal fishery, the recruitment rapidly stabilises at a new equilibrium level However, the rapid and recent increase of purse seine effort induces a disequilibrium of the present fisheries since the effect of purse seine on reducing the adult recruitment (by the juvenile removal) have not yet been observed.

b) Bigeye

The number of bigeye entering the longline fishery is stable (between 12 and 13% of the initial recruitment). This recruitment could be affected by 1988 when the cohorts exploited by the surface fishery in 1985 (more than 4000t) (cf fig. 2) are available to the longline fishery.

4.3 Yield per recruit

A yield per recruit (Y/R) analysis using the Ricker model (RICKER, 1975), has been carried out for different years, based on the F vectors calculated by cohort analysis under M and growth hypothesis.

For yellowfin three specific exploitation patterns have been analyzed; they correspond to the years 1965, 1975 and 1985.

- 1965 : the longline fishery alone
- 1975 : longline and artisanal surface fisheries
- 1985 : development of an active purse seine fishery.

For bigeye, the analysis has been done for the years 1965 and 1975 (only longline) and 1985 (longline and purse seine). The Y/R is multiplied by the recruitment to give a level of yield relevant to the order of magnitude of the catch.

4.3.1 Yellowfin

Three levels of initial recruitment were selected (60, 80 and 100.10^{6}) which correspond respectively to high or low exploitation rates. Corresponding yield isopleths are shown in figure 7. When longline was the only gear in operation, increasing fishing could have theoretically provided a direct increase of the Y/R (3 times when F is multiplied by 4). In 1975, with two fisheries in operation, the Y/R have not changed much except for F multiplier greater than 4 and age at first catch under one year. In 1985, with the actual size of fish entering the surface fishery, the Y/R would increase for higher values of F multiplier, but a maximum would be reached and then Y/R would decrease if F multiplier is still increased. The ranges of F values providing the highest yield for each assumption on R are presented in Table 1.

Table 1. Maximum yield (in metric tons) and corresponding multiplier values for yellowfin, in 1985

R	Range of F. Multiplier	Maximum Yield
60.10^6	1.0 - 1.4	~ 100 000
80.10^6	1.8 - 2.5	115 - 125 000
100.10^6	2.5 - 3.5	135 - 155 000

In 1985, the yellowfin catch was about 100 000 MT which is in the order of the maximum obtained with the lower level of recruitment (high exploitation rate).

The theoretical potential gain of the yield when increasing the age at first capture (Tc) from 0.5 to 1.5 year is presented in Table 2. This gain is zero in 1965 (as longline recruitment occurs on fish older than 3 years), negative in 1975 (because it limits the catch of the artisanal fishery) and positive in 1985 (due to higher levels of catch by purse seine on middle age groups). The higher the F (inversely proportional to the recruitment), the higher the gain. It is not yet possible to assess the real exploitation rate of the stock and the possible corresponding changes of Y/R linked with different age at first capture.

Table 2. Potential gain (in %) of Y/R in yellowfin when increasing the age at first capture from 0.5 to 1.5 year with F = 1.

R	1965	1975	1985
60.10^6	0	- 9.4	+ 26.4
80.10^6	0	- 14.7	+ 9.0
100.10^6	0	- 17.6	+ 0.7

Studies of the theoretical competition for Y/R between years has been attempted.

A first multigear interaction analysis was done for two levels of recruitment (60 and 100.10^6) during two periods, 1975-79 and 1983-85. Several runs took into account the artisanal fishery versus the longline, and the purse seine fishery versus the longline. The results are presented in fig 8.

a) Artisanal versus longline (fig. 8 a, b, c, d)

For the same recruitment, no major changes between 1975-79 and 1983-85 diagrams are noted. An increase of the artisanal fishing effort when keeping the actual level of longline activity would provide a marginal gain of Y/R. On the other hand, increasing the longline F would produce a direct increase of Y/R. In other words good Y/R cannot be achieved by the artisanal fishery.

b) Purse seine versus longline (fig. 8 e, f)

The increase of the Y/R when increasing the purse seine F is rather rapid for a level of longline F multiplier lower than 1.5. Again, it appears that the longline would provide a good Y/R but, in fact, this has not been the case : between the two periods, the effective longline effort has increased by 93% while F increased by 44%. This shows clearly the decreasing of the longline catchability coefficient on yellowfin along the past years. Longline gear is not an efficient fishing gear for yellowfin tuna. The same observation has been made on a world wide basis for yellowfin. The reasons of this longline catchability changes are probably linked with the deep yellowfin stock structure.

4.3.2 Bigeye

The yield estimates are obtained with F calculated under the 35 millions recruitment hypothesis. Between 1965 and 1975, higher longline fishing efforts have provided higher Y/R (fig. 9). The effective effort was multiplied by 2.5 and the Y/R obtained in 1975 with F = 1 and Tc = 3 years is very close to the one estimated in 1965 with F = 2 and Tc = 3 years.

In 1985, even with a lower age at first catch (Tc = 0.5 year), the Y/R has not changed at the actual level of F. By increasing the F multiplier over 2.6, the Y/R will have a slight decrease. Overall, purse seine fishing should not have a significant effect on the longline production.

The actual situation reveals that the greater increase of Y/R could only be obtained by increasing F for an age at first catch older than 2 years, i.e. the fishing mortality due to the longline.

All those conclusions are obviously based on many hypothesis and on possible underestimation of small bigeye catches in the present statistics.

4.4 Simulations of the potential interactions on yellowfin between longline, artisanal and purse seine fisheries

Some simulations have been attempted according to 4 patterns which combine different fishing efforts on yellowfin by the three fisheries (fig. 10). Calculations were made with an initial recruitment of 100.10^6 . The effort multiplier fm = 1 corresponds to the average effort in the period 1983-85. The evolution of the catch is followed during 18 years.

Simulation 1:

All the fisheries are performing at the level fm = 1. The longline starts at year 1, the artisanal fishery at year 7 and the purse seine at year 13 (fig. 10 a). During the first six years, the catch level is at equilibrium (longline catch). The introduction of the artisanal fishery causes a significant decrease of the longline catch, three years later (year 10) when the adults are recruited in the fishery. The artisanal fishery keeps a stable production and a new equilibrium tends to take place. The purse seine fishery increases a lot the total catch, induces a slight decrease of the longline catch but has no effect on the artisanal production.

Simulation 2 :

Starting with fm = 1 for all the fisheries, the purse seine effort is increased by 50% at year 7 and set at fm =2 at year 13, while the other fisheries are keeping a stable effort (fig. 10b). After the equilibrium level is reached for the total production (6 years), the variations of the purse seine effort does not affect the artisanal catch while a weak negative effect on longline is noticed. Furthermore, the total catch is much greater : the purse seine catch is increased nearly by the same proportion than the corresponding effort.

Simulation 3 :

The longline effort is decreased by 50% at year 7. The artisanal fishery effort is set at fm =1, the purse seine effort is set at fm = 1 at year 1, fm = 1.5 at year 7 and fm =2 at year 13 (fig. 10c). After year 7, despite the lower catch by longline, the total production remains stable due to a positive compensation by purse seine catches which can benefit from a greater biomass of older fish.

Simulation 4 :

The longline effort is stable and set at fm = 1; the artisanal fishery effort is decreased by 50% at year 7 and the purse seine effort increased by 100% at year 13 (fig. 10d). In this simulation, it is remarkable that the decrease of an effort leads to an increase of the total catch. This points out the great sensitivity of the yellowfin stock to the activity of the artisanal fishery.

All these simulations are based on a Y/R model concept which does not seem to apply perfectly to yellowfin. The model would suggest a direct interaction between fisheries although this has not yet been clearly demonstrated, especially between longline and purse seine fisheries (FONTENEAU, 1985; SUZUKI, 1985).

5. GENERAL DISCUSSION

All results presented here have to be considered as provisional. Most of the basic assumptions can be discussed. Without an accurate estimation of the growth of yellowfin and bigeye ranging from small to large sizes, we used the relationships established in the Atlantic Ocean. However, the very specific oceanic environment of the Indian Ocean (Monsoon system) might have some effect on those parameters. These uncertainties on growth and mortalities, as well as the levels of recruitment, can have a significant impact on the result of the cohort analysis, and subsequent yield per recruit analysis. Unfortunately it is presently difficult to obtain a fine tuning of the VPA necessary to estimate recruitment level and variability.

The assumption of a constant recruitment is also opened to discussion. In the Western Pacific Ocean, SUZUKI (1985) discerns a possible relationship between the year class strength of yellowfin and El Nino event ; big year class would be generated in the year when El Nino occurs, or one year before or after this event. In the Eastern Atlantic, FONTENEAU (1981) mentioned that, in 1968, a recruitment level, the lowest from 1967 to 1976, was recorded at the same time as an important hydroclimatic anomaly (no occurrence of equatorial upwelling). However, it is ticklish to correlate the recruitment level to the hydrological conditions since many other parameters can interfere, as the importance of the parental stock, the predation of the adults on larvaes and juveniles, etc... The wide habitat of tropical tunas can explain why any of their stocks has collapsed under fishing pressure, when this dramatic issue has already happened to small pelagic fish living in limited areas. Thence, an assumption of constant recruitment can be considered for a first analysis. The real level of this constant recruitment is still difficult to estimate.

The stock structure of yellowfin based on longline catch distribution was studied by MORITA and KOTO (1971), and the possible existence of two populations was suggested, both sides of 100° E. However, no conclusive study supporting this hypothesis has been achieved so our analysis was done on the basis of a single stock for the Indian Ocean yellowfin tuna. For bigeye, KUME et al (1971) have speculated on the existence of a single stock in this ocean. Only intensive tagging conducted in the whole Indian Ocean could reveal the yellowfin stock structure.

The conclusions of the simulations, which tend to demonstrate that an increase of the purse seine yellowfin catch would induce a weak negative effect on the longline catch and would have no effect on artisanal fishery should not be considered as definitive. The migration behaviour of tuna has not been taken into account due to a lack of information. Furthermore, an hypothesis of lower recruitment would show quite different interactions between fisheries, as the fishing mortalities would be at higher levels.

6. CONCLUSIONS

Stock assessment of tuna generally needs detailed information on fishery statistics, biological parameters (growth, mortality...) and stock structure. At the present stage of the research in the Indian Ocean, only preliminary and provisional information are available despite the great improvement of the tuna fishery statistics. Consequently, the present stock assessment is based upon several working hypothesis which need to be validated by direct observations.

However, it seems that the artisanal fishery catching small yellowfin may decrease the overall yield, when the purse seine fishery increases this yield due to its high efficiency. The real potential yield of the fisheries is still unknown because of the lack of long series of reliable CPUE which can measure the trend of abundances. The yellowfin stock in this area should be monitored closely because of all those uncertainties.

The bigeye stock would not require so much care since the major part of the catch (85% in 1985) is made by longline, whose Y/R is good. The recruitment of adult fish (over 3 years) has kept a stable level up to now. It should slightly decrease as a consequence of the catch of the juveniles by the purse seine. However, the bigeye is not a target species of the surface fishery and these catch should not reach levels becoming very competitive with the longline fishery. Furthermore, increasing the depth of fishing has increased the catch and it is likely this situation could happen again if deeper layers are prospected.

Nevertheless, it has been reported that a certain proportion of the yellowfin catches from the artisanal fisheries are made of small bigeye. It is absolutely essential to ascertain the importance of bigeye occurrence among yellowfin catches of Maldives and Sri Lanka. This increase of bigeye catches could greatly change the Y/R analysis.

Taking into account all the serious uncertainties on stock structure and on biological parameters, an intensive tagging programme seems a priority in the Indian Ocean tuna research. This programme is the only source of direct evidence for most of the major uncertainties, i.e. the relations between fisheries, the growth and the exploitation rates.

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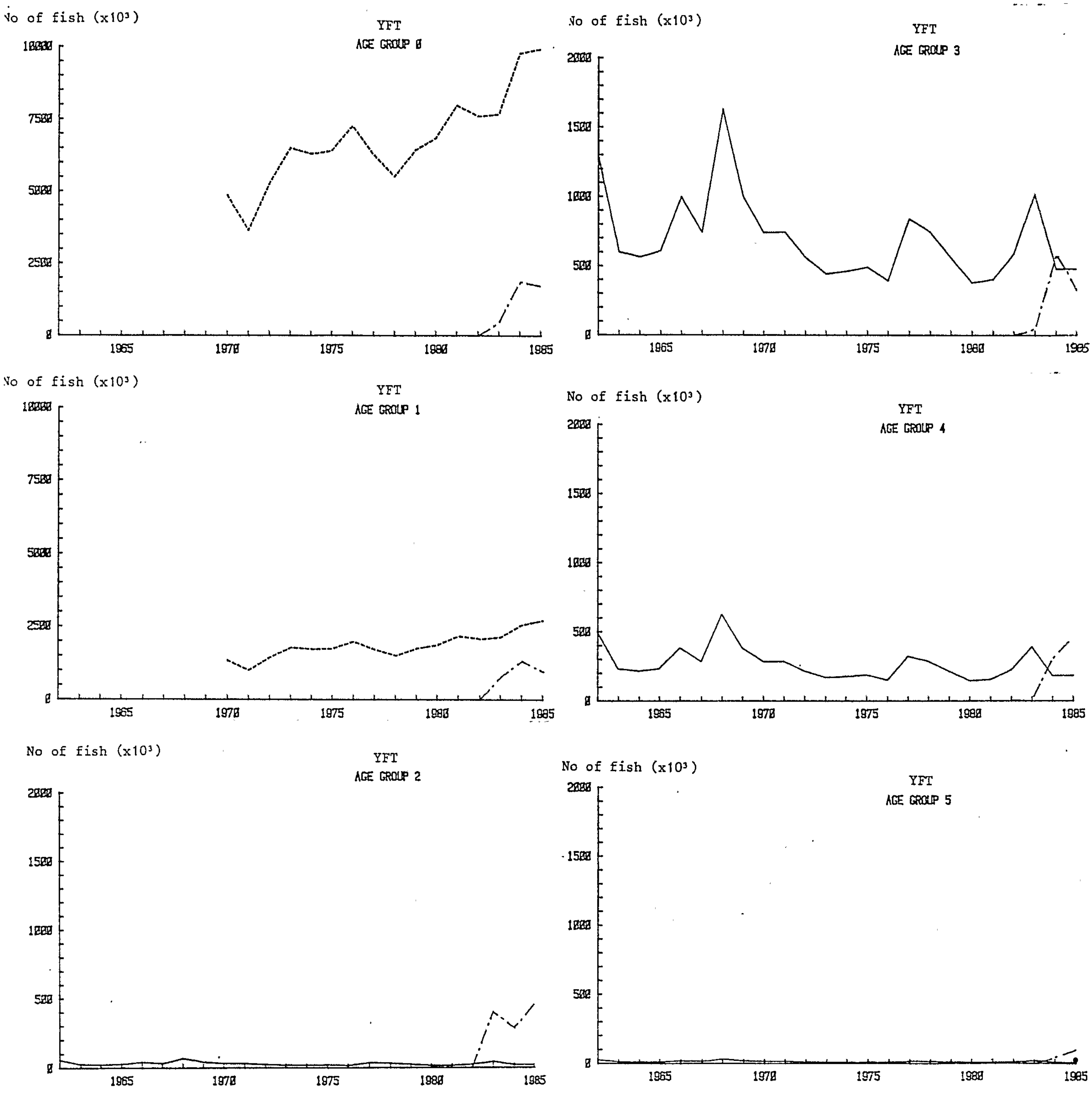


Fig. 1 - Estimated catch by age (in numbers) of yellowfin tuna, by surface and longline fisheries, in the Indian Ocean. (dashed line: artisanal ; chain line: purse seine ; full line: longline) .

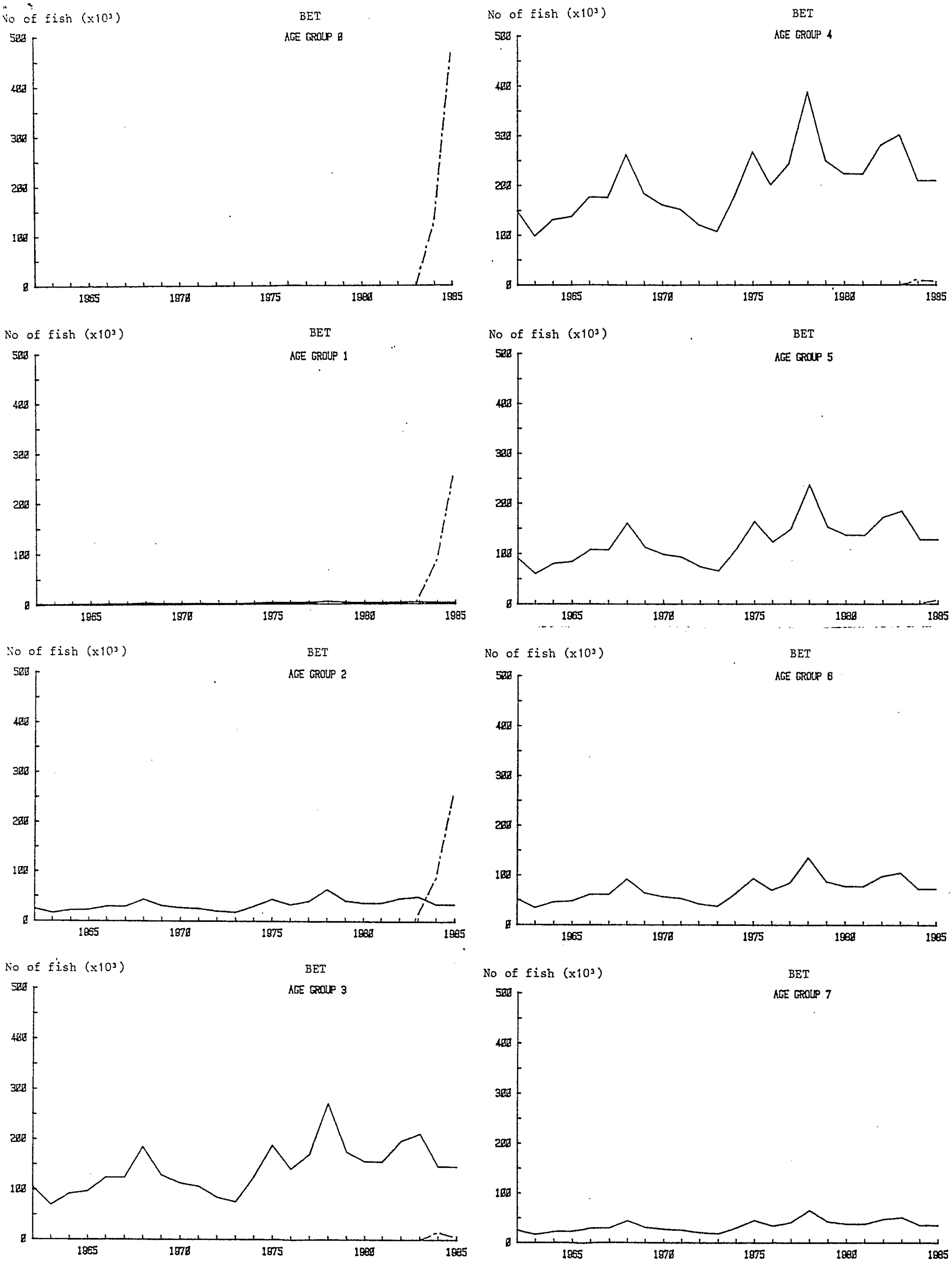


Fig. 2 - Estimated catch by age (in numbers) of bigeye tuna , by surface and longline fisheries, in the Indian Ocean. (chain line: purse seine ; full line: longline) .

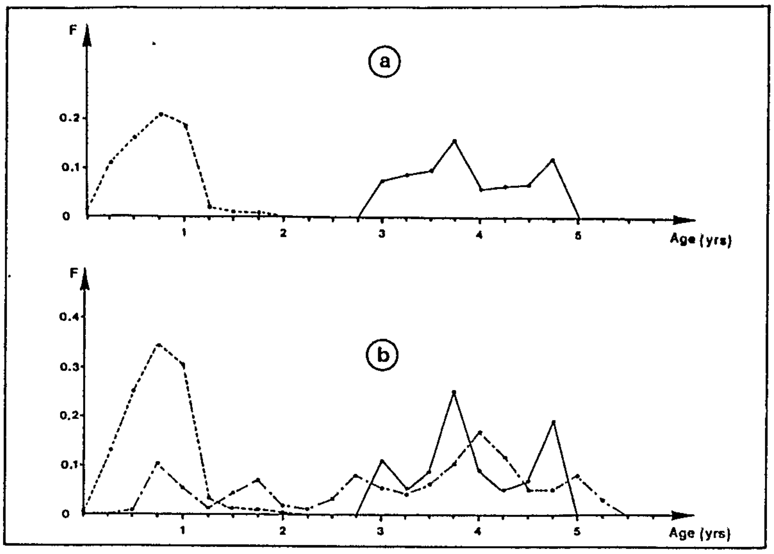


Fig. 3 - Fishing mortality coefficient by age, on a quarterly basis, for yellowfin tuna (with $R=100.10^6$).
(a) 1975 - 1979
(b) 1983 - 1985

(dashed line: artisanal fishery ; chain line: purse seine fishery ; full line: longline fishery).

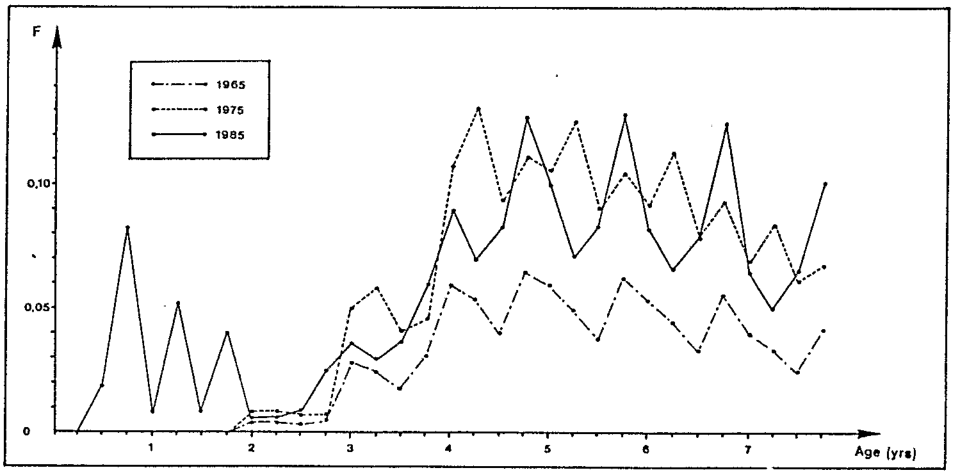


Fig. 4 - Fishing mortality coefficient by age, on a quarterly basis, for bigeye tuna (with $R=35.10^6$).

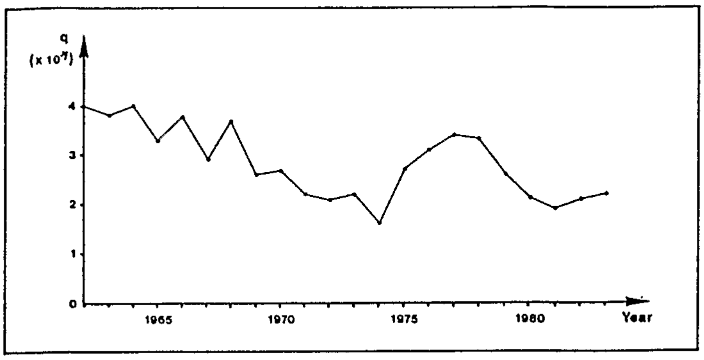


Fig. 5 - Annual catchability coefficient for bigeye tuna taken by longline gear, from 1962 to 1983.

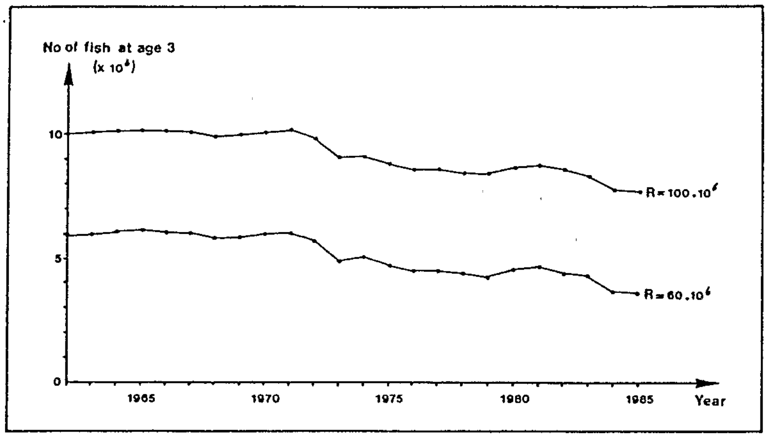
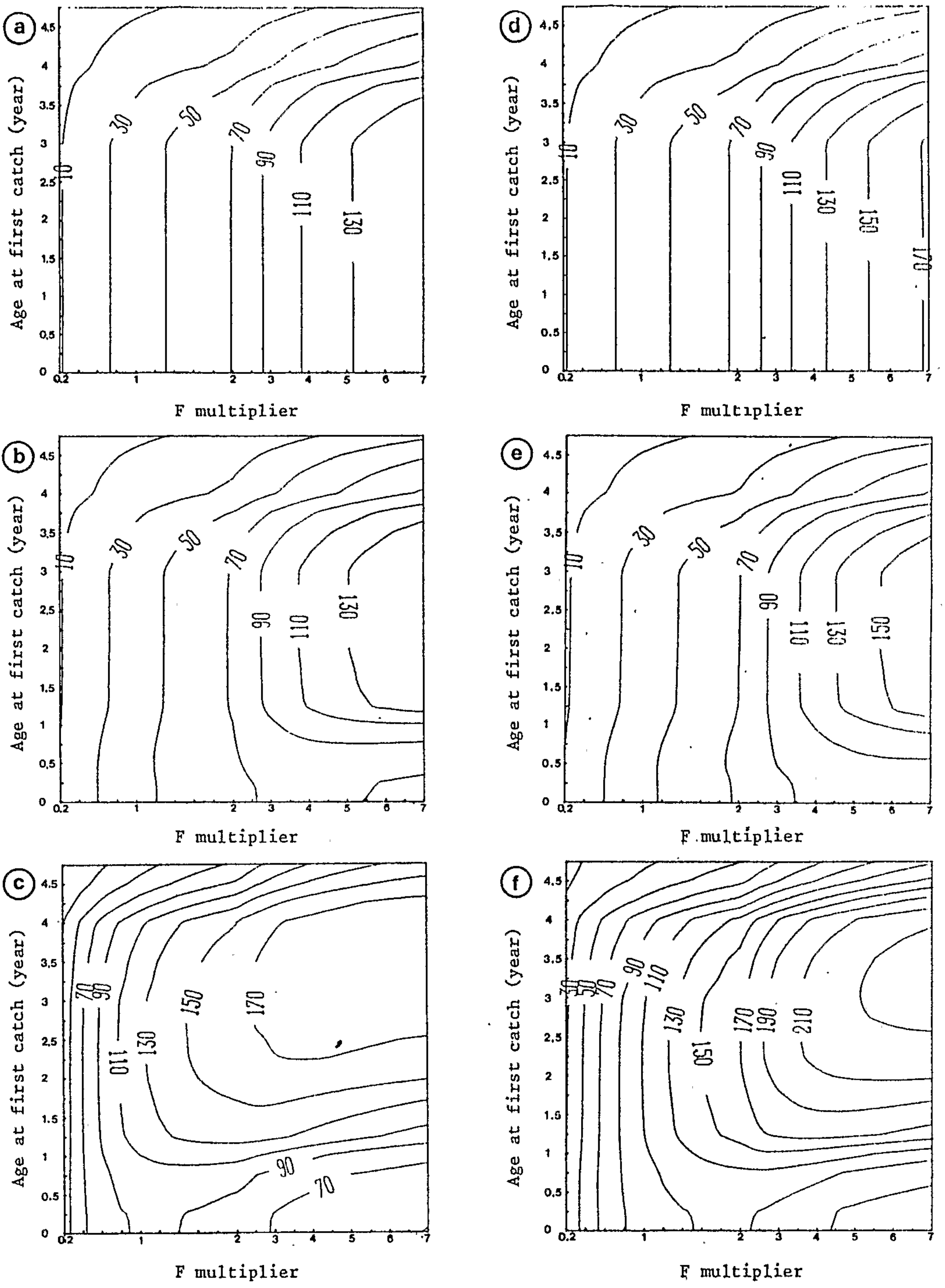


Fig. 6 - Recruitment of yellowfin tuna to the adult fishery (in numbers).


a
b
c
d
e
f
Age at first catch (year)
F multiplier
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0.2
1
2
3
4
5
6
7
10
30
50
70
90
110
130
150
170
190
210

(Fig. 7)

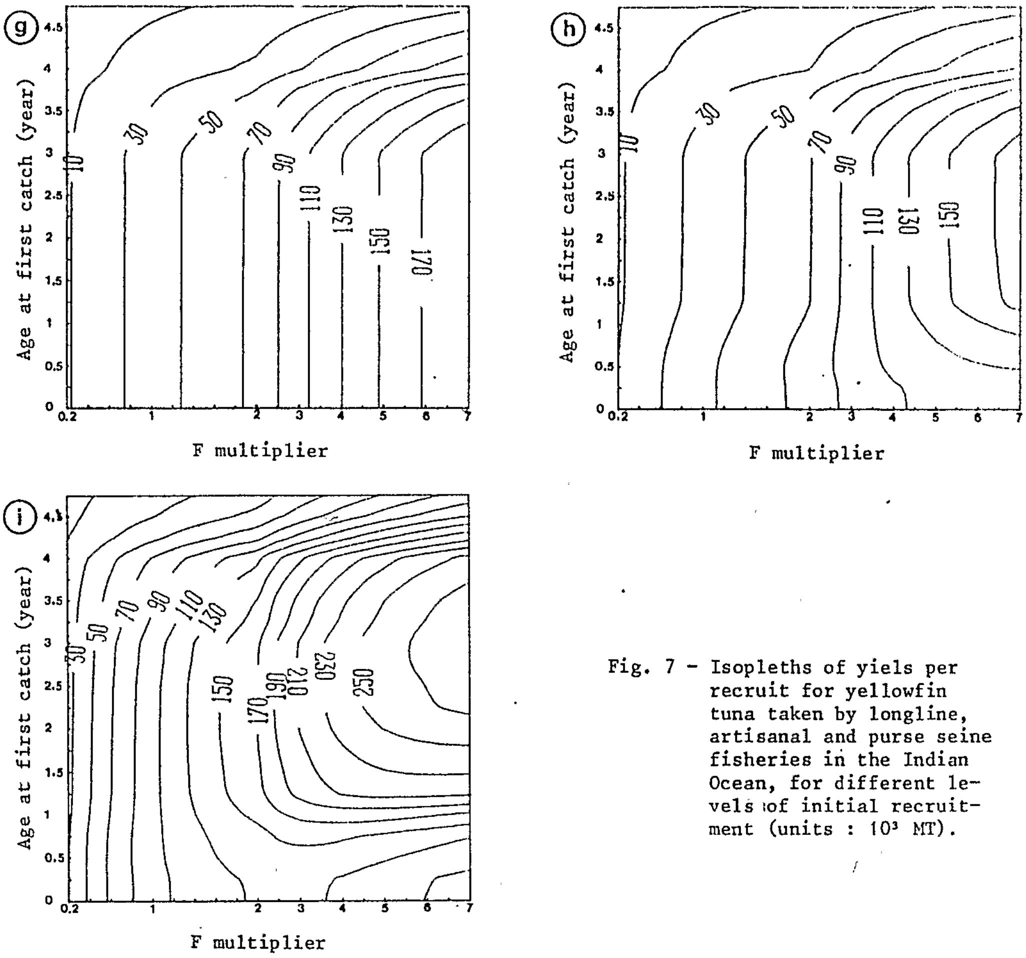


Fig. 7 - Isopleths of yiels per recruit for yellowfin tuna taken by longline, artisanal and purse seine fisheries in the Indian Ocean, for different levels of initial recruitment (units : 10^3 MT).

(a) 1965 , R = 60.10^6
(b) 1975 , R = 60.10^6
(c) 1985 , R = 60.10^6

(d) 1965 , R = 80.10^6
(e) 1975 , R = 80.10^6
(f) 1985 , R = 80.10^6

(g) 1965 , R = 100.10^6
(h) 1975 , R = 100.10^6
(i) 1985 , R = 100.10^6

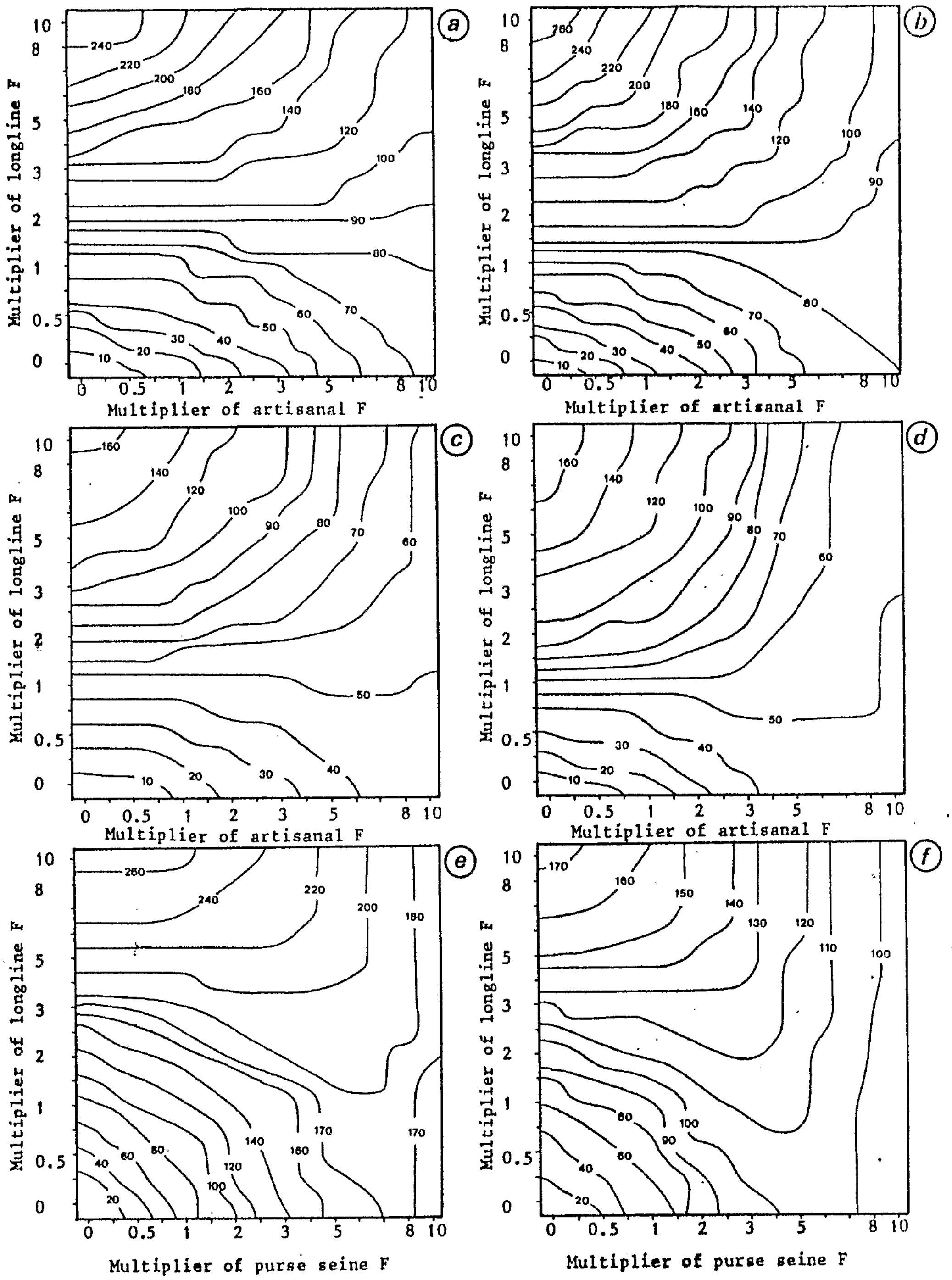
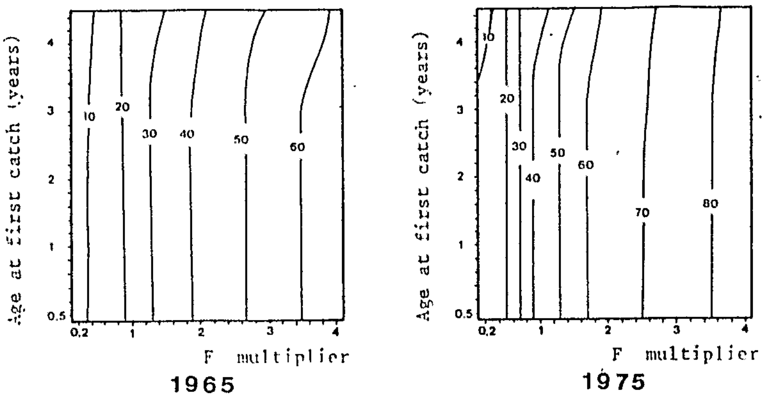


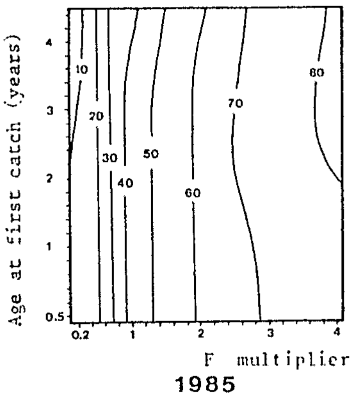
Fig. 8 - Isopleths of yield per recruit (Ricker model) for yellowfin tuna in a two gear model (units : 10^3 MT)

(a) artisanal / longline , 1975 - 79 , R = 100.10^6
(b) artisanal / longline , 1983 - 85 , R = 100.10^6
(c) artisanal / longline , 1975 - 79 , R = 60.10^6
(d) artisanal / longline , 1983 - 85 , R = 60.10^6
(e) purse seine / longline , 1983 - 85 , R = 100.10^6
(f) purse seine / longline , 1983 - 85 , R = 60.10^6



1965

1975



1985

Fig. 9 - Isopleths of yield per recruit for bigeye tuna taken by longline and purse seine gears in the Indian Ocean (with $R = 25.10^6$). (units : 10^3 MT)

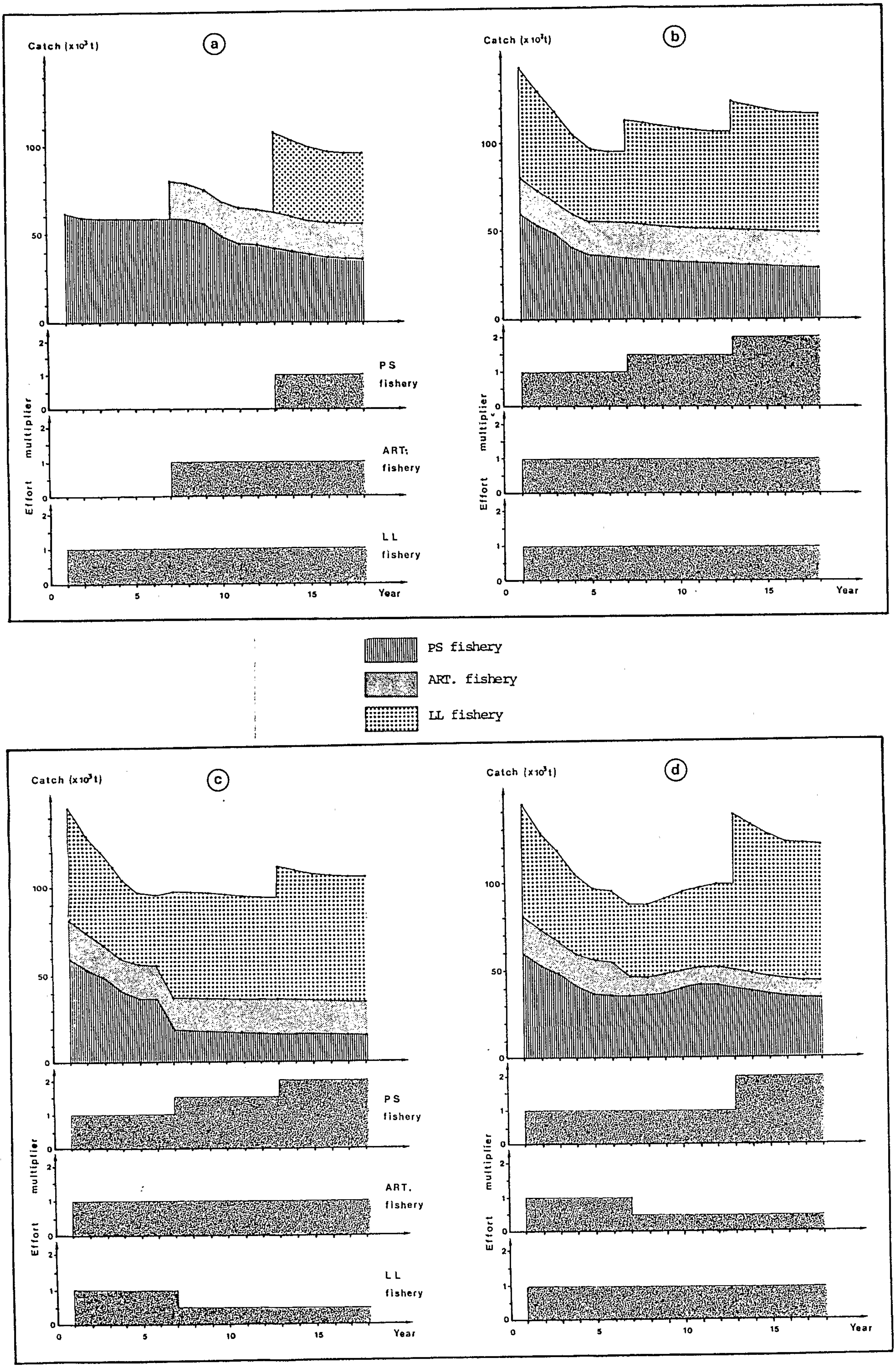


Fig. 10 - Simulation of yellowfin tuna catches by gear, in the Indian Ocean (with $R=100.10^6$).