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INTERACTIONS BETWEEN TUNA FISHERIES

A CRITICAL REVIEW BASED ON SOME ATLANTIC EXAMPLES

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S U M M A R Y

This paper describes some interactions observed in the Atlantic Ocean between tropical tuna fisheries. Seversl types of interactions are distinguished. It is first shown that for tropical tunas, there is not presently a clear relationship between for fisheries adults and for fisheries juvenile. This is probably because, despite of the high level of fishing effort , a recruitment overfishing never has been observed in the Atlantic, probably because of the high fecundity and wide spawning areas of these species. The interactions between small tuna fisheries and large tunas fisheries are also analyzed for yellowfin and biyeye. For both species this interaction is estimateà to be significant at the ocean level, because of the important catches of juveniles. The interaction between gears catching large tunas , such as longline and purse seine, in analyzed. The particularities of the vertical stock structure are hypothesized for both species from the catches and cpue by gear. As a consequence of this vertical stock structure, the purse seine is the gear which can take full profit of the yellowfin biomass, and longline the only gear capable to exploit intensively the deep bigeye stock. Some other short term interactions within small time and area units are also described and discussed ; several exemples of those interactions are presented. A more detailed discussion concerning the short term interactions between fisheries operating in different areas is presented using a "boxes model". Such type of boxes mode1 which are developped needs a huge amount of data (detailed catch, effort and size statistics by small time and area strata, intensive tagging), but seems to be a key tool to evaluate the short and medium term potential interactions between fisheries exploiting a migratçry resource considered as a stock. All the present wcrk

demonstrates, at least, that the interaction study needs, much more than any other stock assesment work , very good and complete statistics associated with intensive tagging.

RESUME

Cet article décrit quelques interactions observées dans l'Atlantique entre des pêcheries de thonidés tropicaux, Plusieurs types d'interactions sont distingués. L'absence de relation claire entre la taille du stock reproducteur et le niveau du recrutement est tout d'abord montrée. Cette stabilité du recrutement et l'absence de chute du recrutement qui est observée malgré les niveaux de pêche élevés correspond à l'absence de "recrutement overfishing". Cette situation est interprêtée comme étant due à la forte fécondité et à l'existence de vastes zones de ponte qui sont des caractères généraux de ces espèces. La compétition entre les pêcheries qui exploitent les juvéniles et celles qui exploitent les adultes d'albacores et de patudo est examinée. Celle-ci semble significative pour les deux espèces, au moins un niveau de l'océan, par suite des prises importantes de juvéniles qui sont observées. La compétition entre les engins qui capturent les individus de grande taille, par exemple les senneurs et les palangriers, est analysée. Pour les deux espèces, cette compétition est interprêtée à partir d'une hypothèse sur la structure verticale des stocks reposant sur les tendances des prises et des efforts par engin. Il apparait que la senne est l'engin qui est le mieux à même d'exploiter pleinement la biomasse d'albacore, alors que la palangre est le seul engin capable d'exploiter intensément les gros patudos de profondeur. Un autre type de compétitions, celles observées à court terme entre des pêcheries pêchant dans de petites zones, sont aussi examinées et plusieurs exemples sont présentés. Enfin une discussion concernant les interactions à court terme entre pêcheries exploitant des zones de pêche différentes est présentée. Un modèle informatique "à boites" a été établi à cet effet . Ce type de modèle qui reste en cours de développement utilise une grande masse de données détaillées : prises et prises par unité d'effort par tailles, selon des zones et périodes réduites, marquages intensifs. Cette approche semble toutefois être du plus grand intérêt futur pour évaluer les interactions à court et moyen terme entre des pêcheries exploitant une ressources migratrice. Le présent travail montre bien la nécessité, pour conduire à bien les études sur les interactions entre pêcheries, d'excellentes statistiques de pêche, fines et complètes, associées à des marquages intensifs.

1 - INTRODUCTION

The concept of interactions between fisheries is quite complex and can be studied from different points of view. Among others, three major types of interactions can be distinguished :

(a).. To what extent large size tuna fisheries can compete with small size tuna fisheries, for long living species? (In the medium and long term).

(b).. To what extent fisheries catching small size tunas can compete with large size tuna fisheries ? (In the medium term, in general during the exploited phase of the fis'h).

(c).. T o what extent two or several fis'heries catching the same sizes of fishes are competing for this common ressource ? (In the short term).

In this type of interaction ,two cases need to be analyzed separately :

- Those exploiting small tunas (in general a plurispecific mixture of small yellowfin, bigeye and skipjack) ,
- Those exploiting large size tunas .

This distinction seems necessary because small size tunas live in plurispecific surface schools, while :Large size tuna tend to be in both deep and surface layers, with a differential geographical distribution between species .

These studies of interactions between fisheries need several types of data which can be listed as follows :

(1).A correct species identification of catches in the statistics. When small bigeye are called yellowfin and both species often registered as skipjack in the statistics, it will be impossible to estimate any interaction for any of the three species. Those problems of species identification are often found for small size tunas and difficult ta solve.

(2).A good size sampling for all fisheries , necessary to study the trends of age specific cpue and to conduct VPA .

(3).Catch and effort statistics established for each gear, with detailed time and area stratification, which are necessary to calculate series of cpue which can be representative of abundance of each year class .

(4).Good knowledge upon stock structure, preferably based upon direct evidence, such as those obtained by intensive tagging.

(5).Good biological studies especially on growth, reproduction processes and fecundity. Growth knowledge is necessary to keep track of cohorts of fishes exploited by fisheries ; spawning biology is necessary to estimate potentials of the spawning stocks.

(6).Preferably high level of fishing efforts, covering various areas and all sizes of fishes, so that the complete range of geographical distribution and all ages of fishes are exploited.

(7). Stock assesment studies, especially stock size estimates by age, based on Virtual Population Analysis (VPA).

(8). Yield per recruit analysis based upon age specific fishing mortalities of each gear.

(9). Mathematical models must be developped on computers in order to analyse the interactions between fisheries. Those models are still quite new in the field of tuna stock managment , but are to be developped in order to better understand the interaction problems ;

All these results must be combined and compared. When they are obtained during a long period of time, they can provide reasonably good answers on the different types of interactions between fisheries .

The Atlantic ocean offers good exemples for all possible types of interactions(type a to c); furthermore these interactions can be well analyzed because of intensive statistics and research conducted in the Atlantic during long periods of time under the coordination of the International Commission for the Conservation of Atlantic Tunas (ICCAT). All researches from type 1 to type 9 have been done in the Atlantic at different degrees, depending on species .

Subsequently the goal of thi-s paper will be to review and discuss the present knowledge and researches on the interactions in the Atlantic.

2 .DATA USED.

The data used for this study are extracted from the ICCAT data base available at the end of the year 1986. Those data are basically the catch, effort and size data , for yellowfin skipjack and bigeye tuna, available during different periods of time for each fleet, with a variable degree of precision. For more details upon the nature of those data, the ICCAT Data Record num.26 can be usefully consulted. In the case of some fleet where the data was not available, the standard-strata substitutions done by SCRS scientists were performed when necessary (see the reports of ICCAT ad hoc working groups). --

3 . HOW MUCH LARGE TUNA FISHERIES CAN AFFECT SMALL SIZE TUNA FISHERIES ?

In most exploited fish stocks- at least small pelagic and demersal species - there is some relationship between adult stock of spawners and number of recruits generated by this spawning stock . In most fish stocks, this relationship between recruitment and stock is highly variable, but a reduction of the spawning stock will tend either to decrease (usually the case),or to increase (Ricker type model) the recruitment level (see figure la).

However this typical stock recruitment mode1 dont really apply for tropical tunas : in any case , at least for tropical species , it seems that recruitment shows only some moderate year to year variability, but no trend , even at high level of exploitation of the adult stock (see figure lb) .

However this stability of recruitment over a large range of spawning stocks cannot be indefinitely extrapolated : if the number of spawners tends to become equal to zero , the recruitment is necessarily affected . This critical level of spawners beyond which the recruitment could be affected has been hypothetized to a 10 % level of the virgin stock, but has never been observed in tuna fisheries , at least for tropical species.

In fact a decreasing recruitment trend due to overfishing - i.e. a recruitment overfishing- has never been observed for tropical tunas , even for highly exploited ones .

Consequently the present paradigm for tropical tunas is that, at moderate or relatively high level of fishing efforts, there will not be any effect or interaction of the adult fisheries on the juvenile ones .

This specificity of tunas (at least the tropical species) seems to be related to the extremely high fecundity of these individuals ; each female of mature yellowfin , skipjack or bigeye will spawn several millions of eggs, several times each year, covering extensive areas and periods of time (Cayre et al. in press FAO) (see figure 2 to 4) , where their larvae can always (statistically) find good conditions for their survival . In such conditions of spawning the recruitment will be limited in general, much more by the carrying capacity of the nursery areas , than by the size of the spawning stock .

4 . HOW FISHERIES CATCHING SMALL TUNAS WILL AFFECT-LARGE TUNAS FISHERIES ?

4.1.The problem:

This type of interaction concerns mainly yellowfin and bigeye tunas, which are exploited at small sizes by surface fisheries and later at large sizes by longline and purse seine fisheries.

How the fisheries catching juveniles will affect fisheries catching adults is consequently an important question to solve .

The Atlantic ocean offers good observations and relevant analysis in that field.

This type of study is based primarily on the analysis of fishery data.

4.2. Atlantic bigeye tuna .

It should be first noted that the fisheries of juveniles are located in areas which are different from the areas of adult concentrations (see figures 5 to 6). This observation is easily explained by the physiology of the species : the young bigeye tunas are physiologically a tropical species, living in surface warm waters; it becomes a temperate deep species when becoming adult , except during seasonal spawning when they corne back to tropical waters (see figure 3).

The juveniles of bigeye tuna are quite difficult to recognize from the juvenile yellowfin . In the Atlantic as in other oceans the small bigeye have been widely misidentified with yellowfin for many years. This species composition problem of juveniles has been treated seriously only since 1976 (FONTENEAU 1975). A systematic control of the species composition of the small tuna catches has been developped in the Atlantic on a routine basis only since 1979. Historical data have been tentatively corrected by ICCAT in 1984, but are still questionable. A review of the pending problems for species identification is given in the report of the ICCAT working group held in 1987 on this subject.

The catch of small (less than 90 cm) bigeye taken in the Atlantic since 1955, beginning of the industrial fisheries,are shown in figure 7, together with the catch of large bigeye.

The cpue of small bigeye for surface fisheries shows fluctuations, but without trend (see figure 8). The cpue of large bigeye, given by the longline Honma index (see figure 9), shows a moderate and regular decline since the beginning of the fisheries.

The stock nssessment analysis on bigeye concludes that this decline can be explained by the increased catch of the longliners and by increased catches of juvenile; the great numbers of small bigeye taken by surface gears correspond to a relatively low fishing mortality (see figure 10) and has had only a moderate effect on adult stock size. This is shown by the results of the VPA, which give estimates of the recruitment in the adult- fishery. The decrease of this adult recruitment is clear, at a rate-of approximately 20 % between the virgin stock and recent years (see figure 11), but is relatively moderate. It can be noticed also that present yield per recruit analysis indicates that the juvenile fishery affects the longline fishery, but does not significantly reduce the overall yields, at least at present levels of fishing mortalities (see figure 12) (PEREIRA 1986).

4.3. Atlantic yellowfin.

The fishing zones of small yellowfin are quite similar to the adult ones(see figure 13 and 14), at least for purse seiners. However it is noticed that small yellowfin in general stay in more coastal waters that the adults . The adults of yellowfin taken by longliners also show a wider area of distribution(see figure 14b), scattered between 10° north and south, from America to Africa.

The numbers of small (-90 cm) and large(+90 cm) yellowfin taken by atlantic fisheries are given in figure 15. This figure shows well the dramatic increase of small yellowfin in the catches du:ring recent years (by baitboats and purse seiners), and the increase of catches of large yellowfin (by purse seine).

The cpue for small yellowfin, (baitboats and purse seiners), shows some year to year variability, but no definite trend, suggesting a relatively stable recruitment (figure 16). The cpüe for large yellowfin is given for two gears : longliners catching only large fishes, and purse seiners (see figure 17). In order to obtain surface index for adults, the usual overall purse seine index has been corrected by the amount of small yellowfin in the catches. Those two adults cpue show, for recent years a similar serious decline. This decline of the adult cpue corresponds to a decline of the adult abundance. The VPA analysis shows that this decline of adult stock is a consequence of two factors:

1.the development of juvenile fisheries which reduces the recruitment to the adult stock .

2.the increased effort and increased catches on adults which reduces directly the adult biomass.

Present analysis suggests that the first effect, interaction between j uvenile and adult fisheries, would be relatively significant. This is shown by the decline of the adult recruitment (figure 18)estimated by VPA at approximately 50 %, decline due to the increased catch of juveniles.

However subsequent yield per recruit analysis shows that the juvenile fishery does not seriously decreases the yield per recruit of the overall fishery because the juvenile catch in weight is only sligthly less than the subsequent theoretical loss of the adult fisheries (FONTENEAU 1986).

4.4. Conclusion : juveniles against adults fisheries.

For bath species, the catch of juvenile seems to reduce significantly the catches of the adult fisheries of about 20 % for Bigeye and 45 % for yellowfish this interaction seems to be moderate compared to the millions of small fishes taken ,because of the relatively low fishing rates estimated on juveniles.

It should also be noticed that the present yield per recruit analysis indicates for both species that the--overall yield per recruit has suffered only a minor reduction due to juvenile fisheries.

5 . HOW LONGLINE AND PURSE SEINE SHARE THE BIG TUNA BIOMASS ?

5.1. Catch versus effort for bigeye and yellowfin for the two gears.

How the two gears compete in the short term to exploit large yellowfin and bigeye tuna is an important problem.

The relationship between fishing efforts of purse seine and longline, and their respective catches of large fishes shows completely different patterns for the two species :

. for yellowfin, the increase of longline effort has produced a decreasing yield curve, while a simultaneous increase of effort by purse seiners has increased the catches at a level much more higher than the catches by longliners (see figure 20).

. for bigeye tuna there is a reverse observation : the increase of longline effort is still producing an increase of the catches, while the increase of surface effort has produced a stable or even decreasing level of catches (see figure 21).

These observations are in contradiction with the yield per recruit analysis , which indicates that increase of effort by purse seiners should have increase the catches of large bigeye and that the longliners should have increased their yellowfin catches. This contradiction between the expected and observed yields for the two gears and the two species is summarized on the figure 24.

5.2. The vertical stock structure heterogeneity hypothesis.

The most probable explanation for this observation is related to a vertical stock structure heterogeneity:

- Yellowfin is a surface tropical tuna, even at large sizes. The purse seiners can exploit the ressource with great efficiency and high fishing mortality . The longliners can exploit only a marginal and fragile fraction of the stock, the deeper one. Consequently the longliners can never exert a real high fishing mortality on the total stock because of the excessive reduction of the deep biomass. Consequently the yield per recruit concept does not really apply to the longline yellowfin fishery because the longline adult recruitment does not show the same trend that the purse seine adult recruitment .

--Bigeye is an opposite case : being basically a deep and temperate tuna, the tropical purse seiners will always exploit tne ressource with a very low fishing mortality, even at hiqh nominal fishing effort. Any increase of fishing effort does not produce an increase of F. The longliners, -on the contrary, can easily concentrate their effort on deep-bigeye, and an increased longline effort produces a corresponding increase in fishing mortality, especially with the introduction of the more efficient deep longlining.

This general hypothesis has been summarized graphically in figure 25.

Under the present hypothesis the sharing of the adult biomass between surface and deep gears would be related much more to a vertical stock structure heterogeineity, than to a real interaction :

- for bigeye, the decline of surface adult cpue is not due to the longline catches or to a real decrease of the total biomass.

- for yellowfin, the early decline of the longline cpue is not a consequence of interaction with purse seine fisheries, but would be related to a vertical stock structure heterogeneity .

5.3.Other more direct interactions between purse seiners and longliners to catch large tunas.

There is still probably some real and direct interactions between the two gears on the adults ; these interactions can be of two types :

. The "urn" interaction, as described in chapter 6 ,where, in summary, a tuna taken by one gear cannot be taken by the other gear, which gives an advantage to the more efficient gear.

. The geographical interaction, where two gears exploiting the same area are more in interaction than if they are exploiting distant areas, even in the case of a unique stock. This is related with the probability of migratory distances of tunas : the probability of moderate migration (for instance less than 500 miles), is always greater than the probability of very large ones(for instance more than 2000 miles). The situations are different depending on the species:

(a) Yellowfin

In- that field it is noticed that the areas where the highest purse seine catches of large yellowfin are observed are the areas where the highest longline catches rates were historically observed (figure 26). Presently it is noticed that the longline cpue are lower (figure 27) that the average in this fishing zone for the purse seiners (see figure 14a).

This is probably a local consequence of high purse seine catches taken in this area. This geographical interaction is similar to the interaction described in the simple "urn model". However the migration of large tunas are much less known and probably more important that those of small tunas; as a consequence the strong hypothesis of a close system does not apply well to the adult yellowfin or bigeye fisheries in any area.

(b)Bigeye :

It is clear for the adults of this species that the purse seine fishery has no sigificant geographical effect on the longline fishery. This is due to the low purse seine catches and to the differences in fishing areas of the two gears (see figure 6).

6. SHORT TERM COMPETITION IN THE SAME AREA : THE "URN" mode1 :

6.1 .Concept:

Tunas are clearly migratory ; however during limited periods and in relatively small areas they can be considered as sedentary, and considired as a locally and temporaly isolated fraction of stock.

In this case, the term "fishing area" can describe a relatively small geographical unit in which tuna can have random movements. As an exemple , an area of 5° by 5° square, i.e. of approximately 3600 nautical square miles, would be a reasonable unit to study. In such type of interaction, only the short term interactions, such as from 1 to 3 months, are concerned ; since tunas are migratory species, it is quite obvious that a group of small tunas staying in a given area will migrate in an other area if the elapsed time is long.

In theory, if the fraction of a stock is stable in the area(e.g. no emigration and no immigration), the interaction problem becomes quite simple.This stability of the sub stock can often be assumed during limited periods of time.

In such case the studies are simplified because:

-the growth of the fish can be neglected.

-the natural mortality becomes much less important that in the long term interaction studies;

-fishing mortality rates can be easily calculated if the total catches are known,and if there is a measure of local abundance(local cpue for instance).

In this simple case, the recruitment in the area will be shared bctween simultaneous fisheries. In such a simple case, the interaction between fishing units will depend of the available total biomass and on the relative effort and catch of each gear. This type of competition will be the "competition" of type 1 as described by Ricker 1975: the catch of each day by a boat reduces the catches of the other units later. The abundance of fish is lower and lower as the fishing is developping, and the rate of this decrease is proportionnal to the number of boats. This has been expressed in figure 28b which is a local production type curve, within a limited time and area stratum : it shows the expected relationship between the local catch during a fishing seasor. and the total fishing effort. In this example the initial biomass and potential catch is 10000 tons which can be taken only with a very high fishing effort. If a local fishery working on this substock takes 5000 tons per fishing season , the addition of a new fleet catching 5000 tons will reduce significantly the catch rates and catches of the first fleet.

6. 2. Possible exemples of the "urn" mode1 :

6.2.1.Introduction:

It is quite difficult to find in the real world of tuna fisheries a true example of this urn model. This difficulty is primarily due to the migratoxy nature of the tunas. However at least three type of examples, belonging more or less to this "urn" concept, can be described in the Atlantic ocean.

6.2.2. The concentrations :

Concentrations have been described in the Atlantic as important groups of schools which are fished in a small area during a short period of time.(FONTENEAU 1986).

Several examples of those concentrations have been analyzed in the Atlantic, The figure 30 summarizes some important characteristics of those groups of tunas(yellowfin in that case).

The analysis shows that the initial biomass can be very high(possibly more than 10000 tons) ; tunas are concentrated in a very small area (with an area equal to 3 % or 30 % of a one degree square).

When the fishing effort is high (for instance 20 to 40 purse seiners), the daily catches are very high, at least at the beginning of the exploitation. This high catch produces a reduction of the catch rates, and a complete removal of the biomass within a short period of time (10 to 30 days). Consequently the analysis of this phenomenon needs very detailed statistics with daily catches for all boats, corresponding size composition, and detailed satellite positions (to the nearest mile). This type of concentration seems to be very often a closed system(like the "urn" model), where there is only some day to day movement of the fish but little or no emigration from , 0r immigration to the system.

6.2.3.The Cape Lopez summer fishery : (figure 30)

This area has been extensively fished from May to August, since 1962, by all types of fleets(longliners ,baitboats and purse seiners). This fishing zone and season is related to an oceanographical front with highly productive waters (STRETTA 1977) which is stabilized in this area during this season. There is probably some input and output of tunas into this strata which are well shown by tagging done in this fishery (HARD 1984). However, those movement may be limited and it is interesting to relate the total catches in the fishing season to the fishing effort (expressed in purse seine fishing days). The result is shown in figure 31. It can be seen that, as in the theorical urn model, there is some maximal production in the local catches 0f tunas. However, when the fishing effort becomes high (as in recent years), the catches are higher during "good" years(1974, 1978, 1981, 1982). The catch is stable or low during other years(1975, 1976, 1977, 1980, 1983), quite independently of fishing efforts. In Süch a case, it can reasonably be assumed that the potential maximum catch is not really proportional to the fishing effort ; however an increased fishing effort can produce a higher average catch , because it can more easily remove nearly all the existing local biomass,

especially during "good" years.

6.2.4. The Canary Island skipjack fishery.

The Canary Island skipjack fishery is a summer artisanal fishery, where approximately 500 baitboats catch, among other species, an average of 3000 tons of skipjack each year (1979 to 1985). This fishery operates exclusively around the Canary Islands. It has been extensively studied by spanish scientists of IEO who conducted tagging cruises on this species every year since 1979. Of the 3515 skipjack tagged during this period, the average recovery rate is very high : 20 %. Most of the tags are recovered in the local fishery, and very few in other areas (Açores, Madeira and Senegal) after the end of the fishing season. Those high local recovery rates strongly suggest that there is a limited local skipjack fraction of stock, which is more or less sedentary during the summer time season, and which suffers a relatively high exploitation rate.

This fishery can be considered, at least to some extent, to belong to the "urn" type,i.e. a close system, where durinq a limited time and in a limited space, there is a high removal rate by the fisheries and a direct interaction between fishing units to catch this limited resource.

6.3. The statistical evidence: cpue and effort relationship within small time and area strata .

The analysis of fishery statistics, cpue versus effort, at a detailed time and area scale, for instance 1" square and 15 days, is also an interesting way to show the local instantaneous interactions between fishing units.

Following that idea, it has been shown for Atlantic skipjack (Fonteneau 1986) that :

-when the effort is low within one square during 15 days,the average cpue is often high or very high.

-when the effort is high in the same strata, the cpue is most of the time low.

This is also observed on the frequency of the overall catch rates of FISM and spanish purse seiners during the period 1980 ta 1986 as shown by figure 33.

In this case of high local effort, it is clear that there was probably, at least at the beginning of the period, a high abundance which is in contradiction with the low cpue.

The easiest explanation for the final low cpue, is probably related to the urn concept: the interaction between a great number of boats on-a limited local resource will increase the catch, but will reduce the cpue, more quickly than a small fishing effort.

7. GEOGRAPHICAL COMPETITION IN THE MEDIUM TERM (less than 2 years) BETWEEN FISHING AREAS: THE BOXES MODEL.

7.1. The concept: migrations treated as a diffusion process;

Any tuna fishery can be divided in time(ex.month) and area boxes (ex. 10° to 10°), which are fished or unfished. In every area there is at any time, a gjven number of fishes(often unknown....). When the area is exploited , the abundance in each box can be easily estimated using an unbiaised cpue index. Aerial survey and direct estimates of biomass can also measure the abundance in each box, especially for the virgin stocks.

From one period to the other, the number of fishes in each box will change because of :

1.Input to the box from other areas (immigration), positive factor.

2.Output from the box toward other areas(emigration).

3.Removal by the natural mortality .

4.Removal by fishing mortality.

These three last factors are negative ones, and reduce the local population.

Migrations can be measured by intensive and repeated tagging results, associated to significant fisheries covering as many areas as possible.

Natural mortality is not estimated precisely for most of tuna species, but this is not necessarily critical in the short and medium term studies .

The fishing mortality in each exploited box will depend on the fishing effort, and more directly on the total catches.

7.2. An example of the boxes model.

Computer models can easily be designed to describe in equations all the previous concepts of boxes, underlying populations, migrations between boxes, fisheries and natural mortalities. Such a mode1 is presently under testing for the eastern Atlantic skipjack fisheries: its framework is shown in figure 34. This mode1 has been built in order to analyze the geographical interactions between skipjack fisheries in the Eastern Atlantic (Figure 35). This mode1 is a catenary reversible differential model, with 5 boxes, the unit of time being the month . A sixth box, adjacent to the 5 others corresponds to the unexploited fraction of the stock. This sixth box is the "cryptic nursery" for thejuveniles during their progressive recruitment , and the "black hole" concept (Fonteneau 1983), where adults skipjack become unavailable and disappear from the fisheries.

Such type of differential linear mode1 is widely used in many research fields in order to describe diffusion processes(Sheppard 1962,Jaquez 1972).

In our present model, the status of the system at the end of each monthly interval will depend of the 18 potential migration rates between boxes .

7.3. Example of skipjack data used for developping and testing the model:

The data used in this mode1 belong to the for following types:

(a) The monthly cpue by age is given in number of skipjack taken by fishing day of FIS and spanish purse seiners (Figure 36). It has been calculated monthly for the 5 selected areas of the model. The cpue is calculated on the catch by size file, assuminq the same growth pattern as the one used by FONTENEAU 1986, i.e. an average growth of 12 cm per year (figure 36). In those calculation the the group of fishes measures from 37 cm to 50 cm in August 81. Some cpue data are missing in 2 cases, first when size data are missing or when the catch is only from baiboats.

(b) The catch is also calculated in numbers, from the same size file and for the same group of fishes, but is estimated for all fleets (baitboat and purseiners) , in order to measure the total removal on the cohort (VPA concept).

(c) The recoveries of tagged skipjack are extracted from the best ICCAT recovery file presently available for the two tagging conducted during skipjack year (1981) in Senegal and Ghana areas (Figure 38 and 39).

(d) The total fishing mortality estimated on the eastern Atlantic stock by age follows the general pattern estimated by FONTENEAU 1986 (Figure 40).

7.4. Estimating the underlying populations and migration rates :

The mode1 will follow numerically a qroup of fish, from its early recruitment until the death of the oldest fish. This basic qeneral concept is similar to the VPA or yield per recruit calculations.

The method used to adjust the parameters of the model to the existing data will be the following :

1.Knowing the cpue by age in each box, the theoretical underlying local population in each box must be proportionaï to the local cpue of the age (at each time).

2.Knowing the catch by age in each box, the-local underlying population must be at least equal to the observed catch. (The removal of fishes by the fisheries is exactly known by fishery statistics.)

3.The total fishing mortality on the cohort (i.e. on the sum of individuals in all the boxes), is the fishing mortality previously calculated on the overall stock by standard VPA.

4.The 18 monthly mixing rates between boxes must be in agrement with the observed diffusion of tagged fish. Only some intensive tagging cruise can be used to that purpose, each one with several thousands of tags applied within a very short time in a small area (see table 1).
The migration parameters estimated by the mode1 should be in agrement with the observed diffusion shown in figures 38 and 39.

Unfortunately, this type of adjustment by the mode1 does not give a unique solution for migration rates, unless in an ideal and hypothetic case with intensive, generalized and permanent tagging in all strata.
However,the present adjustment of the mode1 to the actual 4 sets of data can give a range of possible mixing rates which will be more realistic and quite narrow compared to the previous complete uncertainties.
This work is still under progress on the CRODT computer, and a the possible range of mixing rates has not yet been established.

6.4. Estimating interactions between fisheries with the box model.

Using the boxes mode1 and its parameters, it becomes quite simple to calculate some theoretical short and medium term interactions between fisheries operating in different areas.
For instance,the effect of reducing or increasing the fishing effort in any area, upon the catches and cpue in all other areas can easily be tested by simulations, Also, catches and cpue in each box under various local fishing mortality schemes, can be tested .
The boxes mode1 is still in its development phase, especially in order to explore the full range of possible migration rates between boxes. Several of those parameters will probably remain undetermined because of unsufficient data.

However, some preliminary results may be of some interest:

- most of the time the interactions are universely proportionna1 to the distance. For instance* the Ghana skipjack fishery has some significant effect on the Cape Lopez (average distance = 600 naut.miles)and Liberia fisheries (900 miles). The Senegal fishery has very little or no effect on the Cape Lopez (1800 miles) or Angola fisheries (2500 miles), but some effect on the Liberia fishery (600 miles) .

- a short distance between two fishing areas is not an evidence for strong potential interactions: the Cape Verde Island and Senegal fisheries are located at a short distance, 200 miles only, but show very little or no mixing between the two fisheries. This absence of interactions has been clearly demonstrated by the recoveries of two simultaneous intensive tagging cruises conducted in the 2 areas.

- only intensive fisheries and high catches in one area can affect the othes ones, because of the intensity (in general) and the complexity of mixing processes, at least for skipjack. For instance the Angola fishery which operates presently at a low level, compared to the local biomass, has no effect on any other fishery because the Angola catch is small and the skipjack biomass transient from Angola is diluted very quickly among skipjack originated from other areas, especially with the unfished fraction of the skipjack stock migrating from the "cryptic nursery" to the major fishing areas..

7.5. Discussion of the boxes model.

This type of mode1 is a potentially serious progress in analyzing the stock structure problem , the migration patterns and the interactions between fisheries.

However it requires a huge amount of detailed statistics, especially catches and cpue statistics by sizes. Those statistics must cover all fleets(VPA concept). Intensive tagging with good recovery statistics must also be available. Furthermore this type of mode1 in fundamentally based on the existence of significant fisheries covering preferably most of the stock and operating at relatively high level of fishing mortality (at least locally). Even in the optimum case when mixing rates can be estimated duxing a limited period of intensive researches (such as ISYP), it is not yet clear to what degree the calculated migration pattern can be extrapolated to an other period. More generally the year to year variability of tuna migrations and its determinism is still a great unknown .

Also the mode1 rely on several underlying hypothesis, especially on the homogeneity of boxes and on the box to box relationship, which can probably be more analyzed and improved,. The heterogeneity of the senegalese box has for instance been clearly demonstrated by the low exchange rate between Senegal and Cape Verde islands. Furthermore the analysis assumes that group of fishes is followed (catch and cpue) when the individual are growing. The variance of growth between individuals and between area being apparently large (Bard et Antoine, 1986), this hypothesis is not strictly justified.

However, this type of research is probably a very interesting field to be developped.

8. CONCLUSION.

The present paper has tried to demonstrate the complexity and the heterogeneity of the interaction problem between tuna fisheries. It makes a provisional review of the present observations done upon the atlantic tropical tunas in this field. It is clear that the Atlantic ocean offers good conditions for those studies, because of intensive fisheries, good statistics over a long period of time and some intensive tagging .

Many of the Atlantic results can probably be extrapolated , at least to some extent, from one ocean to the other, even when the ecological conditions are quite different.

This type of worldwide analysis of the interactions betqween tuna fisheries seems presently a key action to conduct.

In any case this paper well shows the fundamental importance for any interaction study of :

-Detailed fishery statistics(catch,effort and sizes taken by gear),with a detailed time and area stratification.

-Intensive tagging.

The tagging of a great number of fish done simultaneously in the same spot, such as the senegalese ,cap verdian or japanese ISYP tagging, seems to be a key action towards the estimation of the short term interaction between fisheries, at least those taking small fishes.

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Table 1.- Skipjack taggings done during recent years which can be used for diffusion analysis because of a significant number of tags released during a single cruise in the same place.

YEAR	ZONE	COUNTRY	TAGGED SKIPJACK
80	GHANA	JAPON	5976
81	GHANA	JAPON	7000
81	SENEGAL	SENEGAL	1391
81	SENEGAL	CAP VERT	2672
82	SENEGAL	CAP VERT	4552
82	SENEGAL	SENEGAL	2794
TOTAL ZONE SENEGAL			11409
TOTAL ZONE GHANA			12976

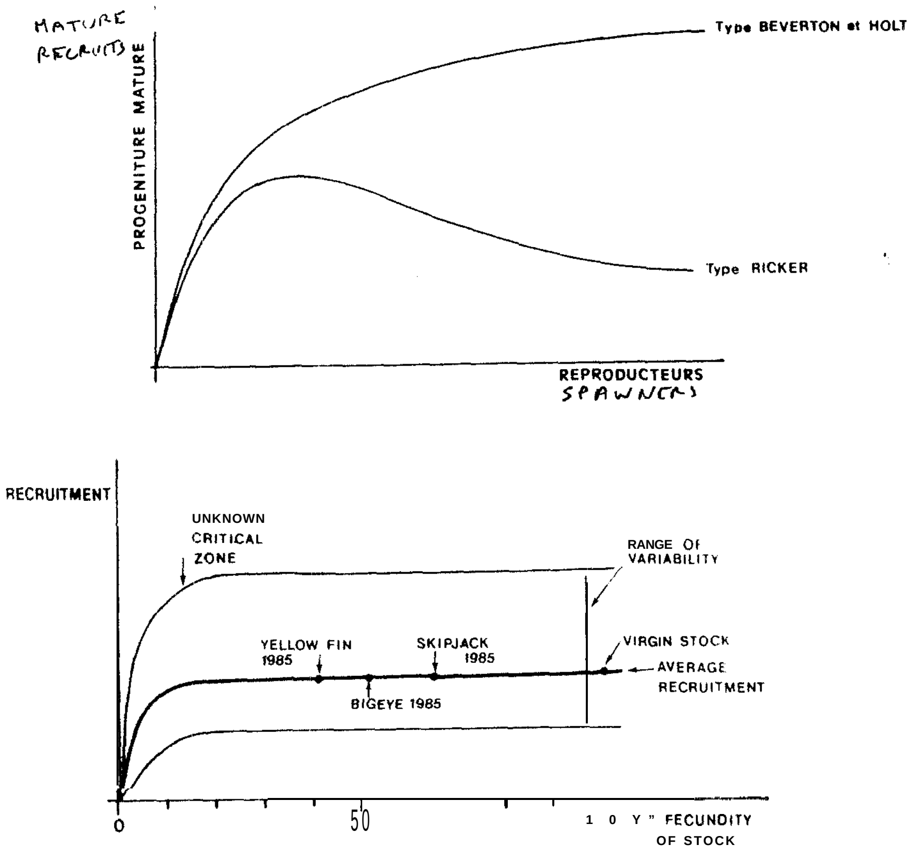


Figure 1.- The classical stock recruitment relationship (a)Ricker type and (b) Beverton and Holt, and the Atlantic stock relationship with the present level of stocks estimated for yellowfin, bigeye and skipjack.

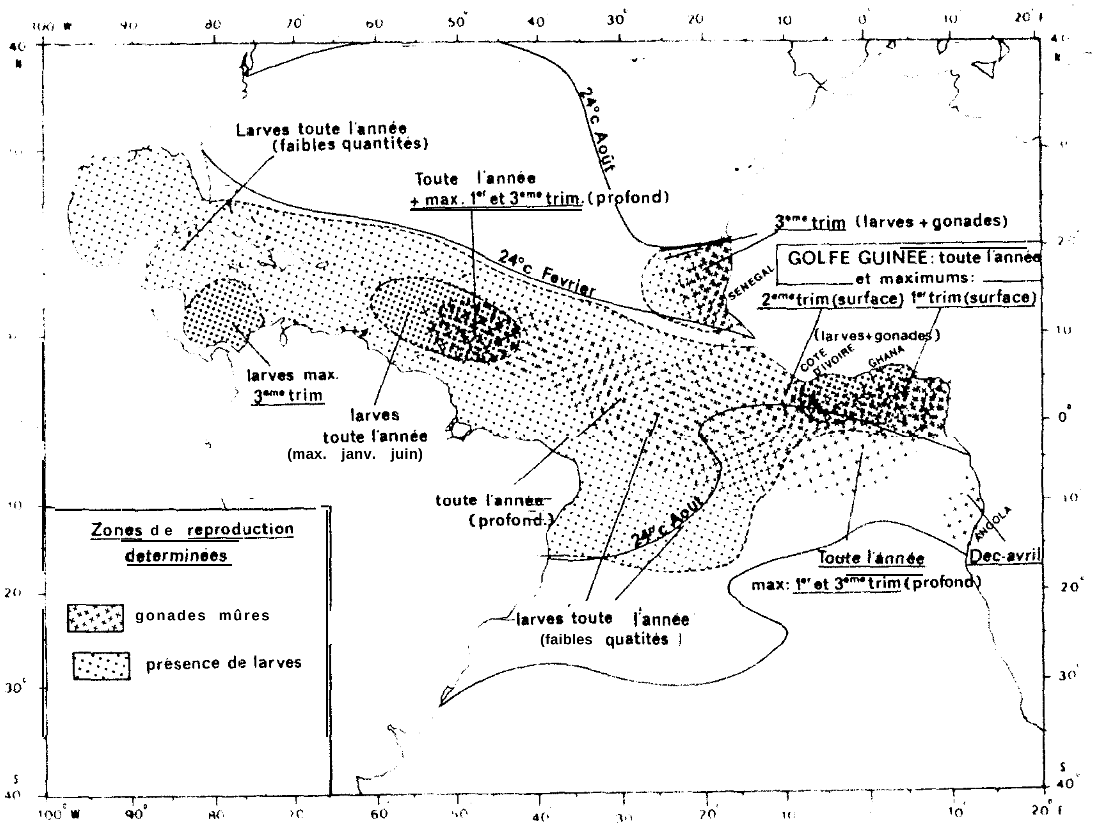


Figure 2.- Spawning areas of Atlantic yellowfin (from Cayre et al. in press in FAO synthesis on eastern Atlantic tuna)

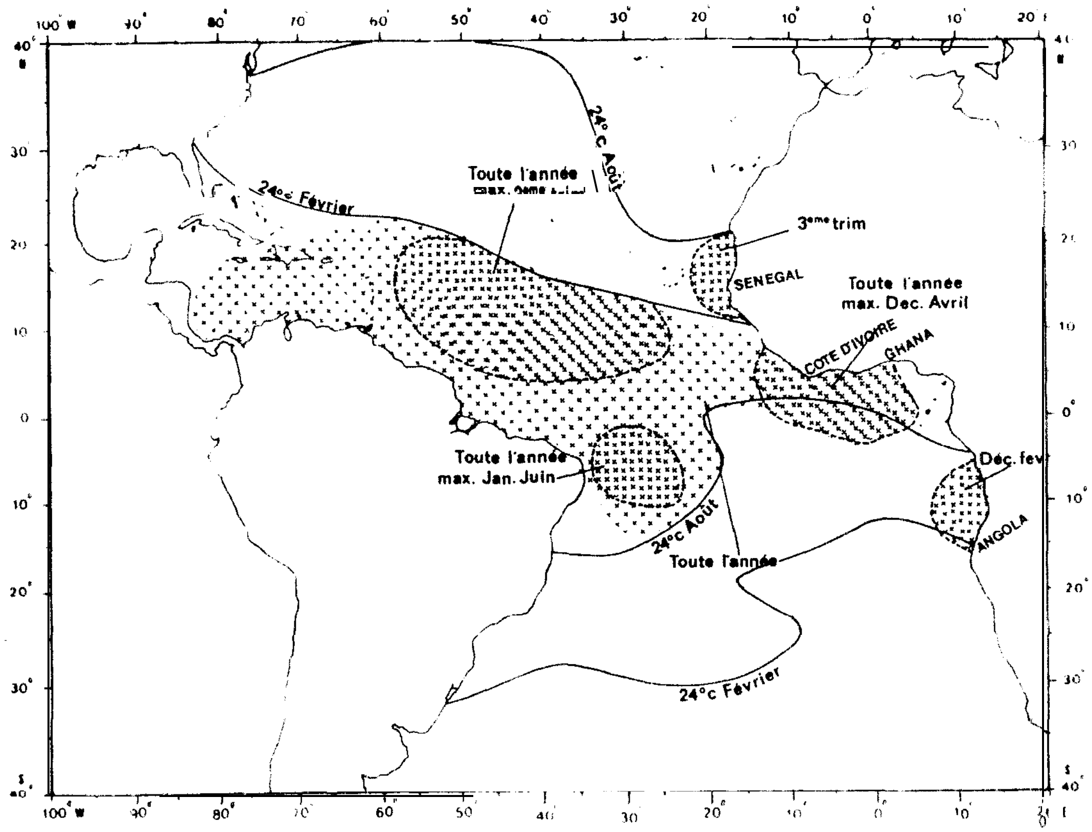


Figure 3.- Spawning areas of Atlantic bigeye (from Cayré et al., in press in FAO synthesis on eastern Atlantic tuna).

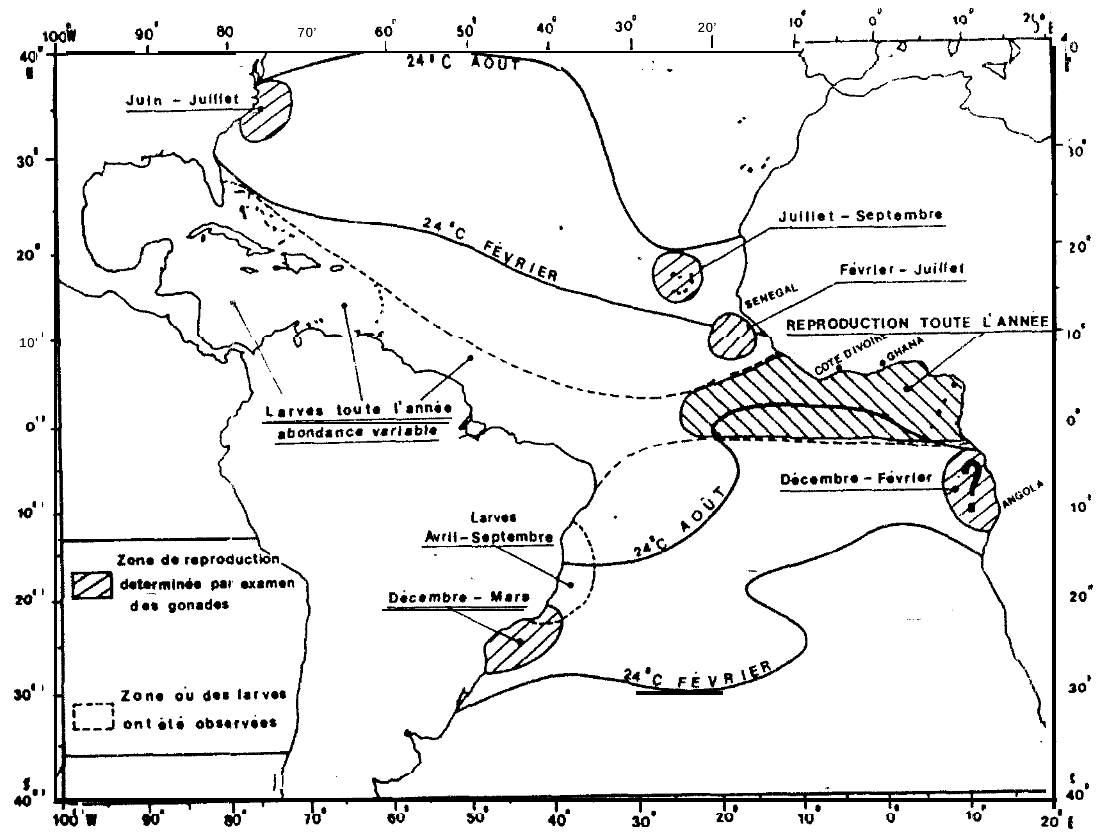


Figure 4.- Spawning areas of Atlantic skipjack (from Cayre et al., in press in FAO synthesis on eastern Atlantic tuna).

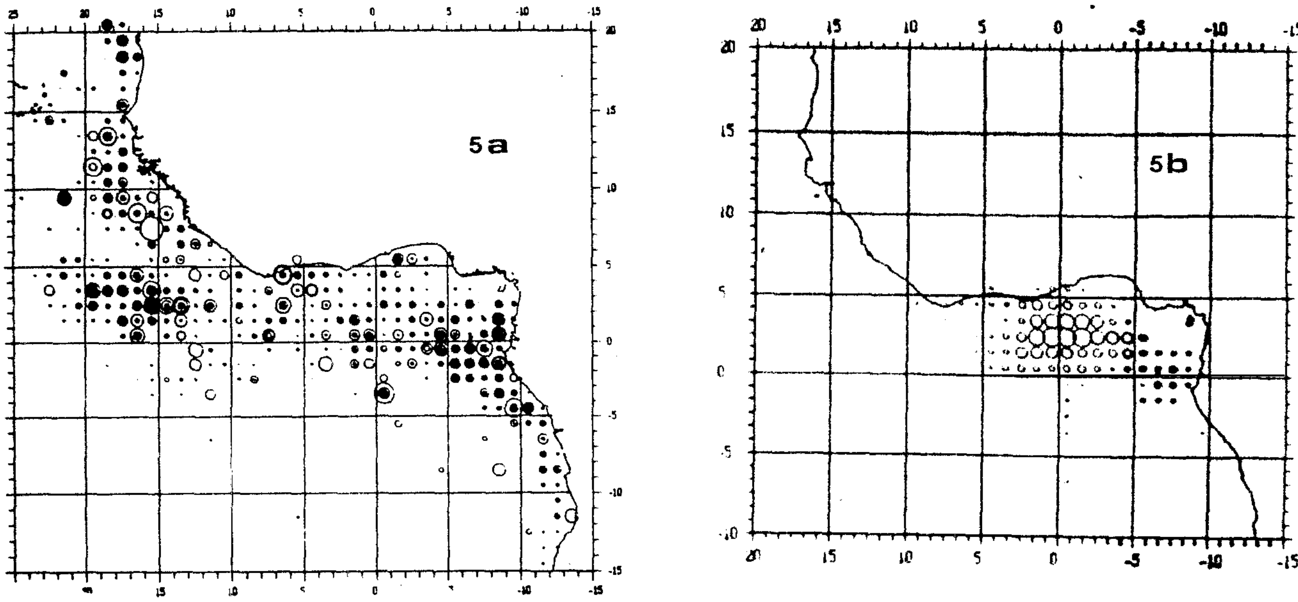


Figure 5.- Areas of catches of small bigeye (less than 90 cm) by purse seiners (1979-1983) (5a) and by Tema baitboats (1975-1982) (5b).

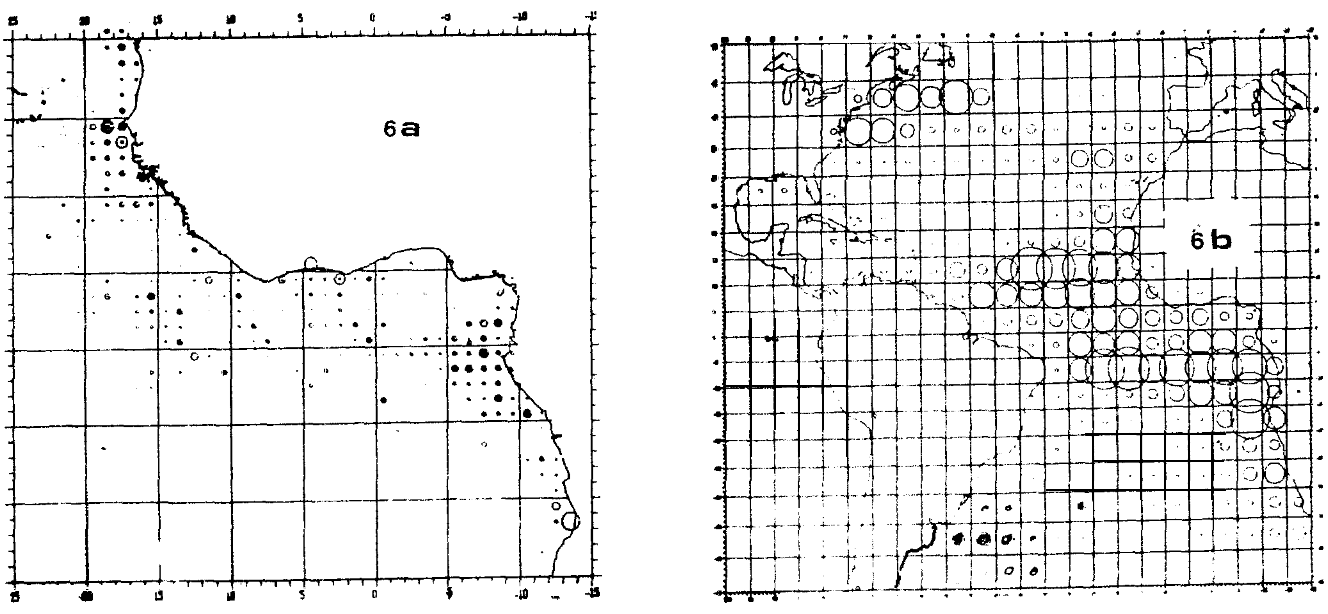


Figure 6.- Areas of catches of large bigeye (more than 90 cm), by purse seiners (1979-1983) (6a) and by longliners (1978-1982) (6b).

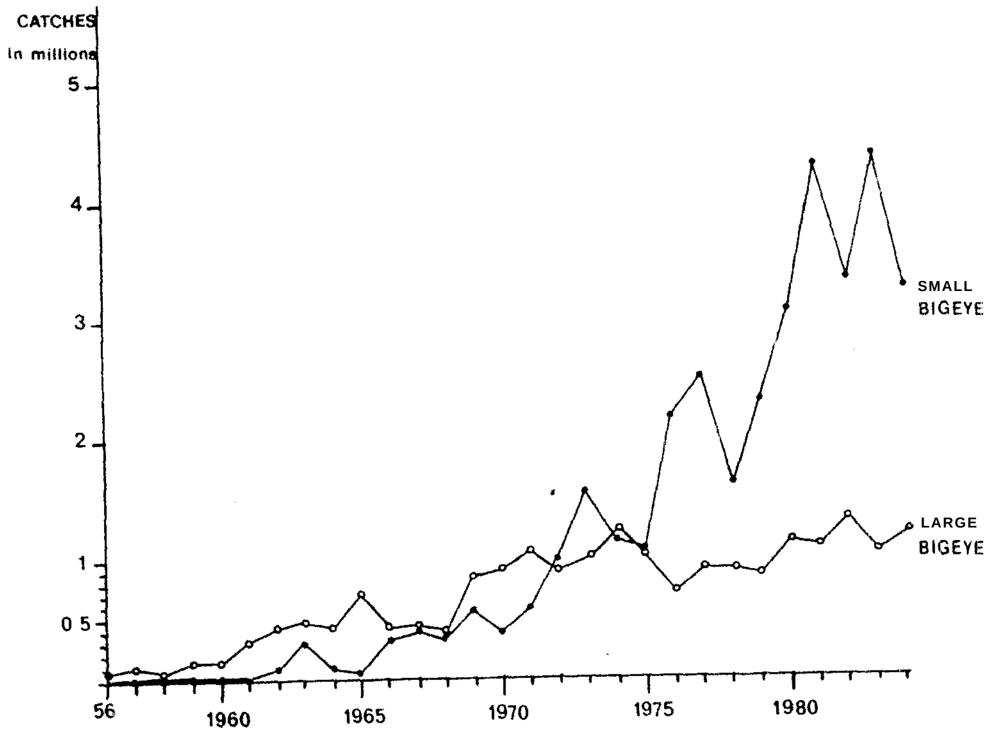


Figure 7.- Catches of small (less than 90 cm) and of large bigeye (more than 90 cm), from 1955 to 1983.

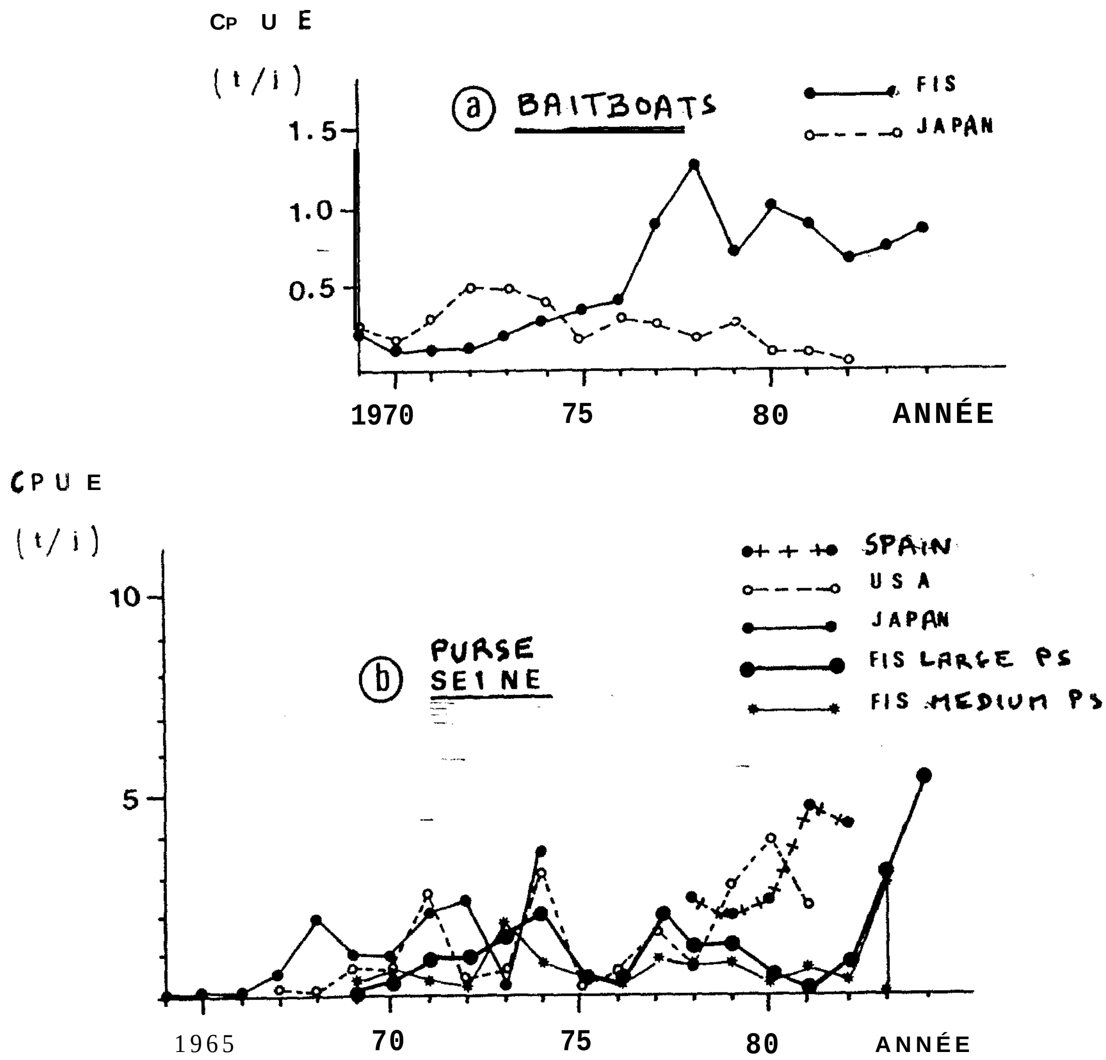


Figure 8.- Catch per unit of effort of bigeye (predominantly less than 90 cm), by surface fleets.

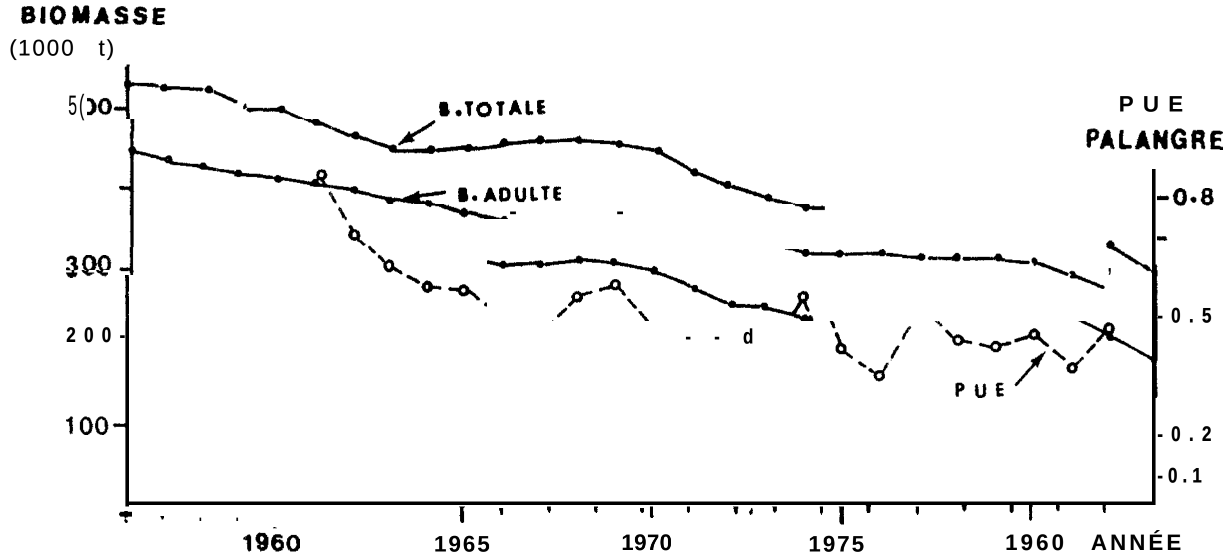


Figure 9.- Index of abundance (calculated for bigeye tuna on japanese longline fisheries by Honma method, corrected for deep longlining) , and adult biomass c-alculated by VPA.

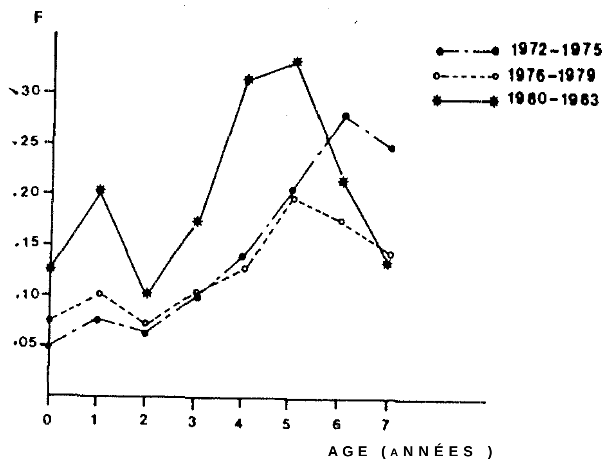


Figure 10.- Average fishing mortalities by age, during recent years on bigeye tuna.

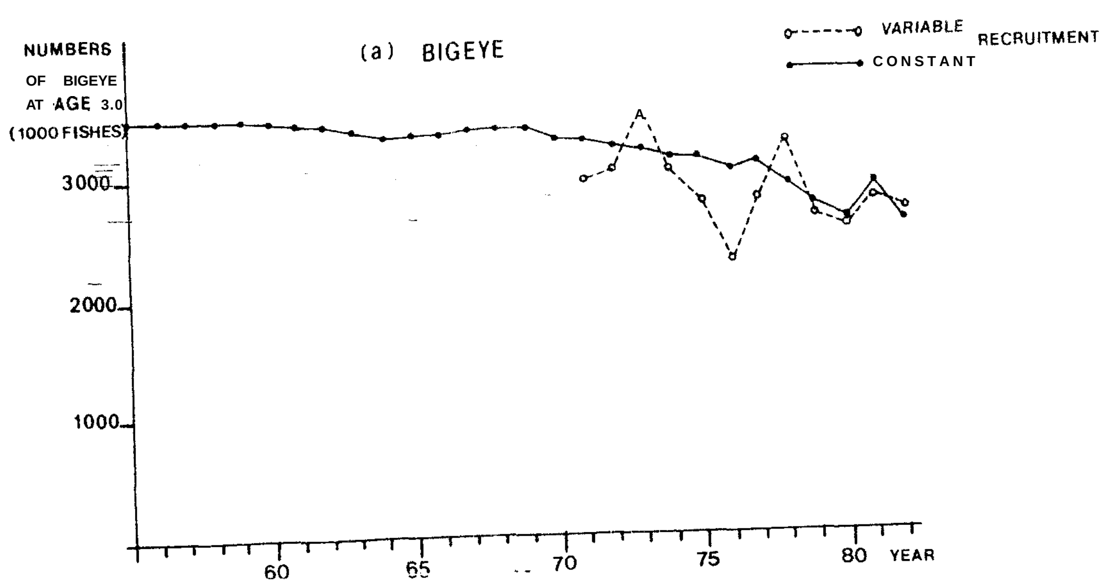
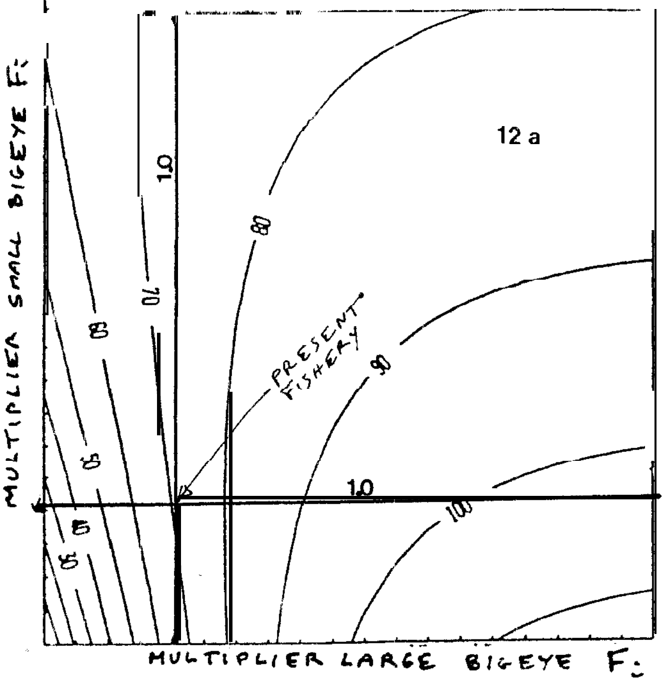


Figure 11.- Estimated numbers of bigeye tunas recruited in the adult fisheries (result of VPA, from Pereira 1984).



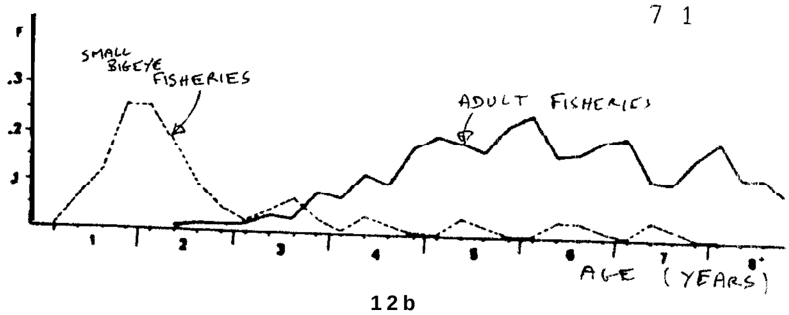
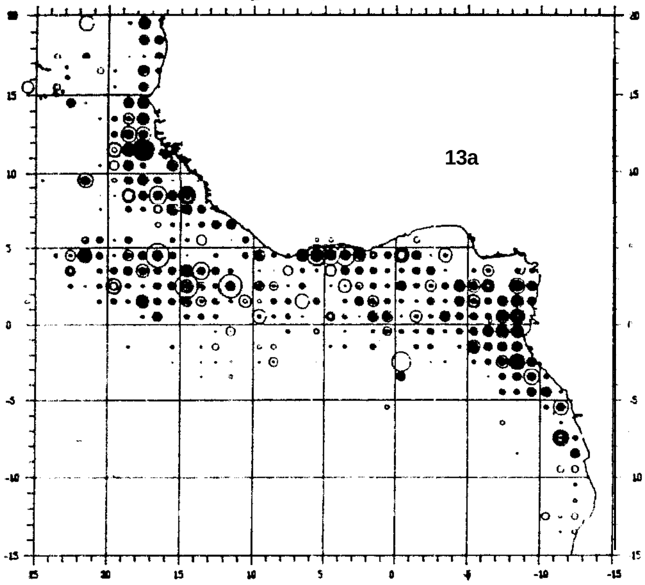


Figure 12.- Multigear yield per recruit analysis for bigeye small bigeye fisheries against large bigeye fishery 12 (a). The Fishing mortalities by age of each gear are given in figure 12(b).



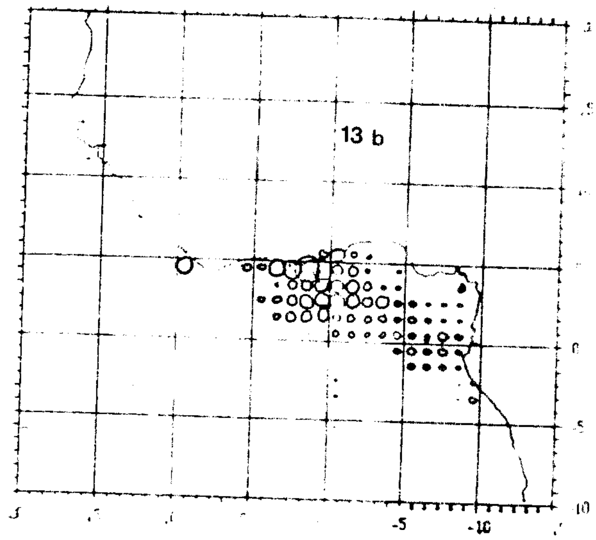
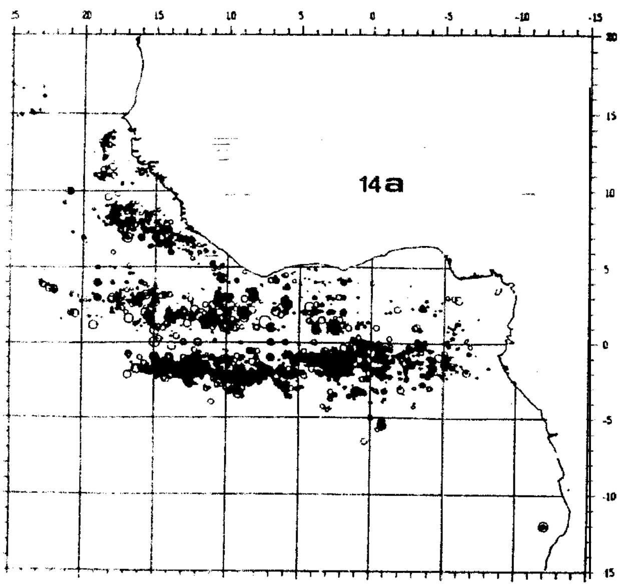


Figure 13.- Fishing areas of small yellowfin (less than 90 cm),by pur-se seiners(13 a) during recent years (1979-1983) and by Tema baitboats (1975-1982) (13b)



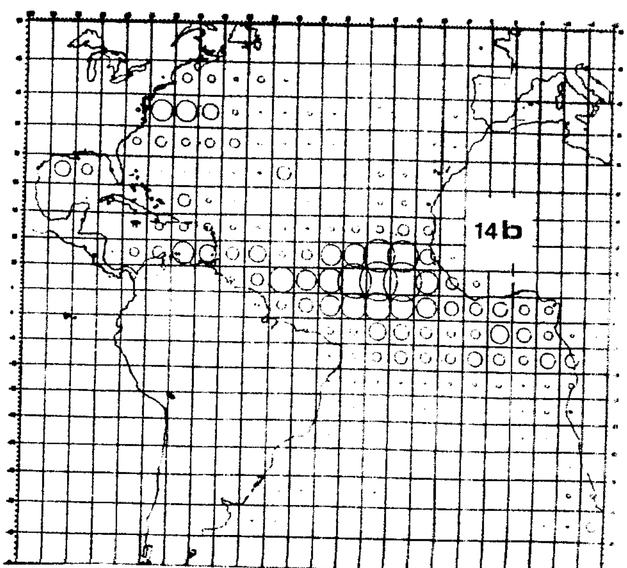


Figure 14.- Fishing areas of large yellowfin (more than 90 cm) by purse seiners (14a) during recent years and fishing areas of longliners (1978-1982) (14 b).

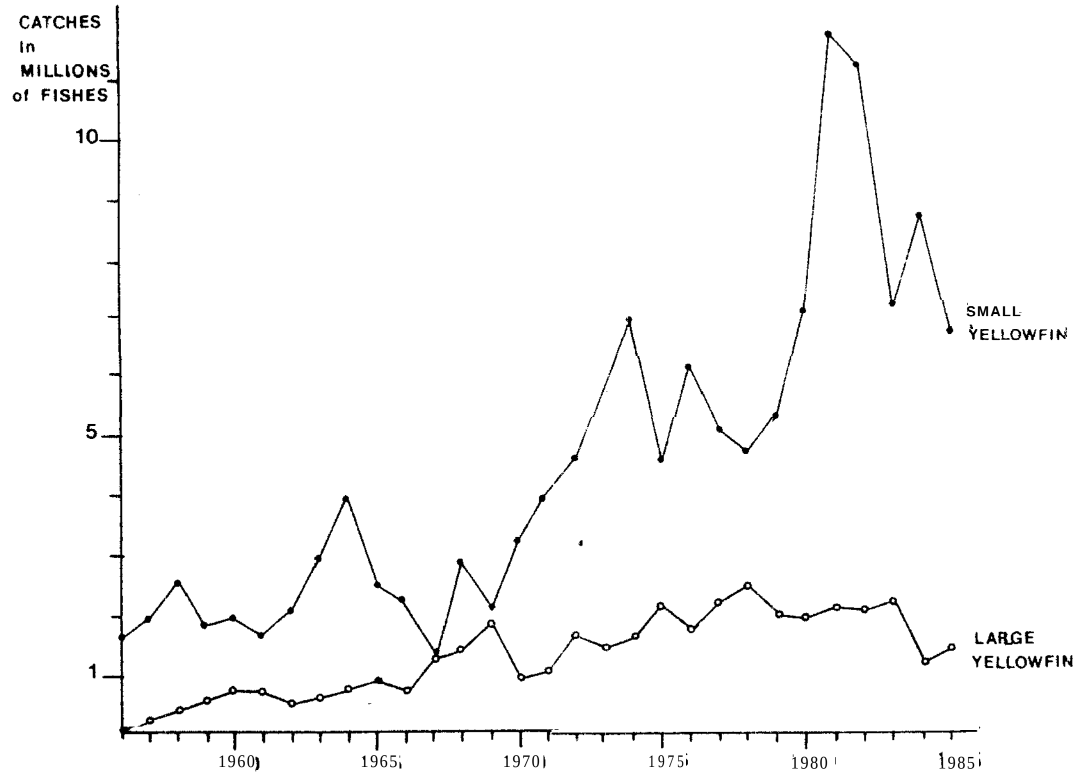


Figure 15.- Numbers of small (less than 90 cm) and large (more than 90 cm) yellowfin taken in the Atlantic by all fisheries.

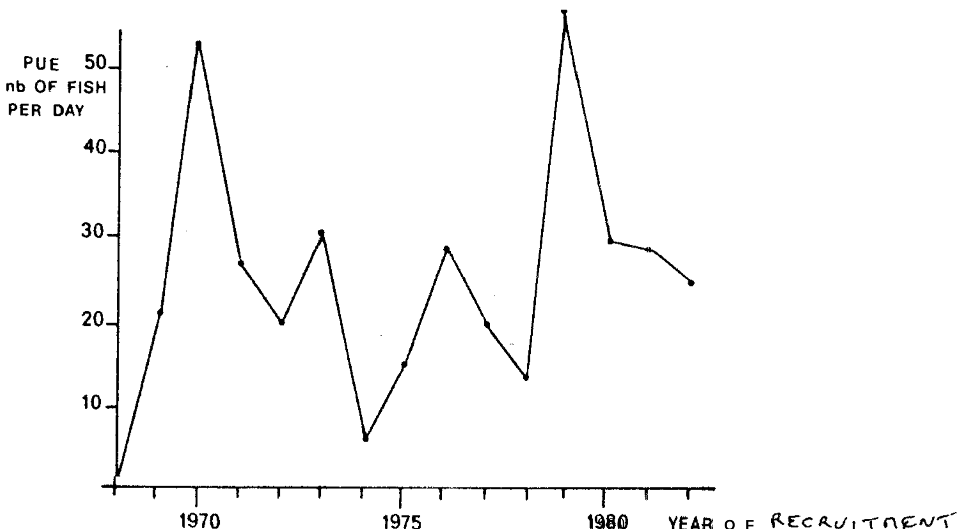


Figure 16.- Catch per unit of effort of yellowfin (from Fonteneau 1984) at age 1 (FISM purse seiners, :LAUREC and FONTENEAU 1977 method), measuring the recruitment.

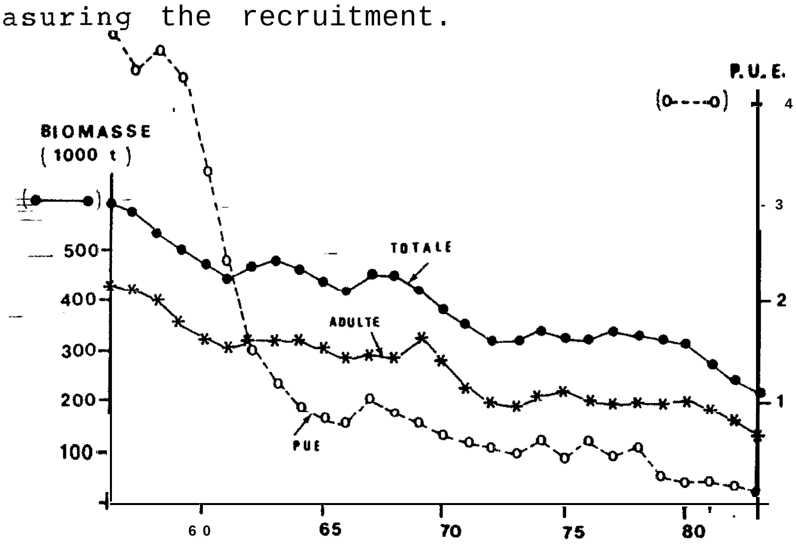


Figure 17.- (a) Catch per unit of effort of the japanese longline fishery (Honma index, uncorrected for deep longlining), and biomass calculated by VPA (from FONTENEAU 1984) and 18(b) catch per unit of effort on large yellowfin by purse seiners (Fonteneau 1986, cpue index corrected for large fishes),and longline cpue index during the same period 1969-1983.

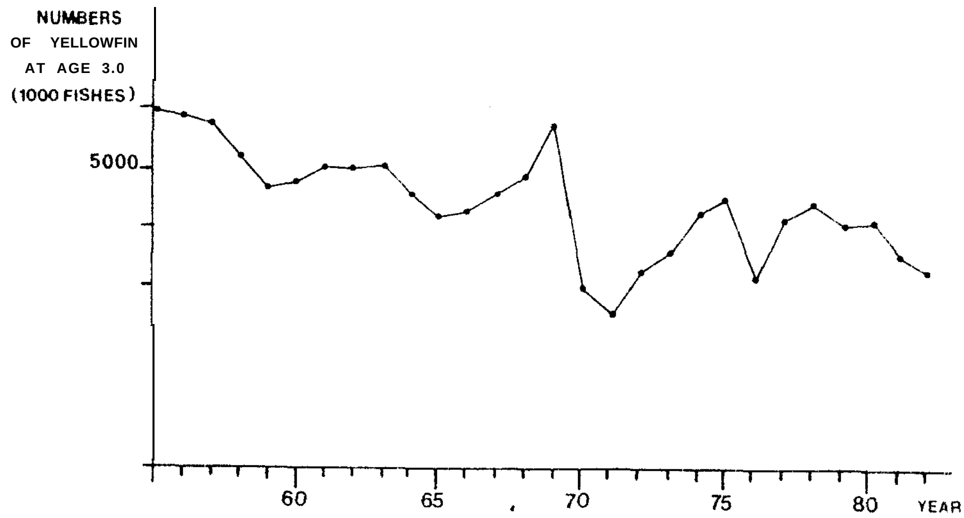


Figure 18.- Changes in the recruitment levels to the adult yellowfin fisheries estimated by VPA.

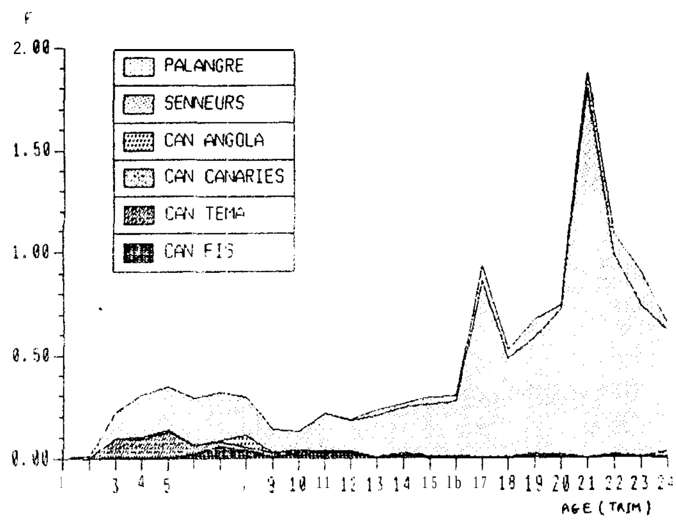


Figure 19.- Average age specific fishing mortality for eastern Atlantic yellowfin (period 1980-1983) (from FONTENEAU 1986).

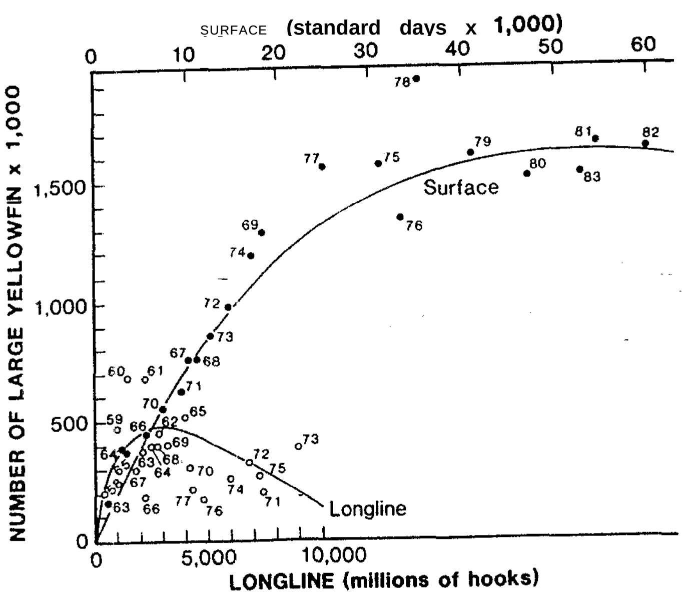


Figure 20.- Catches by purse seiners and by longliners on large yellowfin as a function of their respective fishing effort (From HUNTER et al. 1986).

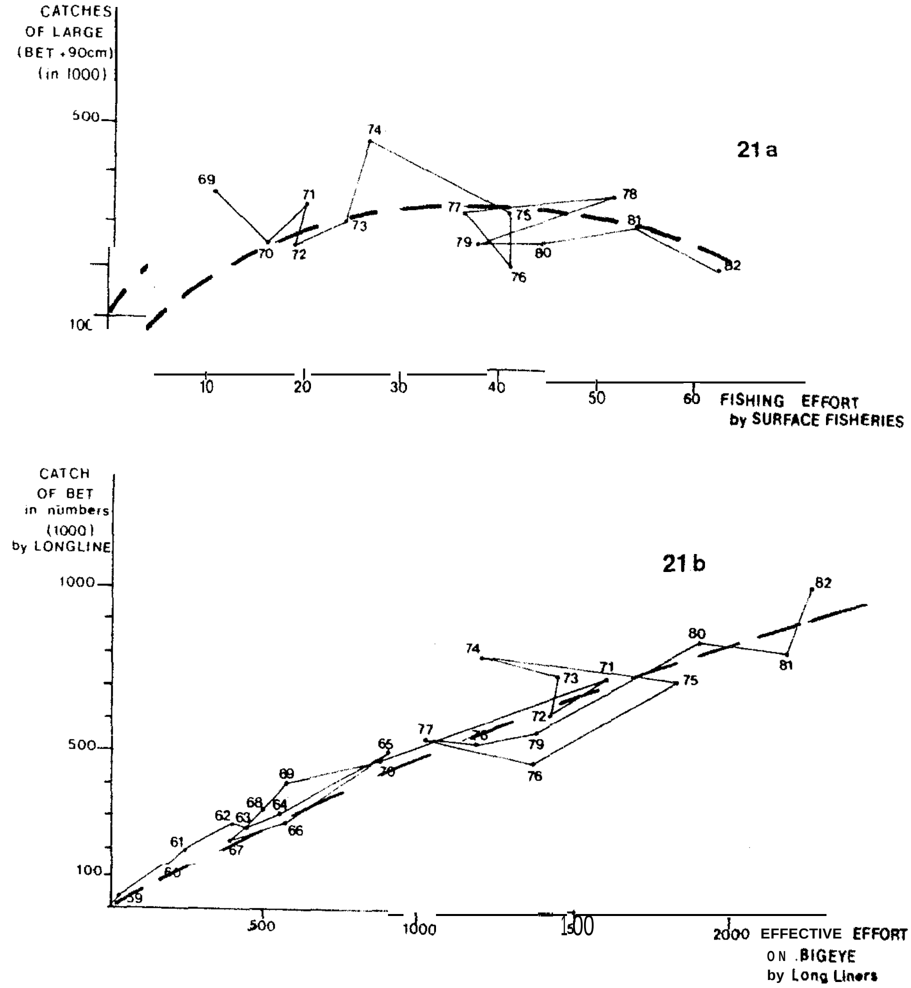


Figure 21.- Catches by purse seiners (21a) and by longliners (21b) on large bigeye as a function of their respective fishing efforts (curves are adjusted by eye).

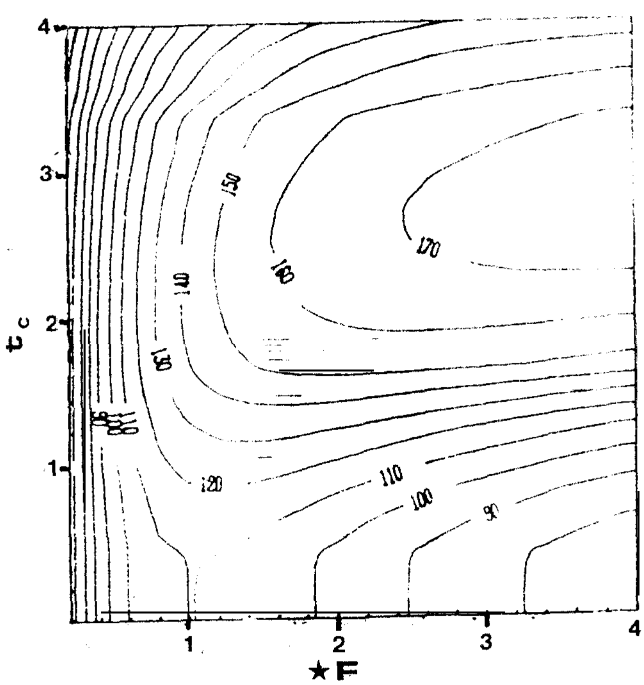


Figure 22.- Yield per recruit of yellowfin eastern Atlantic, period 1980-83, Ricker mode1 corresponding to F vector of figure 19 (from FONTENEAU 2986).

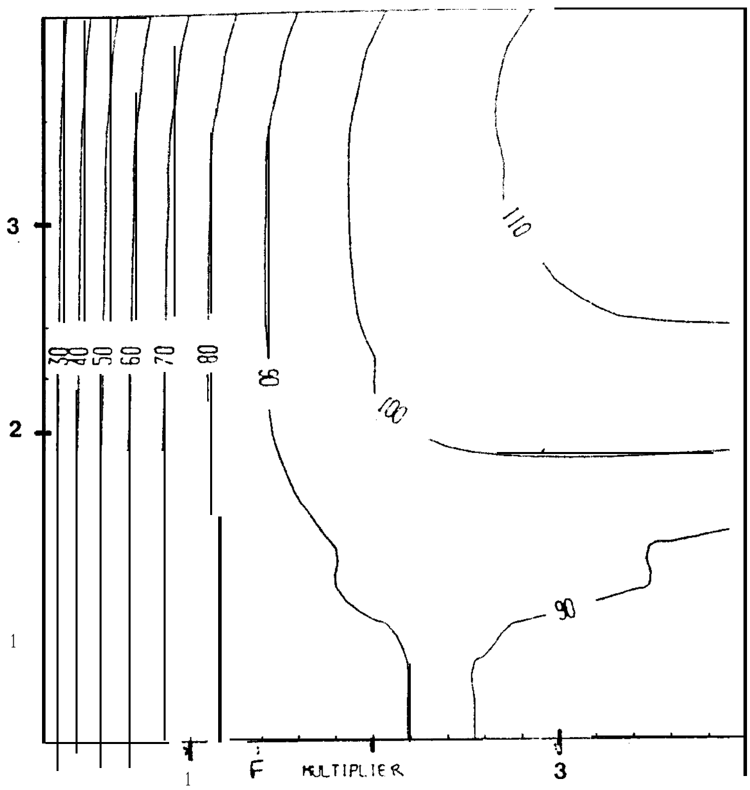


Figure 23.- Yield per recruit of bigeye, all Atlantic, period 1980 to 1984 , Ricker mode1 (from PEREIRA 1986).

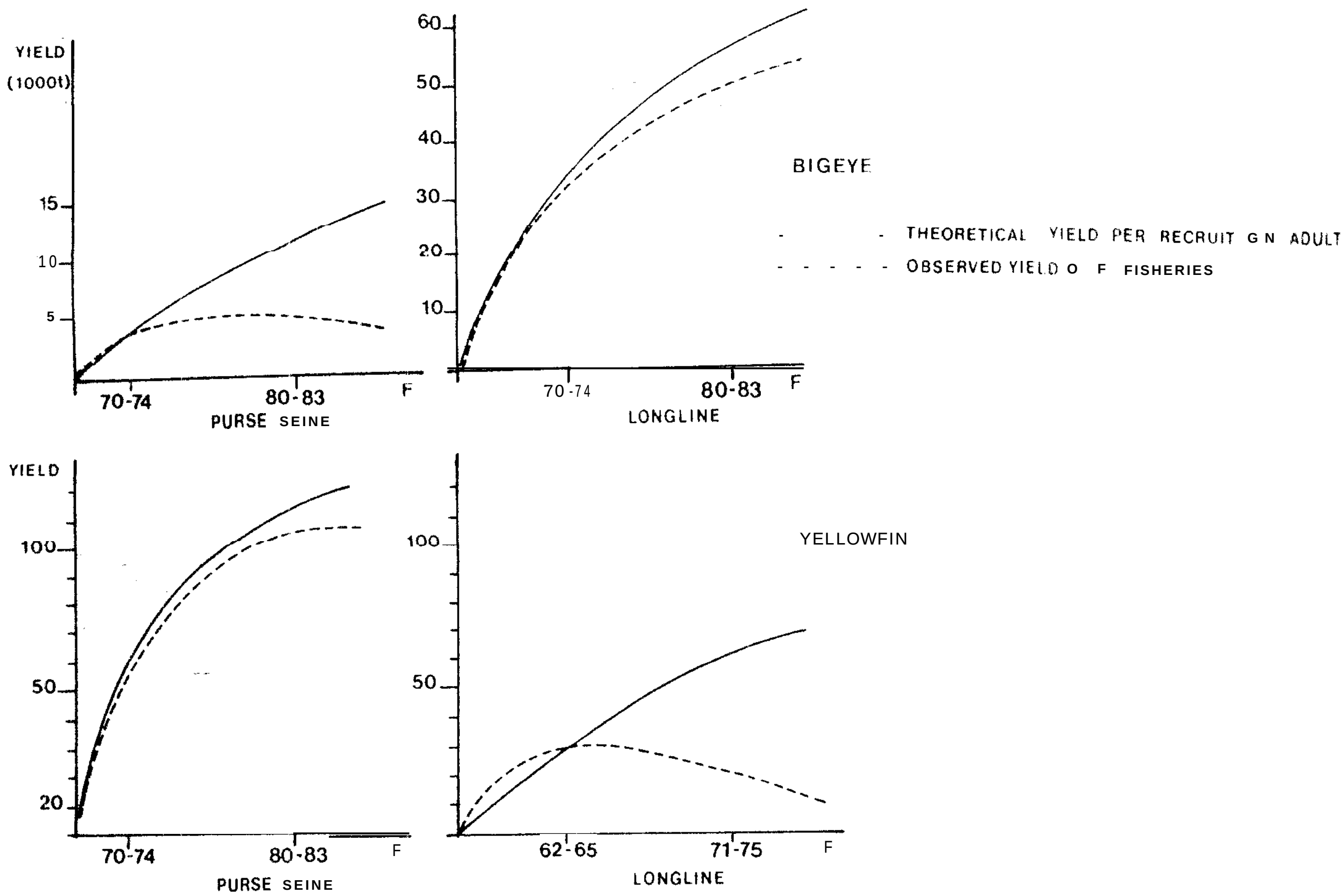


Figure 24- Theoretical and observed yield of purse seiners and longliners,for yellowfin and bigeye tunas.The theoretical yield is a yield per recruit analysis result, Ricker model, where the yield per recruit is multiplied by the recruitment estimated for the adult fishery .In this Y/R analysis,each gear is supposed to h n fi shing alone.

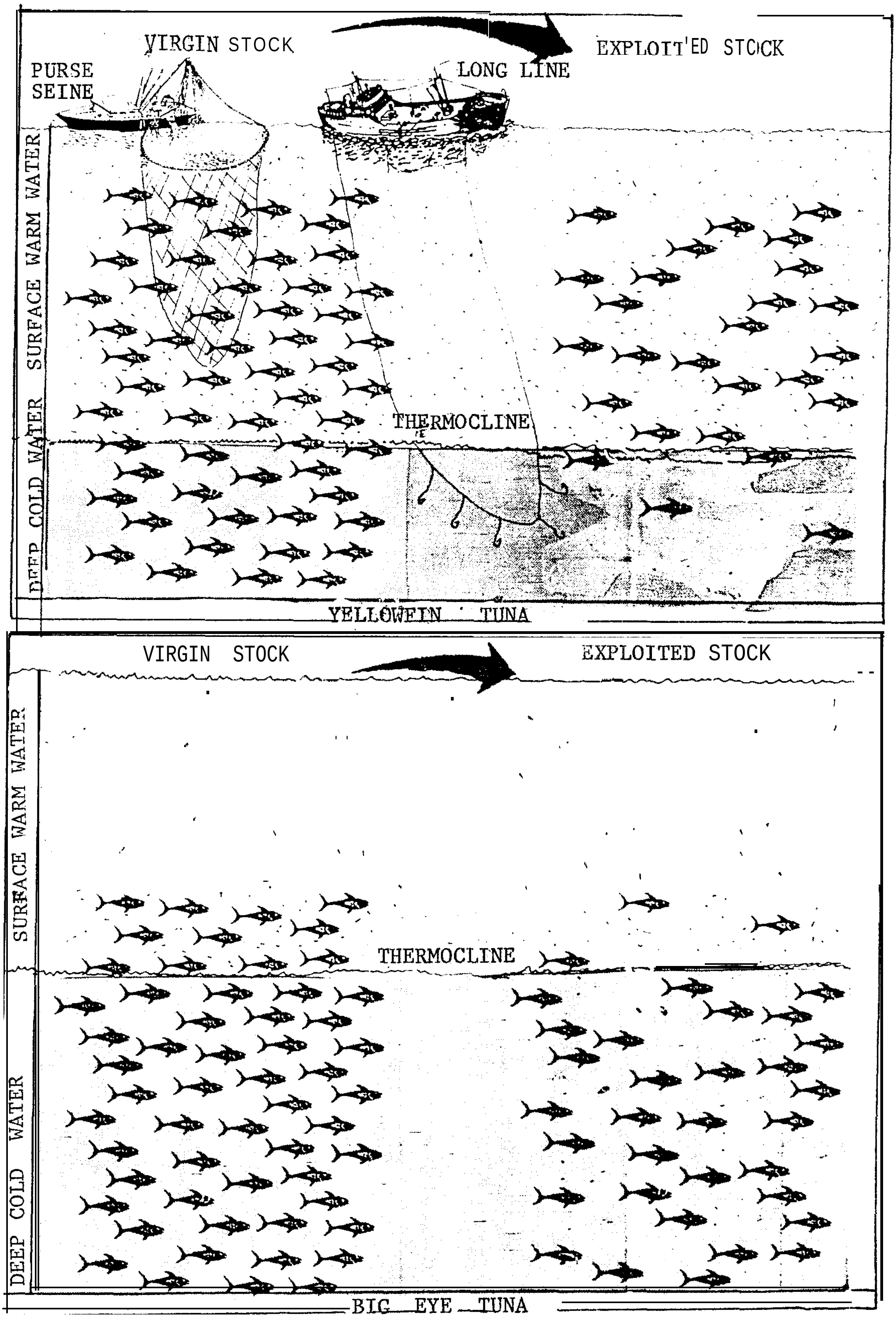


Figure 25.- The hypothetical vertical stock structure of yellowfin and bigeye for the virgin stocks and for the fully exploited stocks.

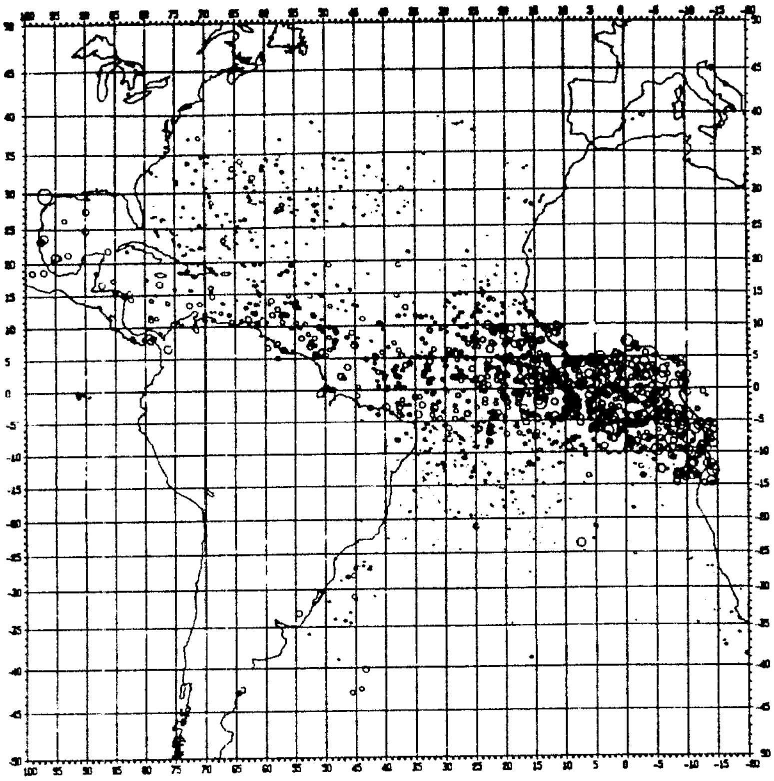


Figure 26.- Catch per unit of effort of japanese longliners during the first quarter e.g. the better fishing season in the Gulf of Guinea (in tons/1000 hooks), for the historical fishery 1961 to 1969 (Each month and 5 to 5 degree square cpue is represented randomly in the corresponding 5 degree square).

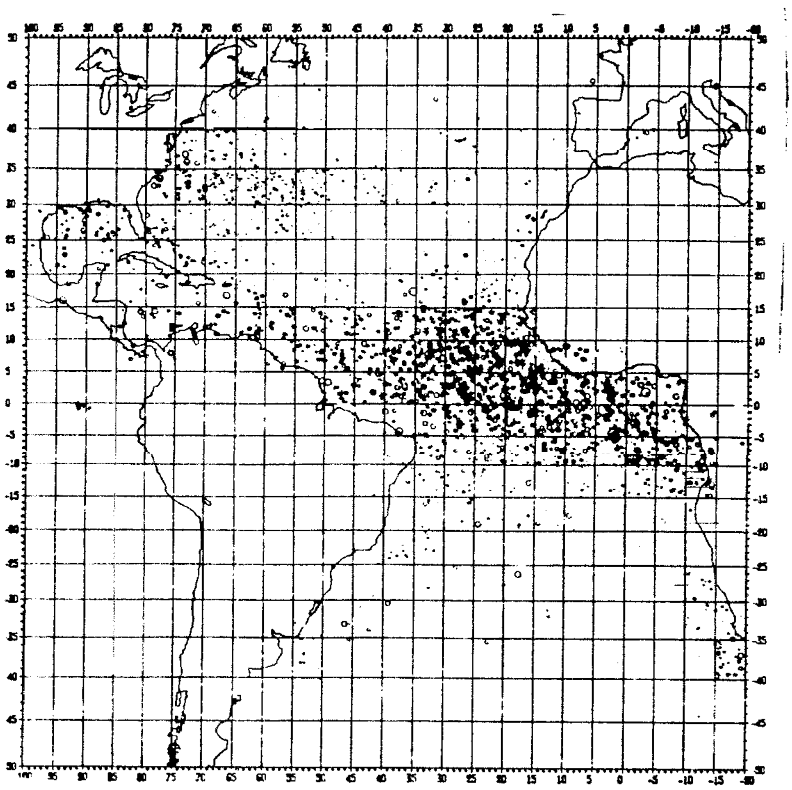
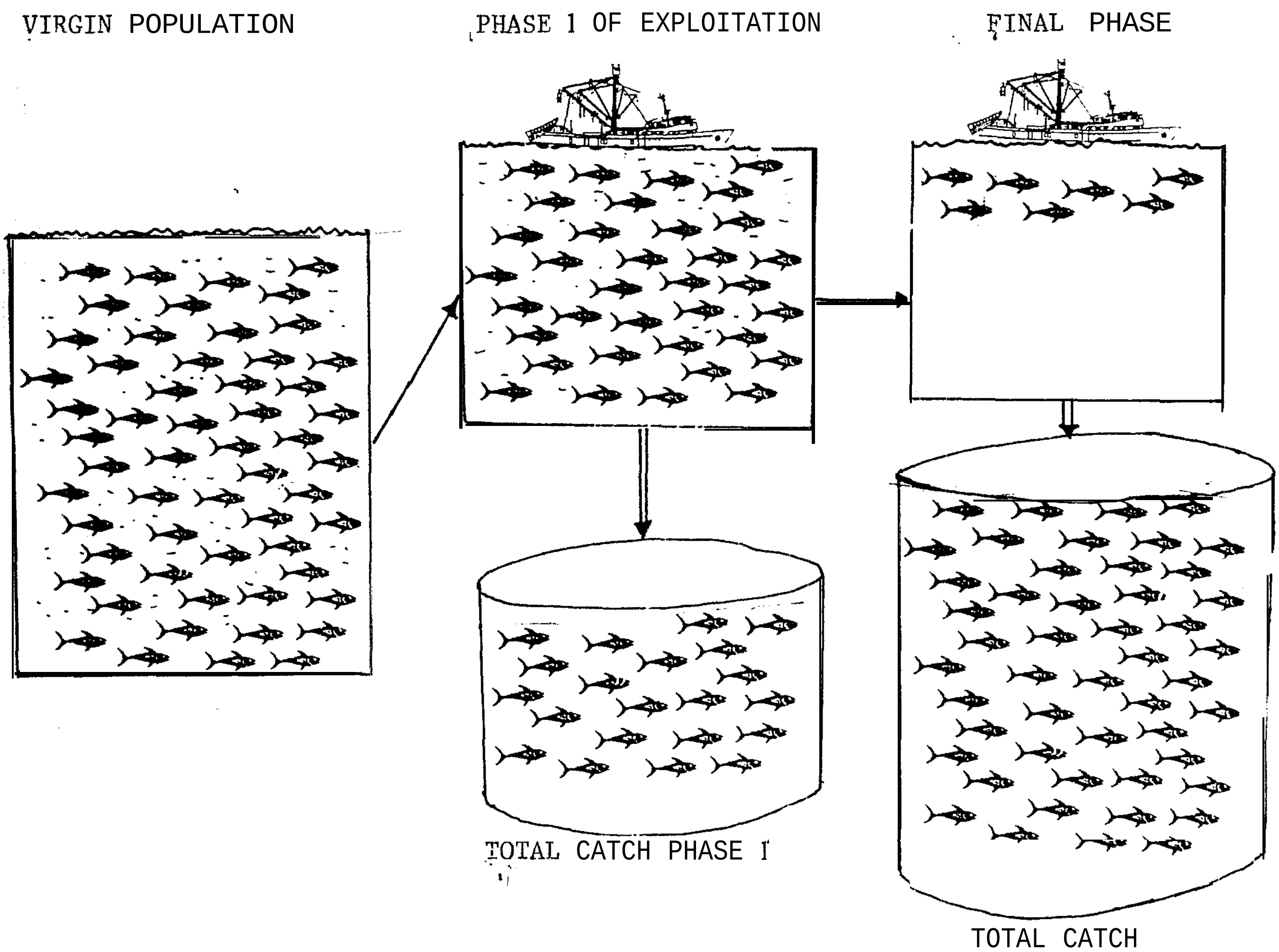


Figure 27.-Catch per unit of effort of japanese longliners during the first quarter (tons/1000 hooks), during the recent period 1970 to 1982 (Each month- 5 to 5 degree cpue is represerted randomly .in the corresponding 5 degree square).

28a : THE "URN" MODEL CONCERT



28 b CATCH, EFFORT , CPUE RELATIONSHIP

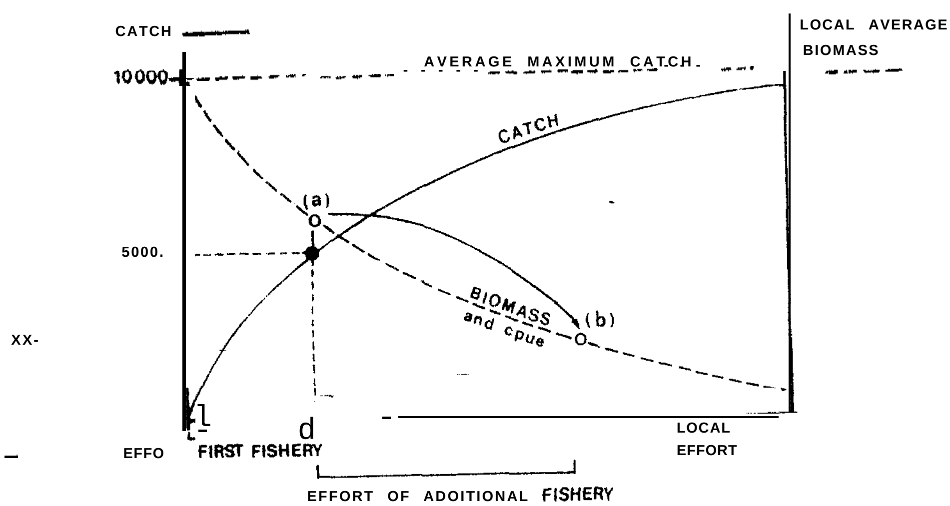


Figure 28.- The "urn model" concept:
(28a) The general simple idea of a closed and limited exploited resource.
(28b) The catch and catch rate trends when an additionnal fishery is added to a first fishery: (a) is the cpue of the first fishery before the arriva.1 of the second one and (b) is the cpue after .

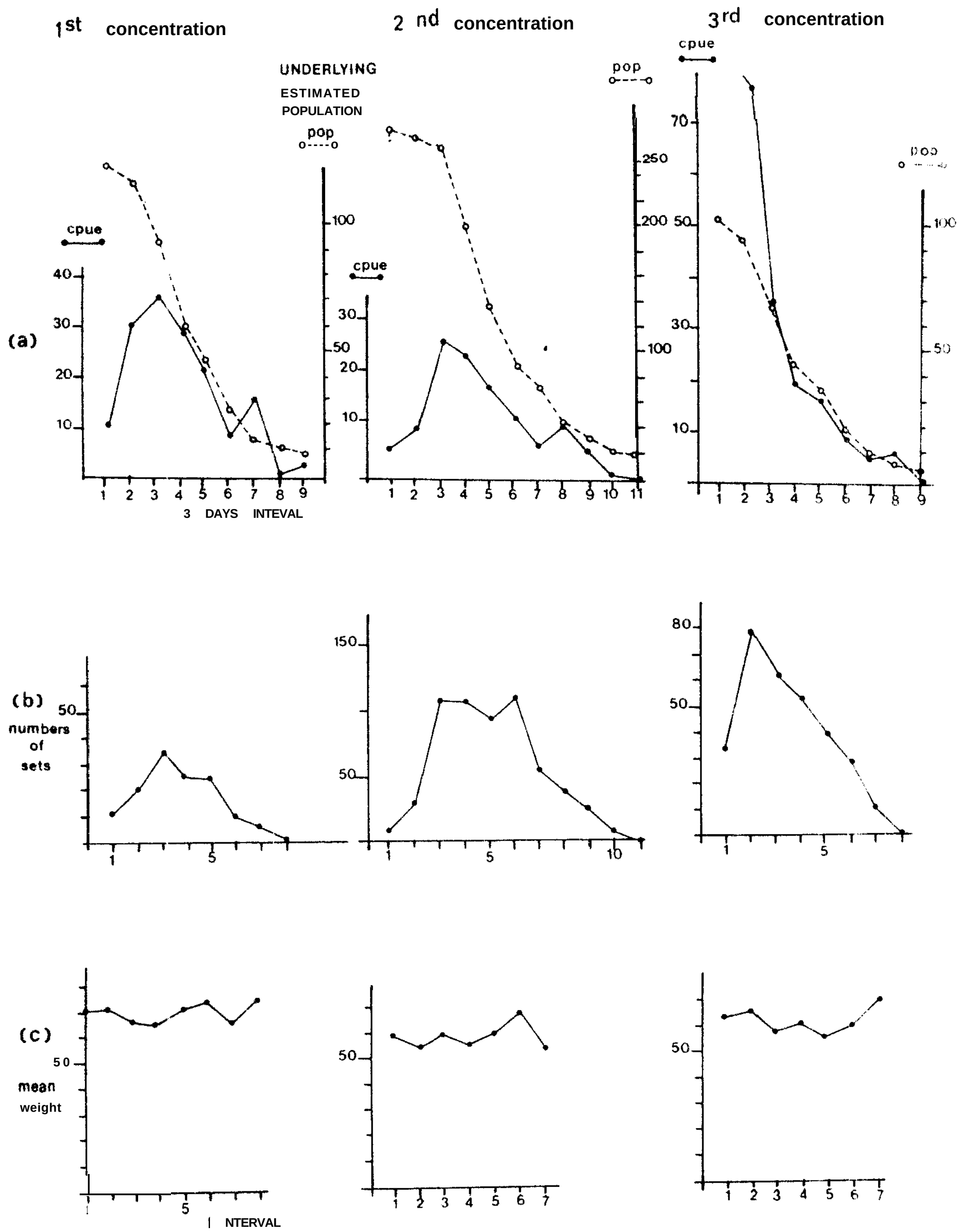


Figure 29.- Exqmple of parameters concerning the exploitation of three yellowfin concentrations in the eastern Atlantic.

(a) observed cpue of purse seiners(in tons by 10 hours of searching),and estimated underlying populations by 3 days periods(From Fonteneau 1986).

(b)Numbers of positive sets by 3 days periods(Which can be considered as the number of schools removed from the concentration)

(c)Average weight of the yellowfin caught.

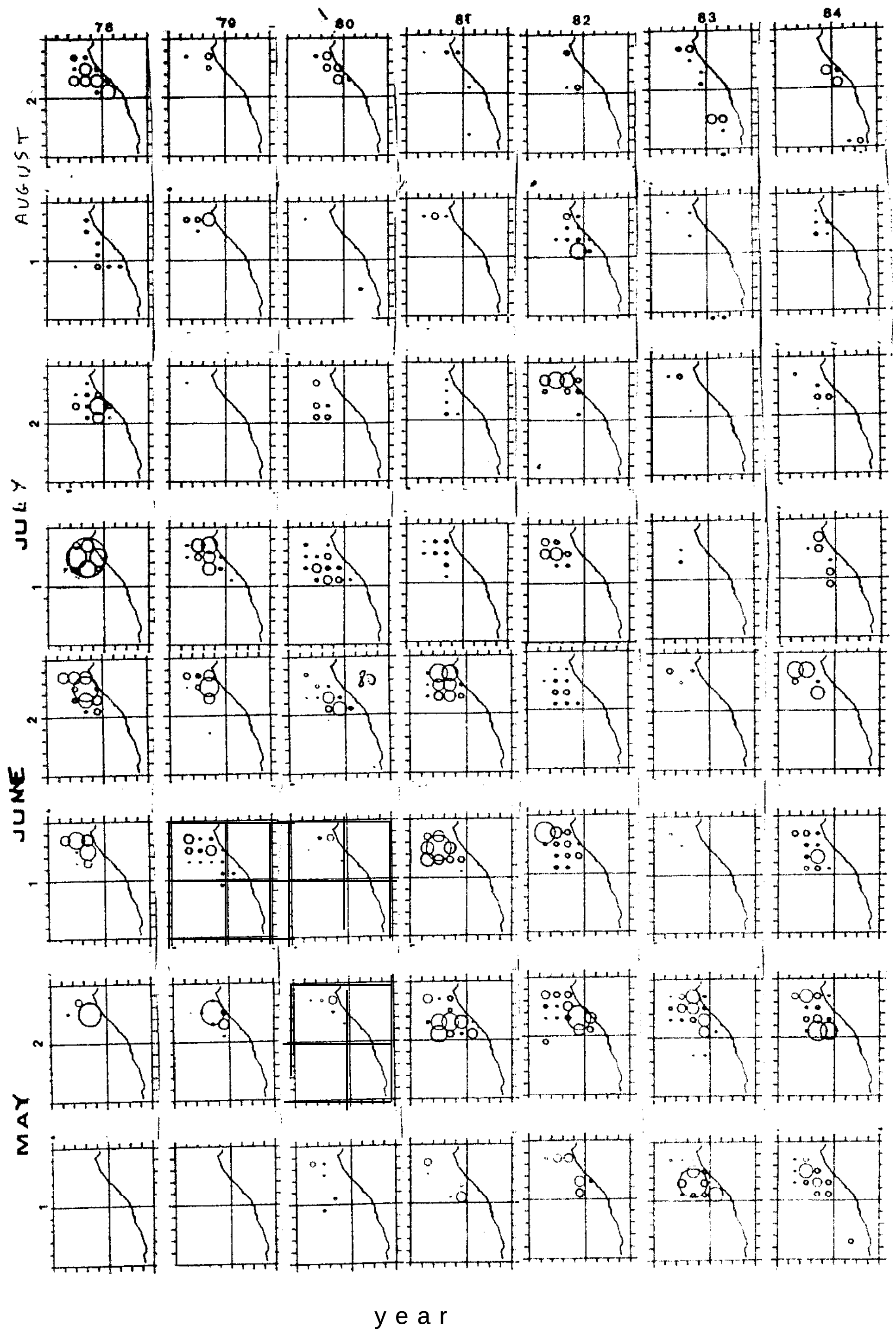


Figure 30.- The fishing area of Cap2 Lopez : geographical distribution of the catches by purse seiners (FIS and Spanish), by 15 days period from 1978 to 1984 (from FONTENEAU and ROY 1987).

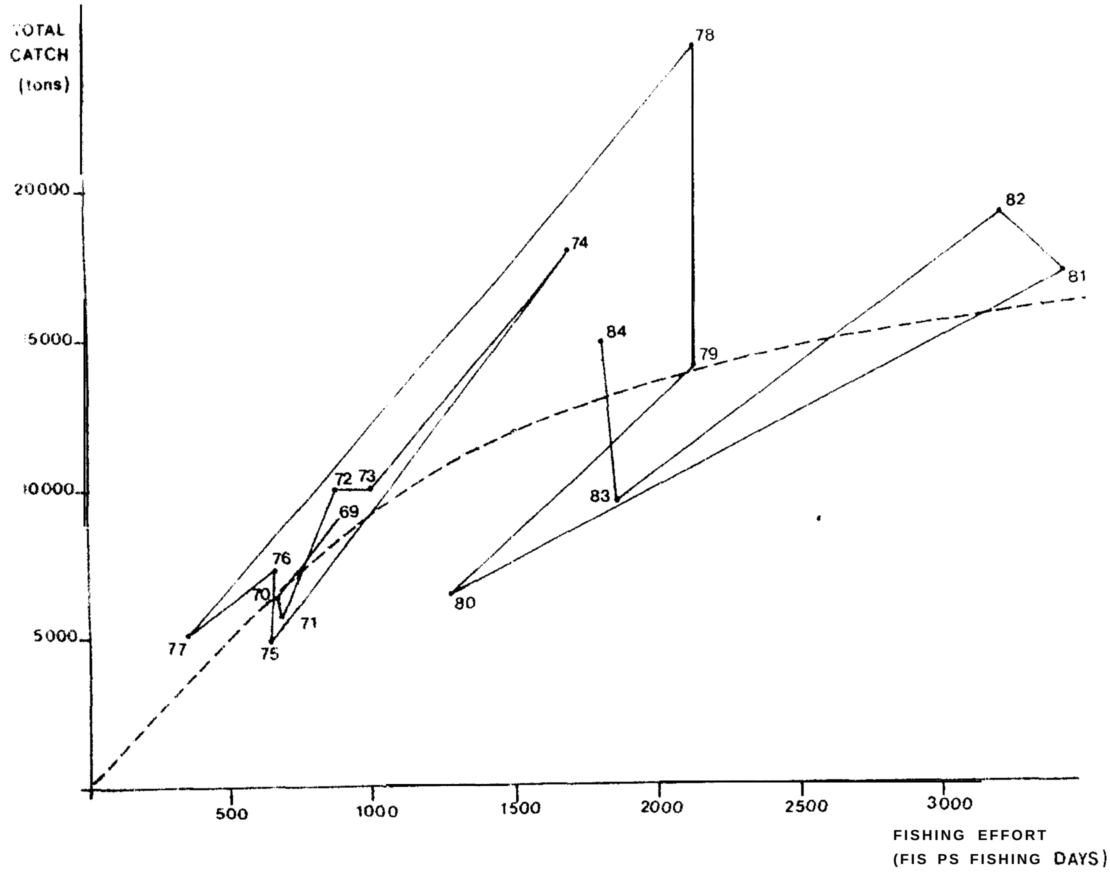


Figure 31.- The relation observed between total catch (yellowfin, skipjack and bigeye) and fishing effort in the area of Cape Lopez during the fishing season from may to july, from 1969 to 1984 (Curve adjusted by eye).

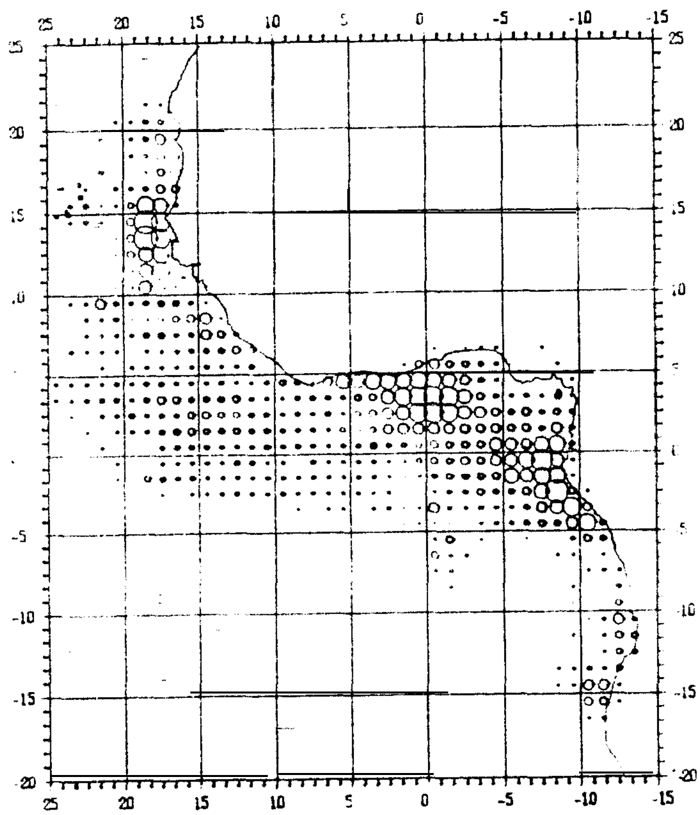


Figure 32.- Average fishing zones of skipjack by one degree squares, all fleets, period 1975-1982.

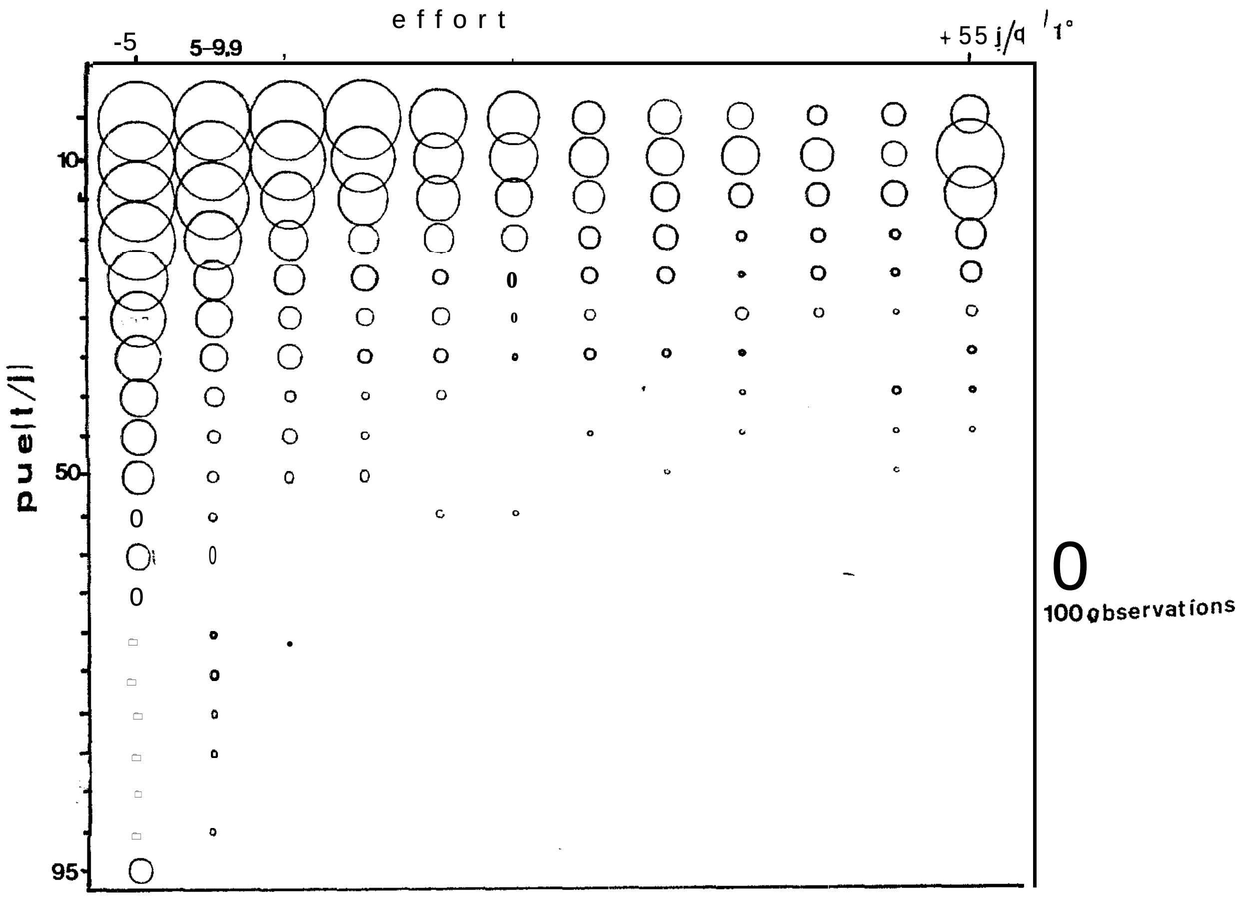


Figure 33.-Frequency of total cpue as a function of fishing effort for spanish and FISM purse seiners fleets, during the period 1980-1986. Each circle is proportionnal ta the number of catch rates observed in the 1° squares during 15 days periods for increasing intensity of fishing efforts. Frequencies greater than 200 have been limited arbitrarily set at the 200 level in order to facilitate the overall representation.

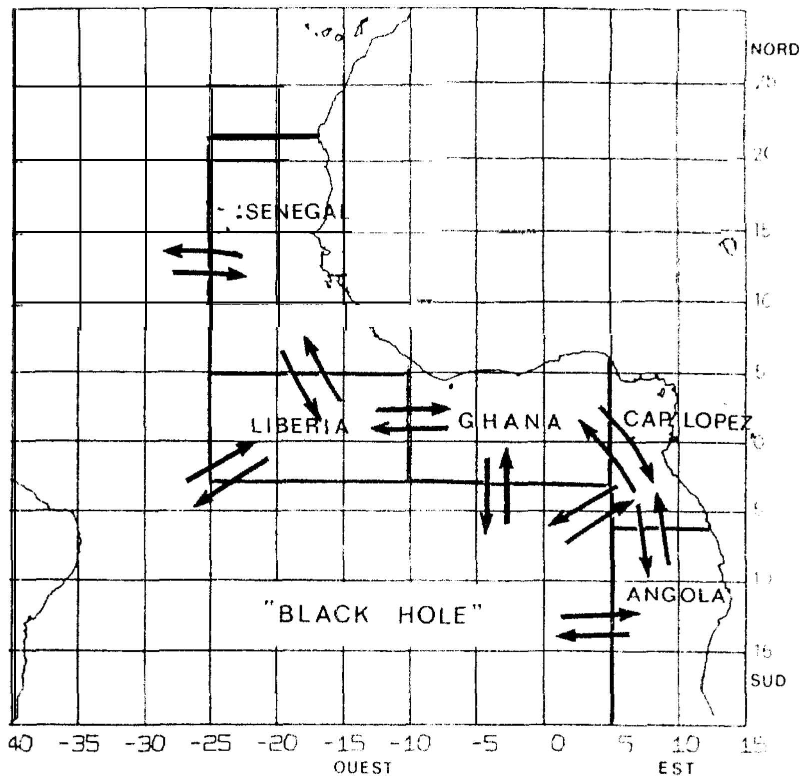


Figure 34.- The concept of the boxes mode1 applied to skipjack in the eastern Atlantic ; each arrow shows a monthly tranfer rate of individuals from one box to the other.

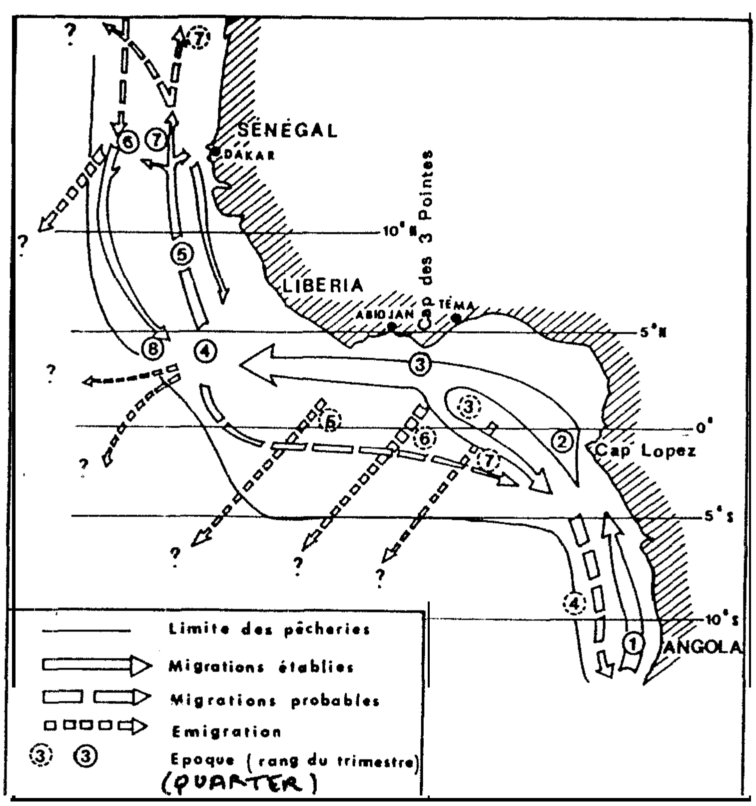


Figure 35.- Hypothetical migrations of skipjack tuna in the eastern Atlantic, based on tagging results (from Cayre et al., FAO tuna synthesis under press).

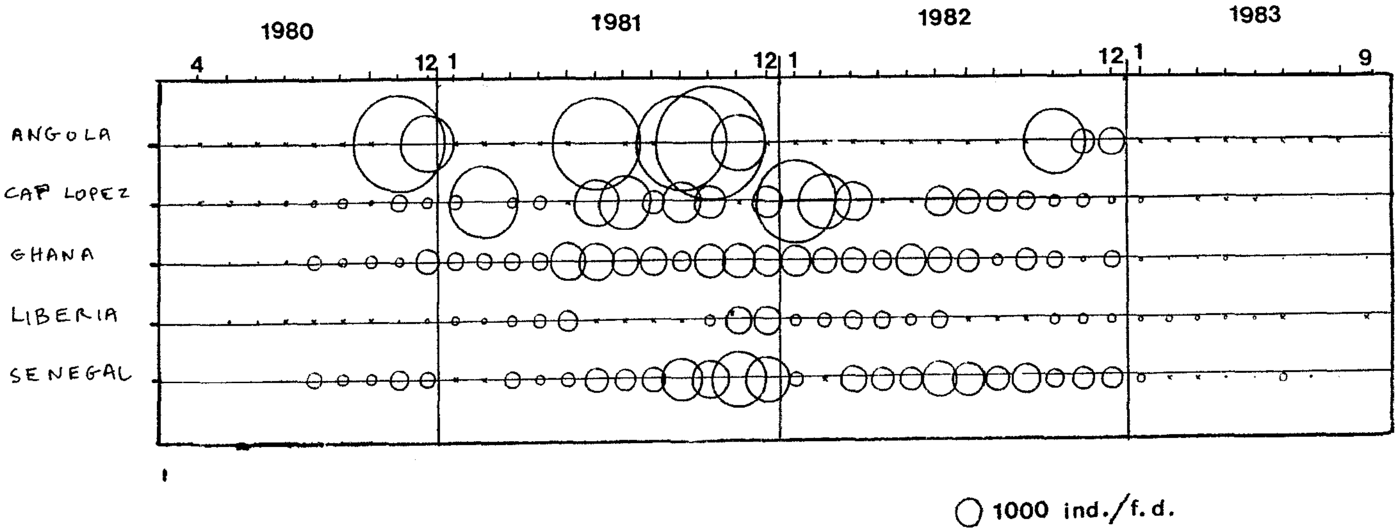


Figure 36.- Monthly cpue for an age group of skipjack, by area, during the period 1979-1982 (each circle has an area proportionnal to the cpue); a blank means a zero cpue, and an x means no purse seine effort data or no size data. This skipjack group is from 37cm to 50 cm in august 1981 (date of japanese tagging); all individual are growing at a constant rate of 1cm per month before and after this date.

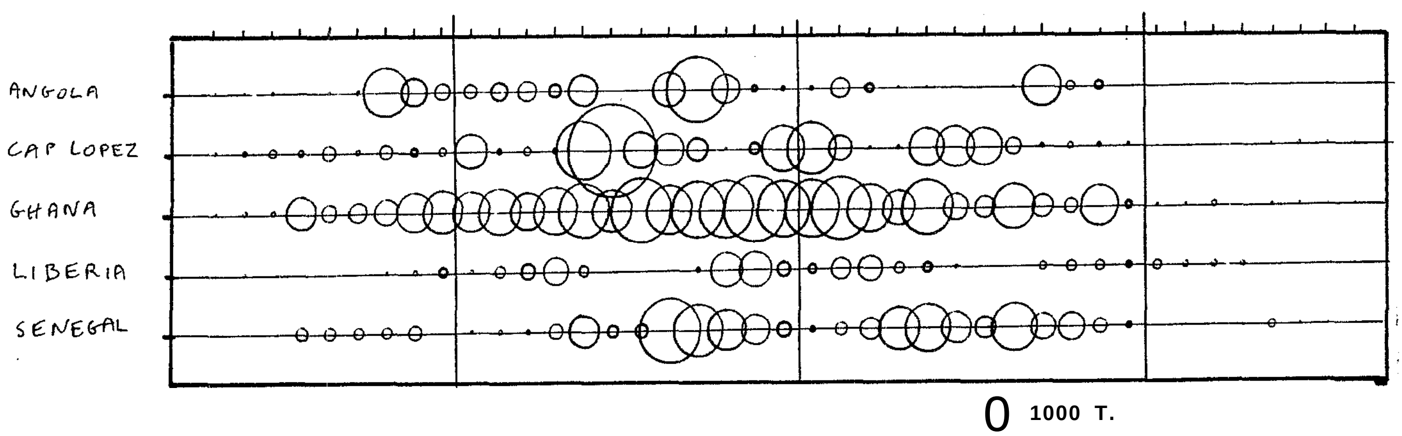
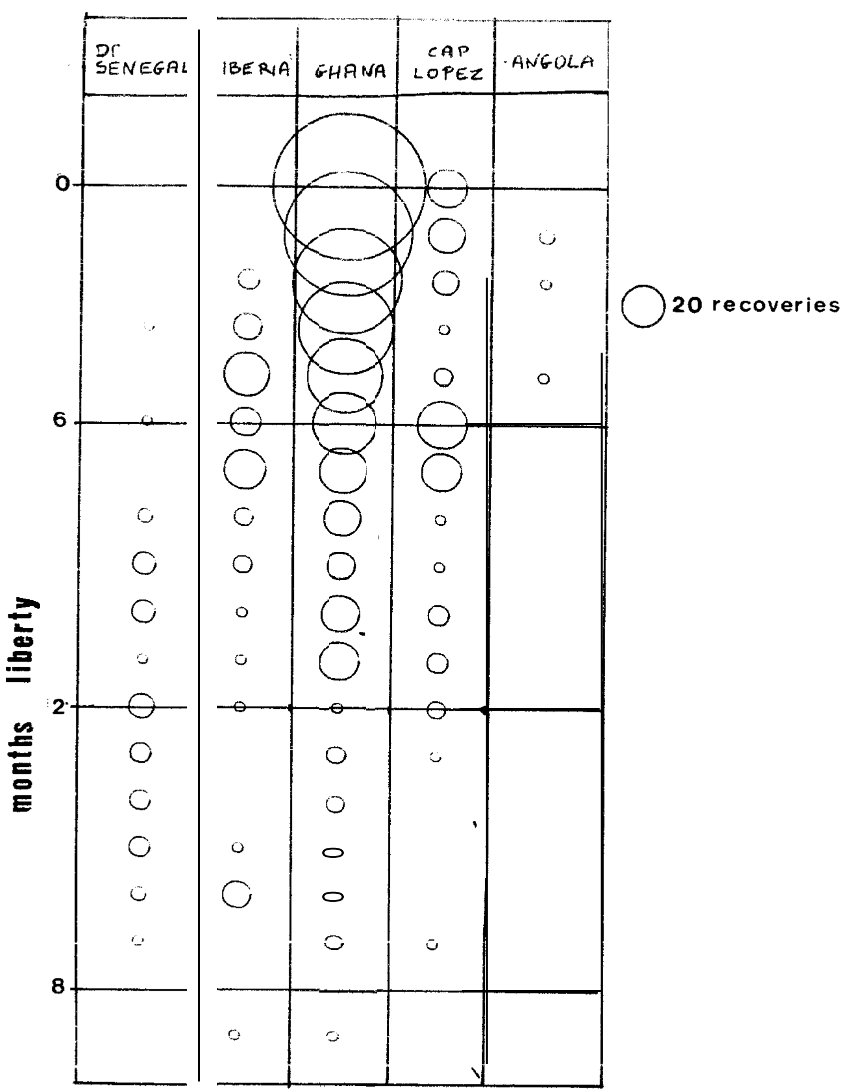


Figure 37.- Monthly catch of skipjack, by area, during the period 1980-1983 (each circle has an area proportionnal to the catch).



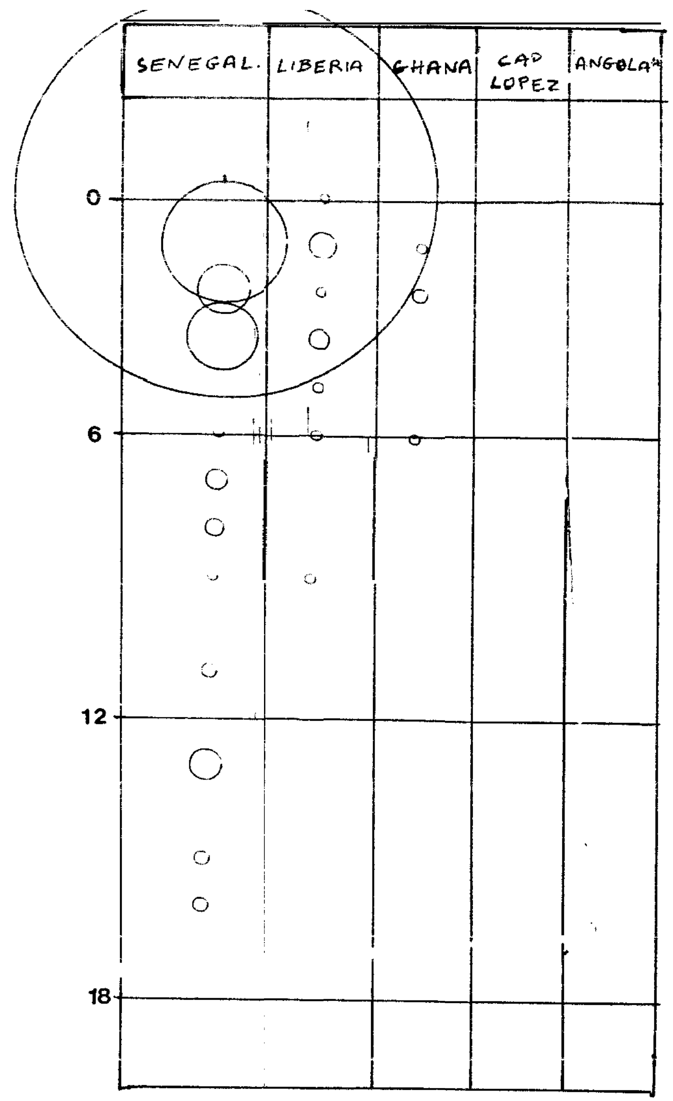


Figure 39.-Recoveries of tagged skipjack by month and area the Senegal area tagging (Senegal and Cape Verde cruises).

Figure 38.-Recoveries of tagged skipjack by month and area from the Ghana area tagging (japanese tagging).

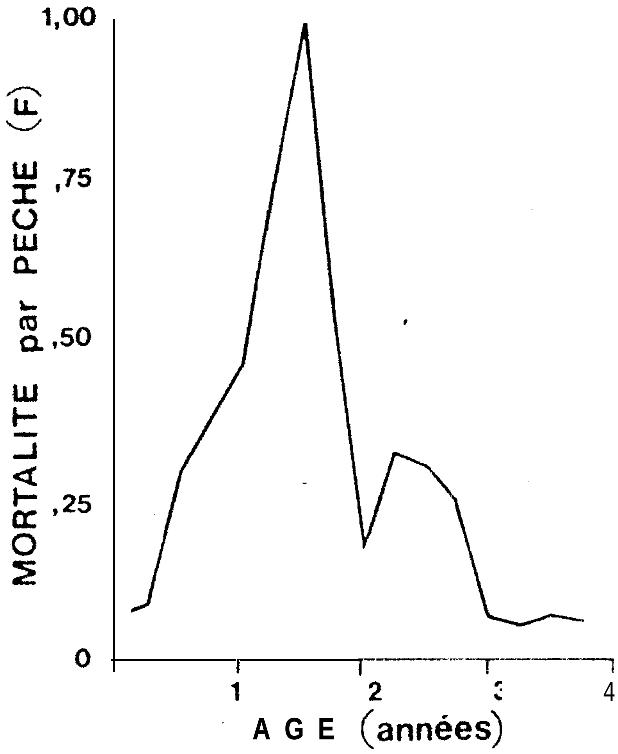


Figure 40.-Vector of fishing mortalities by age estimated for skipjack (From Fonteneau 1986).