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AN OVERVIEW OF PROBLEMS IN THE CPUE-ABUNDANCE RELATIONSHIP FOR THE TROPICAL PURSE SEINE FISHERIES

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SUMMARY

This paper develops an overview of the problems in estimating tuna abundance using purse seine fishery catch and effort data. This study is done on the purse seine fishery operating in the eastern inter-tropical Atlantic. Various potential biases in the CPUE biomass relationship are identified and discussed. Changes in the size of the fishing zone are first examined. A major problem in interpreting the CPUE is due to the large increases in fishing power observed for most purse seiners during recent years. While this increase in fishing power is due to various factors, technical factors among others, it is difficult to evaluate properly. The nature of the CPUE biomass relationship as a function of the level of effort exerted is discussed. As this relationship is not linear, it may introduce serious bias in the CPUE as a function of the effort which is exerted. Furthermore, the massive introduction of artificial floating logs, often maintained by auxiliary vessels, is discussed. Potential methods to estimate abundance using catch and effort data are discussed. The use of auxiliary variables in the abundance index is also discussed.

RÉSUMÉ

Cet article fait un bilan des problèmes d'estimation de l'abondance des thons tropicaux à partir des données de statistiques de pêche des thoniers senneurs. L'étude porte sur les senneurs opérant dans l'Atlantique intertropical est. Divers biais potentiels de la relation PUE-abondance sont ainsi analysées. Les effets des changements dans la taille des zones exploitées sont discutés. Un problème majeur est celui du considérable accroissement des puissances de pêche de la plupart des senneurs, en particulier durant les années récentes. Cet accroissement est dû à de multiples facteurs, technologiques en particulier, mais il demeure difficile à mesurer. La nature de la relation PUE et abondance locale selon le niveau des efforts et des prise est aussi discutée. Cette relation étant non linéaire, elle est susceptible de biaiser fortement les indices d'abondance selon les niveaux de l'effort. Les effets sur la relation PUE-abondance de l'introduction croissante d'objets flottants artificiels et de navires auxiliaires chargés de leur suivi sont aussi discutés. Les méthodes de calcul des indices d'abondance à partir des données de prise et d'effort sont ensuite discutées, ainsi que l'incorporation dans ces indices de variables auxiliaires.

RESUMEN

Este documento presenta un balance de los problemas de la estimación de la abundancia de túnidos tropicales en base a los datos estadísticos de los cerqueros. El estudio versa sobre la pesquería de cerco que faena en el Atlántico este intertropical. Se analizan los potenciales sesgos en la relación CPUE/abundancia. Se discuten los cambios en el tamaño de las zonas explotadas. Un problema importante es el considerable aumento de la potencia pesquera de la mayor parte de los cerqueros, sobre todo en los últimos años. Este aumento se debe a múltiples factores, sobre todo tecnológicos, si bien es difícil de calibrar. Se discute también la naturaleza de la relación CPUE/abundancia local, de acuerdo con el nivel de esfuerzos y capturas. Esta relación no es lineal, por lo que es susceptible de introducir importantes sesgos en los índices de abundancia según sean los niveles de esfuerzo. Se trata la repercusión sobre la relación CPUE/abundancia del uso creciente de objetos flotantes artificiales y de barcos auxiliares encargados de hacer su seguimiento. Después, se trata sobre los métodos de cálculo de los índices de abundancia en base a los datos de captura y esfuerzo, así como la incorporación a estos índices de variables auxiliares.

I-Introduction

In order to obtain trends in abundance indices, information on effort and catch per unit of effort (cpue) is essential for stock assessment studies.

However, the interpretation of cpue data in the tropical purse seine tuna fisheries, and the relationship between cpue and abundance, in this fishery, is quite complex. Catch rate can be defined as the quantity of fish

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caught in a set divided by the searching time preceding it. Searching time measures the amount of time spent when the vessel is moving, actively searching for signs of schools. Roughly speaking, searching time corresponds to the daylight hours spent on the fishing grounds minus the time spent for unsuitable events (bad weather, etc) and for time spent chasing and setting. As raised by Pella and Psaropoulos (1975), it is obvious that the increase in the fishing power of the purse seiners over the years is primarily related with a reduction of the time spent in sets and in an increasing probability to capture tuna schools. *However, various other physical parameters such as the physical characteristics and equipment of the vessels and net, or human factors such as the efficiency of the crews and skippers also play an important role in the efficiency of the vessels.*

The goal of this paper is to make (a) a comprehensive summary of the potential problems and biases in the relationship between cpue and abundance, (b) to highlight the factors that could increase the fishing power of the purse seiners and of the fleets, and (c) to develop some guidelines and consideration on this type of abundance modeling using the purse seine cpue data.

2-Basic data

The original catch and effort data were obtained from the commercial logbook, being primarily estimates of catches and efforts made by the skippers.

For the French fleet, the catch data are adjusted to the real landing figures, whereas this is not the case for the NEI[2] and Spanish fleets, for which only the log book estimates were available. These data sets may then include errors in the quantities caught.

These data are available by size categories in most logbooks, in three commercial size categories: small tunas (less than 10 kg), medium (10 to 30 kg), and large tunas (+30kg).

Surface-swimming schools can be classified as:

•unassociated schools *i.e.* free swimming schools or as

•Associated schools (with floating objects, or with marine animals such as mammals and shark whales).

Considering the large number of type of associations (*i.e.*, fishing modes), this variable was broken down into two categories: free swimming school (including for this study sets made on whales, on the basis of the similarity of the size frequency distributions) and log schools (including, for the same reason, sets made on whale-sharks, on sea-mounts). These fishing modes are well identified for each set for most schools since 1991. However the present analysis is facing two difficulties:

- ❖ Before 1991, schools associated with natural logs were already exploited by purse seiners, but this association was seldom noticed in the logbooks. Thus the available file provides the standard catch and effort figures without reference to their fishing modes.
- ❖ After 1991, artificial logs were increasingly used by purse seiners and this association is well coded in most log books; however this association is not available for a significant proportion of the recorded sets (see table 1: yearly percentages of sets without association or the French, Spanish and NEI fleets).

Keeping in mind these limitations, the "Miami 98 PS file" is given for the period 1991-1996 with the detailed catch and effort statistics of most individual purse seiners which were fishing and landing in the Eastern Atlantic during this period (Annex 1). The catch and effort of each purse-seiner were combined by 15 days periods and 1 degree square, by fishing mode (the"***unit stratum***"). The fishing efforts are given for each unit stratum in terms of days at sea, fishing days (excluding the few periods during which the vessel was not in condition to fish); these fishing times are not related to a given fishing mode. A third value of the estimated effort is given as the corresponding standardized effort exerted in each "***unit stratum***". This estimation of standardized fishing effort is based on the total yearly cpue of the individual purse seiners; the method used to estimate these fishing powers are given in the annex 2.The total number of sets, and positive number of sets are given by fishing mode (free or log schools).

[2] NEI: this acronym is used by ICCAT to classify the statistics of various tuna boats carrying flags of conveniency or not reporting their catch statistics to the ICCAT.

3-CPUE and abundances: some potential biases

3-1- Size of the exploited zone: number of 1° squares fished

It is well known world wide for tunas (Laloé 1989, Die *et al*, 1990, Fonteneau and al. 1999) that the size of the area fished is a key factor in the potential catches of the fisheries: a larger area means a higher potential catch than a smaller one. This increase of potential catches as a function of the area exploited is probably related with the viscosity of the stock biomass (Maccall 1990). At this stage it will be important to follow and to take into account in the cpue-abundance analysis all these changes of the exploited areas.

The major observations in this field of the areas exploited (figure 1) were the following:

⇒ From 1968 to 1978 an increase in the exploited areas was observed; approximately, half of these 1° squares were explored but unfished (no catch of any species); half of the 1° squares of the exploited area had a nil cpue.

⇒ During the period 1978-1985, the size of the explored and fished areas remained stable and at its highest level.

⇒ During the period 1986-1990, before the development of the artificial fishing logs, the size of the explored and fished areas decreased slowly, in relation with the decrease of the nominal fishing effort and numbers of vessels active in the area.

⇒ During recent years (1991-1996), a time period corresponding to the development of the artificial fishing logs, the size of the explored areas remained constant, while the proportion of successfully fished areas increased drastically. It is striking to note that presently, most of the explored areas are successfully fished, primarily because of the catches taken under logs.

All these changes should be taken into account in order to standardize the annual abundance index and to estimate specific abundance.

Another factor in the observed changes in the fished areas is linked to the "ecology" of the exploited areas. It appears (figures 2a, 2b, 2c and 2d) that during the early eighties, large areas near the borders of the south Atlantic gyres were explored unsuccessfully by the purse seiners (cpue=0). During the recent years, all the searching activities of the purse seiners in these quite poor areas were very reduced; the fishing operations were more successful, as they were concentrated in the equatorial systems, which are more suitable for the tropical tunas, and using floating logs (allowing to concentrate and to catch small tunas which were not available before in the area between the Equator and 5° South; see figures 2c and 2d).

3-2- Size of the time and area strata used in the analysis

The analysis and comparison of catch rates and cpue are always based upon a time and area stratification. Preferably these strata should be homogeneous and then small, in area and duration. However when too small time and area units are used in the analysis, too many strata are used, each one being too rarely fished. The choice of an optimal size for the strata (in area and duration) will, thus, need to be studied carefully, in order to obtain a reasonable homogeneity of well selected strata, and a reasonable number of strata which can be well handled by the model used.

An illustration of the heterogeneity of the spatial distributions of tuna catches, cpue and effort in the purse seine fishery is shown in the figure 3, for the months of February and July 1982. This figure highlights the non-randomness distribution of the schools (*i.e.*, the concentrations), the changes in the fishing grounds of the fleets during the year and the fact that some high local cpue where obtained for very low fishing effort. These features should be taken into account in the stratification process.

3-3- Uncorrected increasing of fishing powers of individual vessels:

There has been a permanent evolution of the fishing equipment for purse seining in the eastern Atlantic Ocean since the early eighties. Increased resulting fishing power is mainly due to technical improvement of the existing vessels, or improved fishing efficiencies of the new vessels. Various examples of these two types of improvement can be listed thereafter:

Increased fishing power of the existing purse seiners:

- Development (since the end of eighties) of ***bird radars*** which leads to an increase of the searching area and allows a remote detection of bird flocks associated with tuna schools (Herve et al., 1991). Simulation models developed in the Indian Ocean (Marsac, 1992) indicated that these radars may have a major effect to locate the concentration areas and to detect isolated schools when searching in areas with low densities of schools.
- Improvement of the ***purse seine design***, allowing a deeper and faster closure of the purse seine. This change is easily explained by various changes in the design of the net:

➢ A larger net allowing a deeper closure of the net.
➢ The development of the Spanish method to handle the net in the French fleet, in the middle of the 1970s.
➢ A net more loosely designed.
➢ More weight at the bottom of the net. Chains and other devices are used to increase the speed of submerging the net into water.

The practical consequences of these improvements are quite clear: the purse seine being closed presently at approximately 150 meters or more (a depth shown by scientific measurements recently done on French purse seiners; the deepest measurement previously recorded was 80 meters), much faster that in the recent past. Furthermore, they are now able to set without difficulties in windy areas, for instance in the area north of Dakar (between 15° and 20°N) where strong winds (>Beaufort 4 or 5) are very often encountered by the fishery.

Stronger winches and cables to handle the net and to recover it on board. Major changes have been made in the hauling power of the purse winches and of the power block in order to reduce the time dedicated to hauling the net (Herve et al. 1991).

The subsequent reduction of the set duration is subsequently well shown by the comparison of the set duration during three observer programs carried out on the French and the Spanish PS in 1981 (ICCAT "skipjack year"), in 1987 (ICCAT "yellowfin year program") and in 1995 (E.U. "associated fauna with tropical surface tuna catches"; Stretta and Delgado pers. comm.). Assuming that the set time is linearly related with the catch size of the set, the figure 4 shows the duration of the individual sets during these three periods (estimated duration were performed with linear regressions fitted by ordinary least squares for the first two periods and using robust regression –LTS-, and weighted least squares for the third data set). The salient result is a large decrease in the amount of time spent to haul the catch aboard. For instance, from 1981 to 1995, the setting time to haul a catch of 80 t. decreased from 307 mn to 165 mn in the French fleet and from 223 mn to 166 mn in the Spanish fleet. At the same time, the duration of the sets without catch (*i.e.*, the median of the set time) observed in the French fleet has shown a steady downward trend. (27 mn, from 1981 to 1995 and 49 mn, from 1975 to 1995) (Fig. 5). By contrast, the range of the setting time for the unsuccessful sets in the Spanish fleet has remained constant (at least, since the beginning of the 1980s).

- Introduction of various ***electronic equipment*** allowing a real time measurement of the thermocline depth and of the subsurface currents before each set.
- Development of the log associated fishery using large numbers of **artificial logs**, equipped with radio range beacons (the percentage of sets made on logs equipped with these devices was approximately multiplied by three in five years; Gaertner et al., 1997). Today, each vessel is currently handling tenth of artificial logs. This increase in the fishing power is primarily targeting small sizes tunas: mainly skipjack and yellowfin, but also young bigeye (although, this species is not actively targeted by the European purse-seiners). This new fishing mode was associated with the development of new fishing areas where this range of sizes was not taken under free schools. **Echosounders** are also commonly used on these artificial logs, allowing a real transmission of the tunas associated with each log. The total number of logs presently used in the Eastern Atlantic is not known but can be estimated between 3000 and 5000 (as an order of magnitude).
- Assistance provided by the "**supply vessels**", whose the mainly tasks consist in following and in maintaining the artificial logs, or in controlling physically the access to the sea mounts (for a given fleet).
- Spectacular development of **sonar**, allowing a close follow up of the tuna schools during the set (even when the tuna school is deep and cannot be located by surface signs). It seems that sonar is used now (and not until the nineties) by skippers in order to decide whether the net will be launched or not (depending on the school size and its depth) and during the encircling operation (following the behavior of the school).
- General use of the **satellite imagery**, **fax**, **computers,** real time follow up of surface current, GIS software, etc., often used in real time on board by the skippers.

This increase of fishing power of the purse seiners will remain a major problem in the analysis, because it cannot be evaluated unless all these technological improvements are well identified for each vessel, and well taken into account in the statistical analysis. Unfortunately the difficulty of investigating such changes is partially due to the fact that fishermen are reluctant to give dates of major changes in fishing equipment. This is not presently the case for most fleets.

Increased fishing power of the new purse seiners:

- New purse seiners are faster and can reach 20 knots; this speed may be a key factor during some critical periods of the fishing operations. Fast vessels have two advantages compared to slower ones (a) the increase of the coverage of the searching area which may increase the encounter rate with tuna schools, and (b) the capacity to reach a school competing with other vessels, or to set the net upon the school faster. However this increase in speed was observed only for the new purse seiners. This increased fishing power of the new vessel may not be a major problem in the analysis because the fishing power of these new vessels can be estimated in comparison with the traditional fleet.

3-4- Local total effort and total catches in the strata: local catch and cpue relationship

One major factor and major difficulty in the analysis of any catch, effort and cpue relationship is now well established but seldom taken into account. **The fundamental point is that a value of cpue can be interpreted only as a function of the total fishing effort and of the total catches in the stratum**; this fundamental problem is well explained and discussed by various authors, among others Foucher 1994, Fonteneau *et al.* 1999, Maury 1998.

This apparent lack of relationship between the local abundance and local cpue of purse seiners can easily be shown using the catch, effort and cpue data of the Eastern Atlantic PS (period selected: 1991-1996). The following statistical overview will be based on the very strong hypothesis that, under average circumstances, if the tuna biomass in a strata is high, then the catches will also be high; then the cpue should be high primarily in the 5°-month strata with large catches and on the contrary, low catches in any strata probably means a low local biomass (on the average).

Statistical relationship between the catches and cpue by 5°-month in the purse seine fishery (all flags) was assessed by classifying catches as a function of decreasing cpue (all species). It appears that the highest cpue are often associated with the lowest catches (indicating that these strata likely had low local biomass), when the strata with largest catches (the richest strata) always show moderate cpue (Fig. 6). The exclusion of all the strata with low fishing efforts (less than 10 fishing days by 5° and month) leads to the same conclusion (Fig. 7); showing that the elimination of the strata with low fishing efforts does not solve this problem.

Another way to analyze this relationship is to stratify the areas (5° month) in term of their productivity (*i.e.*, total catch in the strata). Hence, the 5° month catches by the PS fishery were broken down into three categories:

⇒ Cat A: poor areas, with less than 500 tons in the 5° month strata

⇒ Cat B: average abundance, with a catch between 500 and 2000 tons in the 5° month strata

⇒ Cat C: rich areas, with more than 2000 tons taken in the 5° month strata

The figures 8 to 10 show that the cpue are often larger in the poor areas of category A; this category is often encountered (in term of numbers of strata), even if its contribution in terms of total efforts and catches is quite low. A general observation is that the cpue of category C is seldom very high in comparison with the cpue's of categories A and B.

The conclusion is that a **cpue can not be interpreted alone without knowledge of the total local catch and effort in the strata**. The concept of this "unfortunate" lack of relationship between local cpue and biomasses is summarized in figure 11.

Various reasons can explain these statistical observations, among others:

- Very high fishing effort is exerted only in the areas with large biomasses of tunas. When very high fishing mortalities are exerted in these areas, they will most often (or always?) produce a local exhaustion of the biomass, producing at the end of each period low cpues. In such a case, the local high biomasses lead to medium or low cpues, instead of providing the high cpue corresponding to the real large local abundance In addition, if the exploitation rate is high enough to induce a significant depletion of the local biomass, it appears a competition phenomenon between purse-seiners (Laurec and Le Guen, 1977). Roughly speaking in such case, the local cpue doesn't represent the local abundance.

- When very low fishing mortalities are exerted in a given stratum with a moderate biomass of tunas by a small number of cooperating vessels, the cpue is often high, even when the biomass was probably low or moderate (the "learning effect", which occurs progressively when a new concentration is exploited, Fonteneau, 1986).

This bias is frequently observed comparing catch and cpue maps: the areas with large cpue are often areas with low fishing efforts and few fishes caught; this reduced effort is in most cases the best proof that the available biomass of tunas in the area was low (otherwise the effort exerted in the strata would have been higher, because of the communication within mobile fleets of purse seiners!).

This fundamental problem is faced by all gears catching tunas; a comparison of monthly fishing maps shown with the total catches and the total cpue also fairly well shows these structural bias (as previously shown in figure 3). In these maps, it is quite obvious that only the areas with large efforts and catches were the areas with large biomasses of tunas; all the areas with large cpues but low catches were very probably areas of low or moderate local biomasses.

The result is that the correlation between local cpues and local biomasses in the various strata is by nature weak or very weak. Probably a large effort in any strata would be the best measure of a high local abundance.

The recommendation to handle this problem is that the **total catches (or the total effort) in the strata should be taken into account in any standardization procedure** (e.g., GLM) as an **explanatory variable** (similar to the amount of tunas taken on logs). One difficulty remains that this relationship is probably not linear as shown by figure 11. To overcome the likely non-linearity in this relationship, adequate transformations should be investigated: mathematical transformation of the continuous variable, or creation of a categorical variable (*e.g.*, level of catches or fishing efforts in the strata).

3-5- Change in fishing mode: free school versus *log school effort.*

The nature of the present fishery developing an active searching and follow-up of logs is by nature quite different from the effort deployed in a free swimming school fishery.

- In the traditional free swimming school fishery (including "natural floating objects"), the purse seiners were alternating between "searching times" and "setting times".
- In the new fishery with a mixture of free schools and log schools (equipped with devices to improve their location), this binary type of activity is no longer valid: the time spent to set is still the same by nature, but the searching time can be:

(1) Either a <u>**real searching time**</u> trying to locate tuna schools by a searching activity (visual or using bird radar), or

(2) A <u>**directed movement targeting an already well identified log**</u>, often with an already well known quantity of tunas (when the log is equipped with a sounder, or when the log was followed by an auxiliary supply vessel).

This fundamental change in the concept of the fishing effort was shown by Fonteneau et al. 1999 (figure 12).

3-6- Changes in fishing strategies & cooperation

An important factor in the efficiency of any tuna fleet is the factor of cooperation or competition between fishing units. This cooperation is developed within sub groups of vessels formed between friendly skippers (code groups). This cooperation was developed primarily (but not exclusively) within each flag (e.g. French or Spanish, but the NEI vessels corresponding to each flag may be part of each of these fishing groups). This active communication inside groups of vessels explain why any large concentration of tunas located by an individual purse seiner will rapidly be exploited (in general until its complete exhaustion) by a friendly group of purse seiners. In such a situation, running toward the concentration (including running at night) should be included in the fishing effort (Laurec and Le Guen, 1977).

Unfortunately this component is quite difficult or impossible to handle, because this parameter is never recorded in the logbooks and probably quite variable over time. However it is quite clear that these changes may introduce serious biases during a long period in the interpretation of any cpue and biomass relationship.

3.7 Changes in prices of the species or in the commercial size category.

The evolution of commercial categories' prices is likely one of the major causes of changes in fishermen's behavior. Accordingly, the decision to pursue, then to set the net, can be related to the estimated commercial size category of the fishes and the estimated size of the school. Depending on variations in prices, yearly changes in the targeted commercial size category can be suspected. The necessity of coupling traditional cpue data sets with auxiliary variables, (in this case the prices of the different species*commercial category) has been raised, as well as some multivariate methods to take into account these strategies into the statistical analysis of the cpues' data (Gaertner *et al* 1999). This type of information can easily be obtained and included in the standardization process.

3-8-Changes in abundance and school sizes

When the abundance decreases, fishermen could have the necessity to catch smaller and smaller schools, since the larger ones are probably less frequently found. According to this assumption, setting time will be reduced and searching time will increase. It would be proper to check the frequency distribution of the school size over the years, in order to take into account this reduction in the searching times.

3-9-Ageing of vessels

It is often assumed that the fishing power of individual purse seiner remains constant over time. This was the case in the present effort standardization for the French and Spanish fleets. This assumption may seem reasonable, at least as long as the purse seiner is well maintained. However there is still some possibility that the fishing efficiency be decreasing over time for various reasons, for instance because of the interaction between vessels and crews: the best crews and best skippers will move to the new vessels; the less efficient ones will go on the oldest vessels. This factor may be significant as various purse seiners in the French and Spanish fleets are now quite old (20 years or more).

4- What abundance indices: What types of explanatory variables and how to standardize the annual abundance index in the surface tuna fishery?

4-1- Choice of fishing modes representatives of the target species

Previous studies, made during the "E. T. Program"[3] have shown that it is more appropriate to consider the association of tunas with the two selected fishing modes on the basis of fish size than on tuna species. This means that the probability to catch large fishes (mainly yellowfin tuna) in an unassociated school is larger than in log set, by contrast that it is observed for juveniles which are mainly associated with logs. Hence, the fishing mode associated with the set (or at least the proportion of fishing modes by strata) must be considered in the standardization step.

4-2- Size of the schools (in the log fishery)

It is obvious that the "searching time" spent to localize a log equipped with a radio range beacon can not be compared with the searching time preceding an unassociated school set. In the first situation the vessel travels directly toward the log, whereas in the second case the encounter rate is approximately random. Considering the difficulty to evaluate the amount of fishing effort associated with a log set, an alternative abundance index could be **the catch per log set**. Nevertheless, considering that the attraction power of a log is limited in the time and in the space, the effect of the density of all floating objects in the stratum must be investigated.

It is logical that for the tuna species and sizes, which are associated with floating logs (e.g. skipjack, small yellowfin and small bigeye), there, is *some proportionality* between:

- the size of the tuna schools associated with each log (and of the corresponding catch per set),
- And the biomass located in the area.

The catch per set will then fluctuate between two extremes:

- a large biomass of tunas producing large catch per set,

[3] ET program was a EU funding program targeting the statistical analysis and optimization sampling of tuna purse seiners (sizes and species composition of the catches); nothing to do with an extraterrestrial life...

•No tunas in the area and thus no tunas associated with the logs.

This concept is quite obvious and strong, but **the relationship between local biomass and catch per set is far from being simple** and known. Various parameters may interact in this relationship such as:

⇒ Sizes and species of tunas in the area,
⇒ Densities of logs in the areas,
⇒ Fishing effort on logs in the area,
⇒ Oceanographical conditions (currents, food available under the log and in its proximity, transparency of the water),
⇒ Behavior and movement patterns of these tunas in the area,
⇒ Design of the log (fishermen gave been developing various types of logs, especially in their underwater accessories, but it is not known if these additional devices have increased the efficiency of the logs)
⇒ Availability of species other than tunas under the log (which may play a role in the tuna aggregation), etc.

At this early stage of the analysis, the conclusion is that the abundance of all small tunas can probably be estimated using the catch per sets of the log sets; however this potential relationship should be well analyzed, because the catch per set and biomass relationship is probably complex, variable and not linear.

4-3- Total catches or total fishing effort in the time and area strata

It clearly appears (Fig. 7 for observed data and Fig. 9 for the interpretation) that cpue parameters are not independent of the fishing effort developed in the stratum. On one hand (a) strata with low effort, show relatively low local cpue in average (but with a very large variance), and on the other hand, strata with large effort have a local cpue lower than expected. Despite the easy understanding of this concept, the great difficulty is to build an automatic statistical criterion to design the lower and upper thresholds for a range of fishing effort values, in which it can be assumed that cpue correctly measures the local biomass. In order to reduce the bias introduced by the fishery concentrating on the greatest concentration of fish, Punsly and Deriso (1991) proposed to weight observations such that each hour of searching received equal weight independently of the size of its time and area strata (thus independently of the amount of fishing effort exerted). Nevertheless, it is not clear whether this method is adequate to correct the "depletion-competition effect" which occurs for high levels of fishing effort.

4-4- Impact school distribution within concentrations.

As raised by Laurec and Le Guen (1977), the relation between cpue and tuna abundance may be altered by the existence of a non-random distribution of the tuna schools in space and in time (as observed in figure 3). A concentration of school is defined by a set of schools, clustered on small time-and-area strata. Thus the impact of this effect will depend on the size of the strata chosen for the standardization process. In this case, the estimate of the searching time should take into account the time spent to move between concentrations (including running time at night) and to locate this concentration. In the lack of precise information (that could be obtained by an observer aboard program), an indicator of this "active" running time could be the length of **sequences of days without catch**. This index of absence of tuna schools could *a contrario* be an **index of scarcity of tuna schools.**

4-5- Use of auxiliary variables

Analysis of the relationship between cpue and abundance index, and especially possible changes in catchability requires the coupling of traditional data on different species cpues with auxiliary data sets, such as environmental factors (*e.g.*, depth of the thermocline, ecological areas, etc), fishing modes (*i.e.*, fishing strategies), prices by commercial categories, etc. All of these data are often broken down into spatial-temporal strata for the analysis. The analysis of such large databases becomes difficult and one has to use multivariate statistical methods. These methods allow to identify underlying structures within the data and to synthesize the information that they contain (Gaertner *et al.* 1999). The resulting principal factors, which are a linear combination of the raw variables and summarize their major patterns, could be introduced as explanatory variables in the generalized linear model used to evaluate trends in catch rates.

4-6 - Choice of the size of spatial-temporal unit of observation

As mentioned, the choice of an adequate size for the unit of observation (e.g., fortnight*1° square, month*5° square, etc) is a critical step. A very small unit can avoid the problems caused by the non-random distribution of the school, as well as limiting saturation effects, but it will drastically increase the number of cells (including cells with no effort, cells with low effort, *i.e.,* cpue with large variability, etc). The difficulty to represent these small units (*e.g.*, broken down into homogeneous classes on the basis of a classification method) on a map should also be noticed (there is no evidence that these units be contiguous). Although that some smoothing methods can be used (Buckland and Anganuzzi, 1988, Punsly and Deriso, 1991), this "mosaic" of classes of small units can be problematic during the stratification procedure.

4.7 – Stratification.

As mentioned by different authors (Buckland and Anganuzzi, 1988, Punsly and Deriso, 1991; among others) stratification can be seen as an attempt to alleviate the effects of non-random distribution of both search effort and tuna schools.

Within the boundaries of the area distribution of the species, it would be proper to identify strata in which fishermen are targeting the species (or the size class) of interest. However, changes in spatial pattern over the years can be related with changes in stock size. In order to avoid the problem of the reduction of the spatial distribution of the stock in case of overexploitation, it is important to work with the largest data series. Bearing in mind this consideration, we might try to create homogeneous strata by using many different stratification factors, such as encounter rates, fishing effort, catch of the targeted species, etc. The projection of individual stratum on the first factors of some multivariate methods is a good way to identify spatial-temporal effort clusters. The adequate number of strata must be investigated taking into account the estimated variance of the annual abundance index.

4-8- Statistical models

Generalized linear models (GLM) are characterized by (a) the probability distribution of the response variable (i.e., the random component), (b) the linear function of explanatory variables (e.g., the predictors) and (c) the relationship between the both (i.e., the link function).

Before the choice of an adequate model, the sampling distribution of the abundance index must be done. For instance, it is not clear whether cpue (namely, catch per fishing time for unassociated school) has the same distribution pattern than catch per log set. Then, adequate transformation can be investigated.

The model-building strategy can be divided into two steps (a) variable selection in order to retain only the significant relevant factors, and (b) model selection for assessing a good fit of the observations and capturing the major underlying structure between these explanatory variables and the abundance index. Variables selection must be done bearing in mind that we attempt to estimate abundance index, independently of yearly changes in the fishing patterns. That means that the factors known, *a priori*, to have a possible effect on the cpue variability must be included in the list of the candidate variables. Nevertheless, the number of explanatory variables retained for the model selection (checking for instance the inclusion of interaction effect) must be reduced in order to build a model easy to manipulate. Accordingly, the aim is to reach a tradeoff between the extremes of:

- underfitting the data, e.g. too little structure which means large bias, and
- overfitting the data, e.g. too many parameters, hence large variance.

With the above consideration in mind, the "**Principle of parsimony**" (McCullagh and Nelder 1983) is based on the search for the number of parameters which minimize both functions of bias and variance.

In order to limit the addition of unnecessary variables, the use of the Akaike's Information Criterion (AIC) in likelihood contexts should be preferred to the classical stepwise selection procedure. The model with the smallest AIC is defined as the parsimonious model. The AIC statistic is identical to the much-used Mallow's Cp for model selection in linear regression fitted by least squares.

As previously mentioned, the spatial and time aggregation of tuna schools in concentration is an important feature of this fishery. As raised by Laurec and Le Guen (1977) variations in tuna abundance may be related to the school size and the number of concentrations, thus resulting estimates may be made within in a "double Poisson model". More recently, modeling spatial aggregation of daily catch of tuna with mixtures of

Poisson distributions was reviewed by O' Brien et al, (1997). After analyzing the assumptions made in the probability distribution of tuna catches and the resulting choices in the link functions traditionally used in GLM, these authors suggested that the negative binomial distribution might be used in over-dispersion context. It is difficult to give an exhaustive list of factors that can alter the relationship between cpue and abundance but we believe that during the ICCAT Miami working group, a special attention should be paid to the analysis of these types of models, as well as to the choice of appropriate weighing factors.

5-Conclusion

Standardized catch per unit effort analysis is widely used to evaluate trends in population density. However, keeping in mind that the use of the largest cpue series are suitable in stock assessment studies, it is important at the same time to have **a thorough understanding of the mechanisms** that could modify the catchability coefficient over the time period analyzed. In the case of the tropical surface tuna fishery, the key questions are the following:

- How to take into account the major changes in the catchability coefficient over time (mainly due to the improvement of the fishing power of the vessels and to the changes in the fishermen's behaviors) in order to keep a " stable " relationship between fishing mortality and fishing effort (namely, F=q f). In addition, a careful analysis of this relationship should be done before any VPA analyses to avoid severe errors in the interpretation of the results, especially when these VPA are built on the basis of an automatic tuning of fishing mortality coefficient by fishing effort (or abundance index by cpue). Such a bias may be quite dangerous in stock assessment because any uncorrected increase of the catchability will produce a false overestimation of the stock and an underestimation of recent fishing mortality.

- How to take into account the over-dispersion of the tuna schools (e.g. the concentrations) in the standardization procedure of the cpue and how to weight the strata with an inadequate levels of fishing effort (i.e., too low fishing effort to be significant or instead too high level of fishing effort leading to local depletion of local biomass, competition phenomenon between vessels, etc).

. Those serious problems are faced world-wide by each of the tuna commission which are trying to use the purse seine fishery catch and effort data in order to evaluate the status of the tuna stocks. This research effort is of key importance because of the universal, large and dangerous bias in the catch and effort relationship, and because the analysis of fishery data will remain for most tuna stocks the only method available. Taking into account the fact that most of the changes in the purse seine fisheries have been observed world wide, a more active scientific cooperation between the various scientists and tuna commission on this topic is strongly recommended.

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ANNEX 1

Eastern Atlantic Purse Seine files for the Miami working group on CPUE

Three files have been created with a special format for the Miami working group on CPUE.. The data included are PS data from 1991 to 1996 for Spain, France and NEI and records are cumulated by year, country (21,8,73), vessel number, fortnight and cwp1x1. Each record contains these classification variables as heading and then the different types of fishing effort (hours at sea, fishing hours, standardized fishing hours, number of positive sets and number of null sets), followed by three groups of data corresponding to the three association types (logs, free schools and unknown) with number of sets and catches (YFT -10, YFT +10, SKJ, BET –10, BET +10, ALB, LTA, AUX, sharks, discards and others/unknown). Catches are expressed in 100kg.

The files are cae9196.mia,cef9196.mia and cax9196.mia.

File structure :

Field	Field length	Description
ANPECHE	7	Year
PAYS	7	Country
CATEGBATEAU	7	Vessel category
NUMBATR	7	Vessel number
TRIMESTRE	7	Quarter
MOISPECHE	7	Month
QUINZAINEPECHE	7	Fortnight
CWP11	7	Cwp 1x1
CWP55	7	Cwp 5x5
HMER	7.1	Hours at sea
HPECHE	7.1	Fishing hours
HPECHS	7.1	Standardized fishing hours
NCALTO	7.1	Total # of sets
NCALNU	7.1	# of null sets
NCALPO	7.1	# of positive sets on logs
COYFT1	7.1	YFT catches –10 logs
COYFT2	7.1	YFT catches +10 logs
COSKJ	7.1	SKJ catches logs
COBET1	7.1	BET catches –10 logs
COBET2	7.1	BET catches +10 logs
COALB	7.1	ALB catches logs
COLTA	7.1	LTA catches logs
COAUX	7.1	AUX catches logs
COREQ	7.1	Shark catches logs
COREJ	7.1	Discard catches logs
COINC	7.1	Unknown/others logs
NCALPL	7.1	# of positive sets on free schools
CLYFT1	7.1	YFT catches –10 free
CLYFT2	7.1	YFT catches +10 free
CLSKJ	7.1	SKJ catches free
CLBET1	7.1	BET catches –10 free
CLBET2	7.1	BET catches +10 free
CLALB	7.1	ALB catches free
CLLTA	7.1	LTA catches free
CLAUX	7.1	AUX catches free
CLREQ	7.1	Shark catches free
CLREJ	7.1	Discards free
CLINC	7.1	Unknown/others free

NCALPI	7.1	# of positive sets unknown association type
CIYFT1	7.1	YFT catches –10 unknown
CIYFT2	7.1	YFT catches +10 unknown
CISKJ	7.1	SKJ catches unknown
CIBET1	7.1	BET catches –10 unknown
CIBET2	7.1	BET catches +10 unknown
CIALB	7.1	ALB catches unknown
CILTA	7.1	LTA catches unknown
CIAUX	7.1	AUX catchesunknown
CIREQ	7.1	Shark catches unknown
CIREJ	7.1	Discards unknown
CIINC	7.1	Unknown/others unknown

Total lrecl 350

ANNEX 2

Estimation of global fishing powers of individual purse seiners

1-Method

The global fishing power of each purse seiner was estimated as a function of its yearly catch rates. The selected reference purse seiner was a group of 2 vessels of the same category and selected because they had similar catch rates. These two vessels were of category 5 for France and category 6 for Spain.

The fishing power of each purse seiner was assumed to be constant over time during the entire period covered by the fishery.

The fishing power used is the **global fishing power**, i.e. a measure of the fishing efficiency of each purse seiner independently of the fishing zones. The estimation of each fishing power was done during the three first years of activity in the fishery; afterwards, this fishing power was kept constant.

The calculation of each individual fishing power was estimated (independently for each fleet, France or Spain) by the ratio of the cpue of each purse seiner, to the average total cpue of the couple of standard reference purse seiner.

As an example, if the two purse seiner number 1 and 2 constitute the reference fleet, and vessel 3 the fishing power to estimate, the fishing power of vessel 3 relative to vessel 1&2 will be estimated as following:

	Year						
	89	90	91	92	93	94	95
pue PS 1 (referenceA)	1.2	1.4	1.6	1.5	1.3	1.2	1.4
pue PS 2 (referenceB)	1.1	1.3	1.2	1.3	1.1	1.0	1.1
Average pue PS1-PS2		1.35	1.4	1.4			
pue PS 3		1.0	0.9	1.1	1.1	1.3	1.2
pue PS3/PS1&2		.74	.64	.78			
Fishing power PS3		.74	.69	.72	.72	.72	.72

⇒ At the beginning of its first year of activity, this PS number 3 will have the average fishing power of its size category;

⇒ At the end of its first year of activity, the PS3 will have an estimated fishing power of .74;

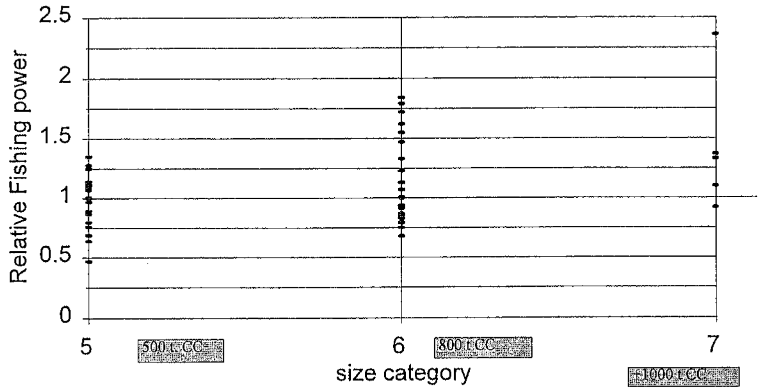
⇒ At the end of its second year of activity, this estimation of the fishing power will be adjusted to .69;

⇒ At the end of its third year of activity and thereafter (permanently, as it is asssumed that the fishing power of each vessel is stable over time), this PS will have a fishing power of 0.72;

Then, for the calculation of its standardized fishing time, the fishing times of this vessel will be multiplied by a factor of 0.74 (e.g. 74% of the standard vessels).

2-Results

The fishing powers of the French purse seiners are shown in the following figure.



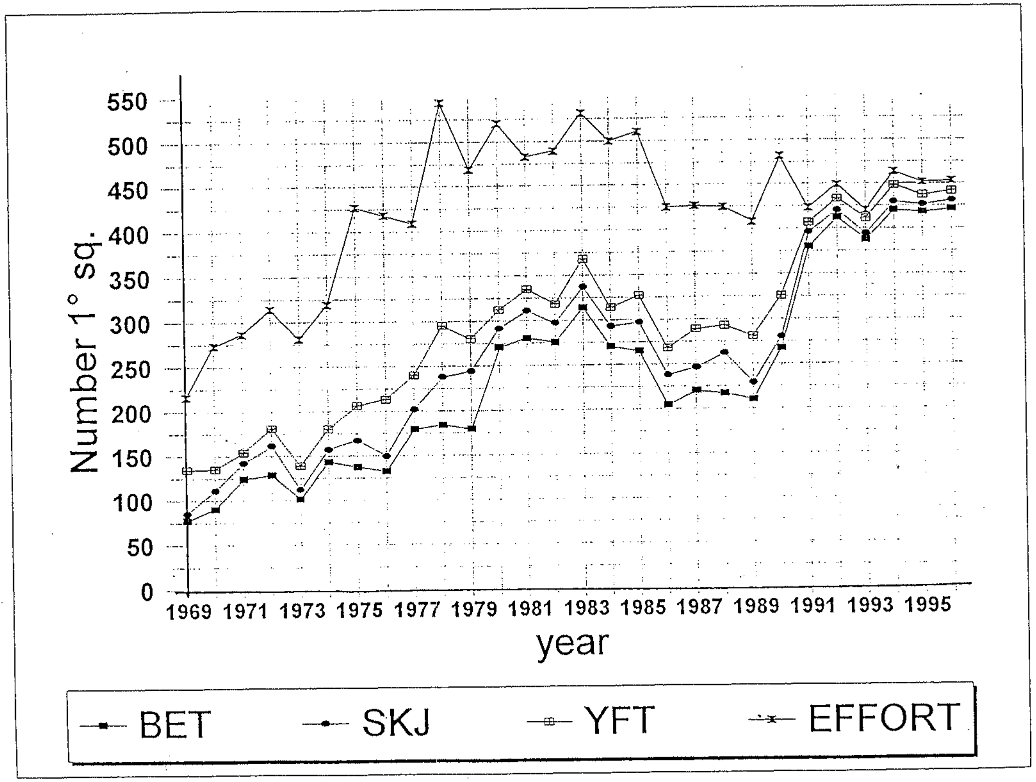


Figure 1 : Changes in the total exploited area visited by the purse seiner fleets and in the number of 1° squares with catches (from 1969 to 1995). *The salient result is the increase in proportion of successfully fished areas during the recent time period corresponding to the development of the artificial fishing logs (since 1990).*

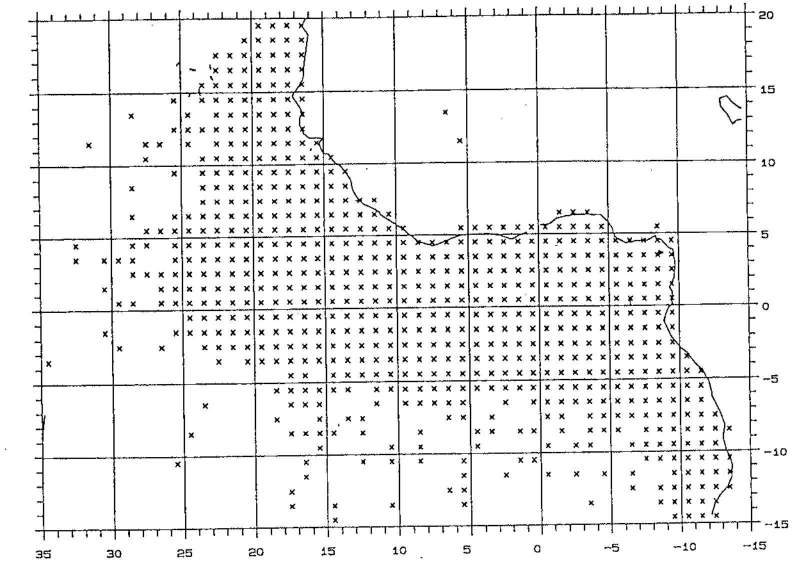


Figure 2 a,b,c and d: Average fishing maps of the purse seine fleets during the 2 periods 1979-1985 and 1991-1996: average catches by species, by 1° squares, and fished areas. *Although that the total fishing grounq stayed relatively constant, changes can be observed with the recent increase in the catches made at the south of latitude 2° N. as well as in the western part of the fishing grounds.*

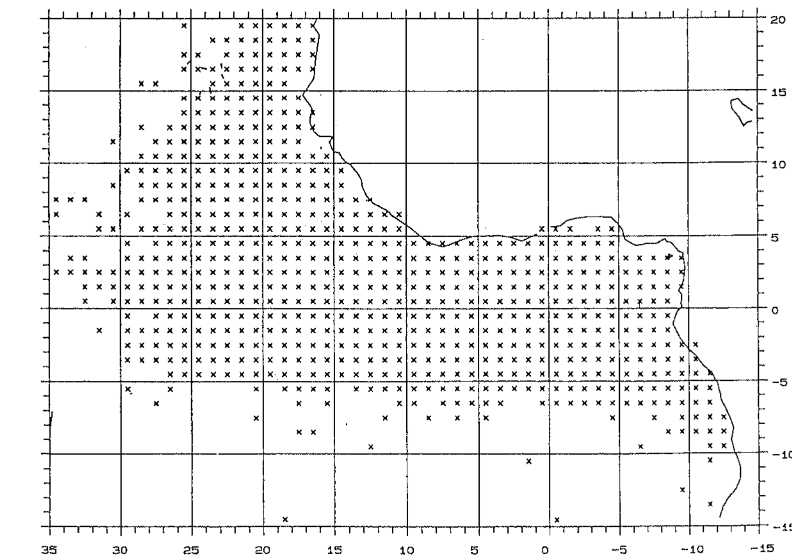


Figure 2b

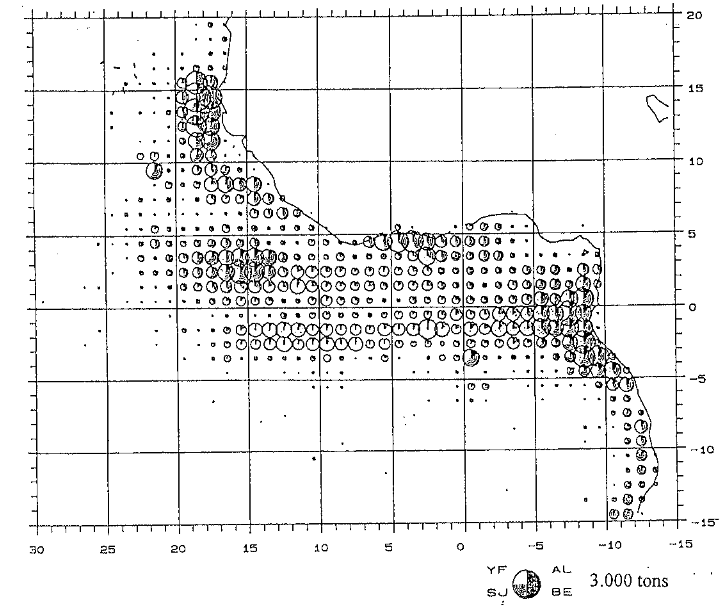


Figure 2c

(YF : yellowfin, SJ : skipjack, BE : bigeye, AL : albacore)

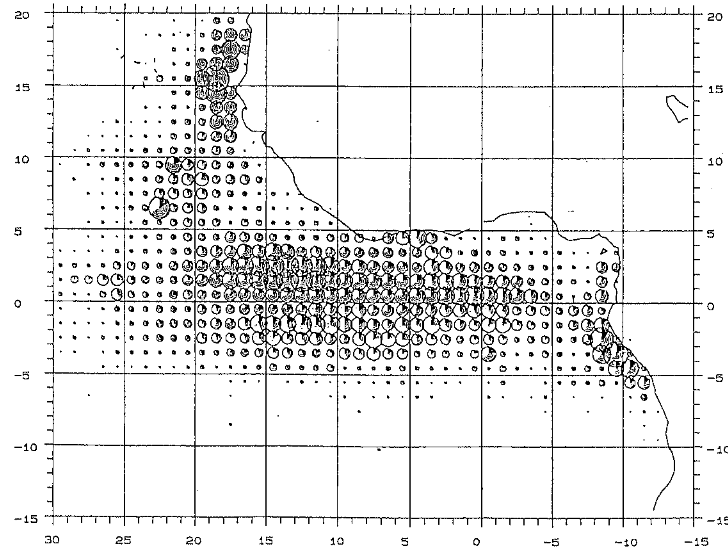


Figure 2d

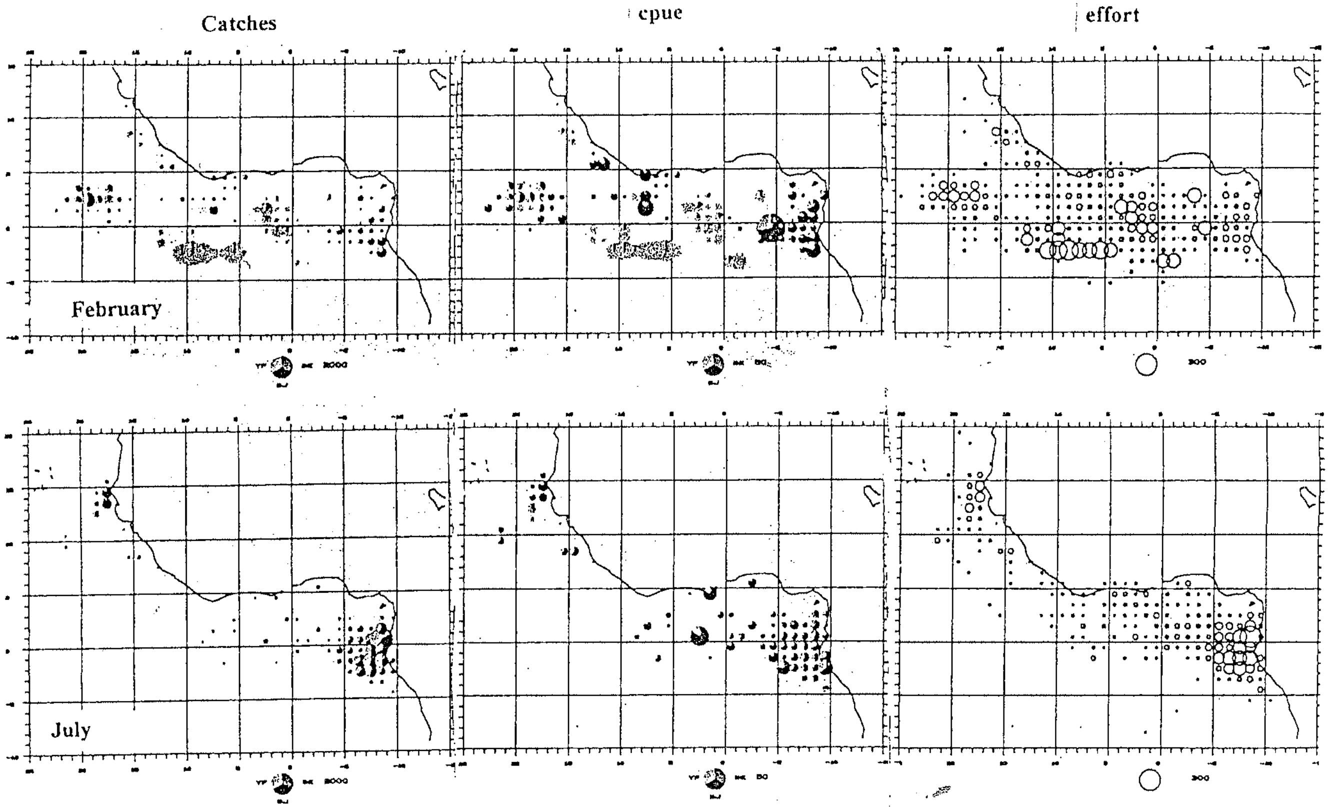


Figure 3: Spatial distribution of catches, cpue and fishing effort for the purse seiner fishery in February and July of 1982. *This figure shows the aggregation of tuna schools in patches, the variability of the fishing pattern over the year and the fact that high cpue are not necessarily associated with high efforts.*

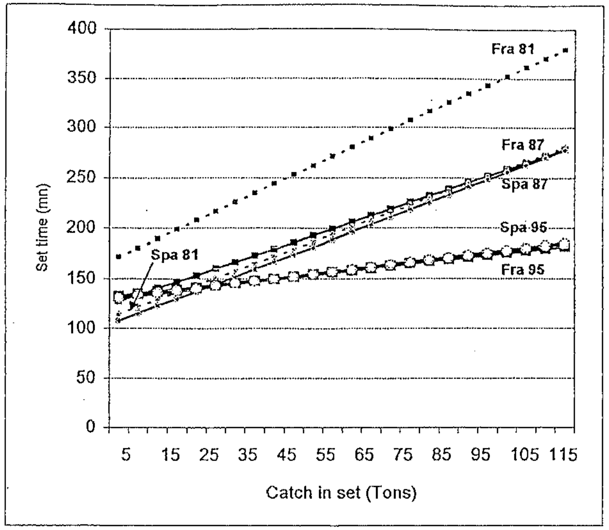


Figure 4. Estimated regression lines of set time and catch by fleets (French and Spanish) for 1981 (ICCAT SKJ Program), 1987 (ICCAT YFT Program) and 1995 (EU Associated Fauna with the surface tuna catches Program; Stretta and Delgado, pers. Comm.).

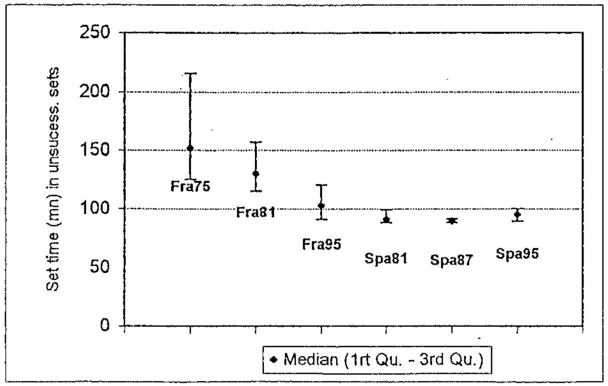


Figure 5. Estimated median set time (with its first and third quartile) in unsuccessful sets for the French and Spanish fleets (comparison is made for 1975, 1981 and 1995 for the French fleet and, for 1981, 1987 and 1995 for the Spanish fleet).

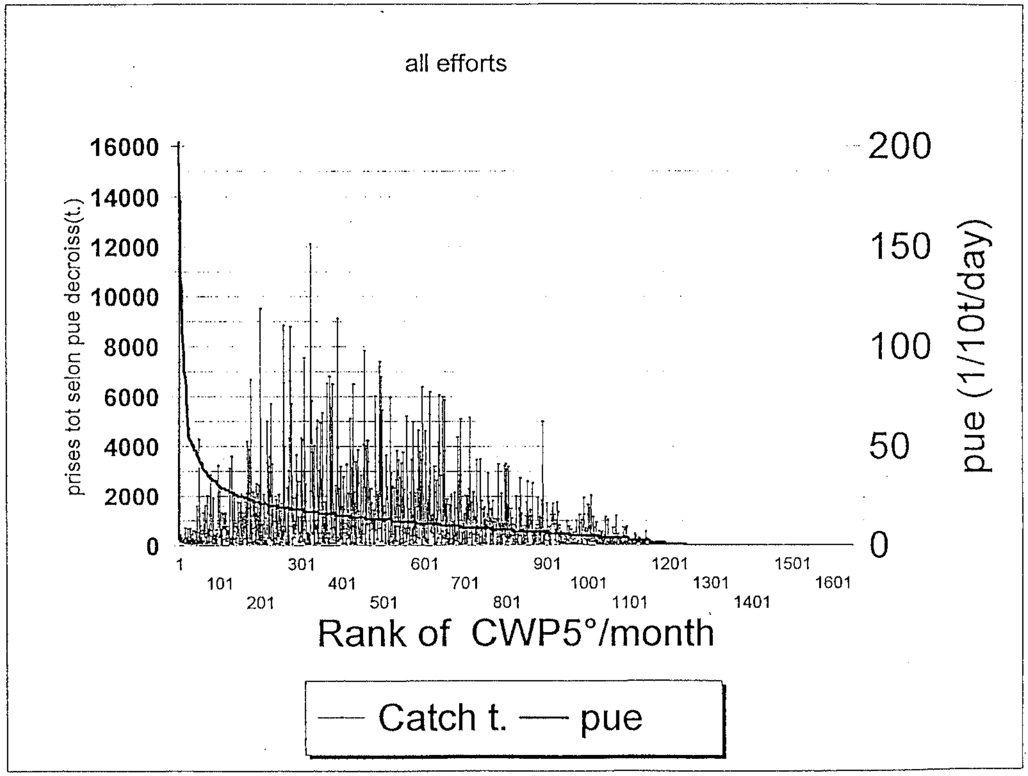


Figure 6: Statistical relationship between the catches and cpue by 5°-month in the PS fishery, all flags: catches classified as a function of decreasing cpue (all species). During this period 1991-1996 a total number of 1650 5°-month squares were explored and fished. *This figure well shows the paradox that the highest cpue are often associated with the low catch (and probably low biomass..) strata, while the strata with large catches (the rich strata) always show moderate cpue's (never extreme).*

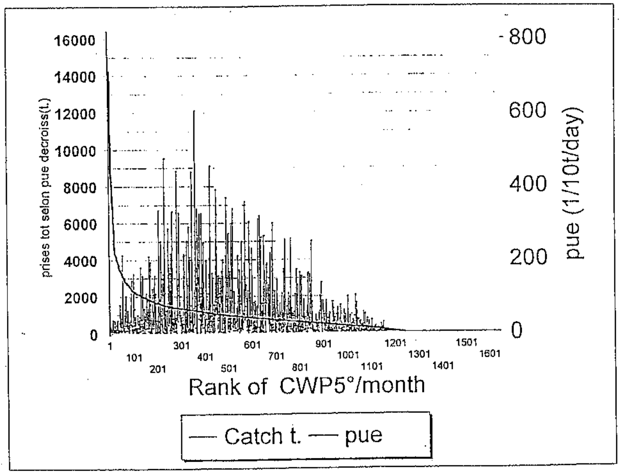


Figure 7: Same figure as figure 6 but excluding all the strata with low fishing efforts (less than 10 fishing days by 5° and month). *The conclusion is the same as for figure 6, showing that the elimination of the strata with low fishing efforts does not solve this problem.*

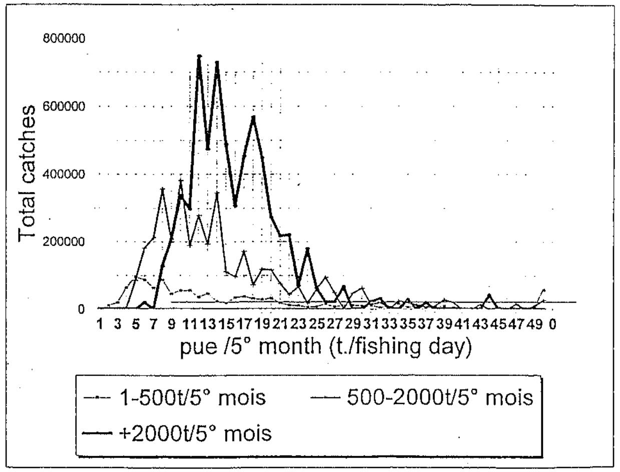


Figure 9: Observed catches as a function of cpue in the 3 groups of 5°-month squares (period 1991-1996). (poor areas, with less than 500 tons in the 5°-month strata (Cat A), average abundances, with a catch between 500 and 2000 tons in the 5° month strata (Cat B), and rich areas, with more than 2000 tons taken in the 5°-month strata (Cat C).

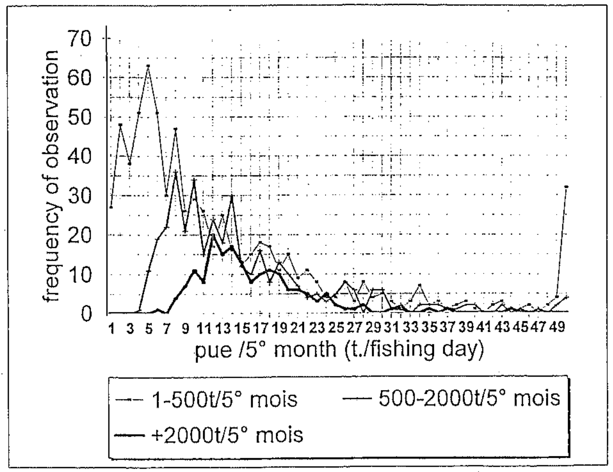


Figure 8: Frequency of the observed cpue by 5°-month during the period 1991-1996 classified in 3 categories: poor areas, with less than 500 tons in the 5°-month strata (Cat A), average abundances, with a catch between 500 and 2000 tons in the 5°- month strata (Cat B), and rich areas, with more than 2000 tons taken in the 5°- month strata (Cat C).

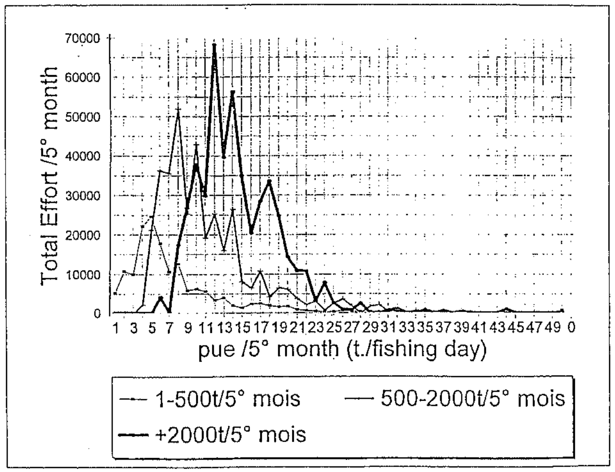


Figure 10: Observed fishing efforts as a function of cpue in the 3 groups of 5°-month squares (period 1991-1996). (poor areas, with less than 500 tons in the 5°-month strata (Cat A), average abundances, with a catch between 500 and 2000 tons in the 5°-month strata (Cat B), and rich areas, with more than 2000 tons taken in the 5°-month strata (Cat C)).

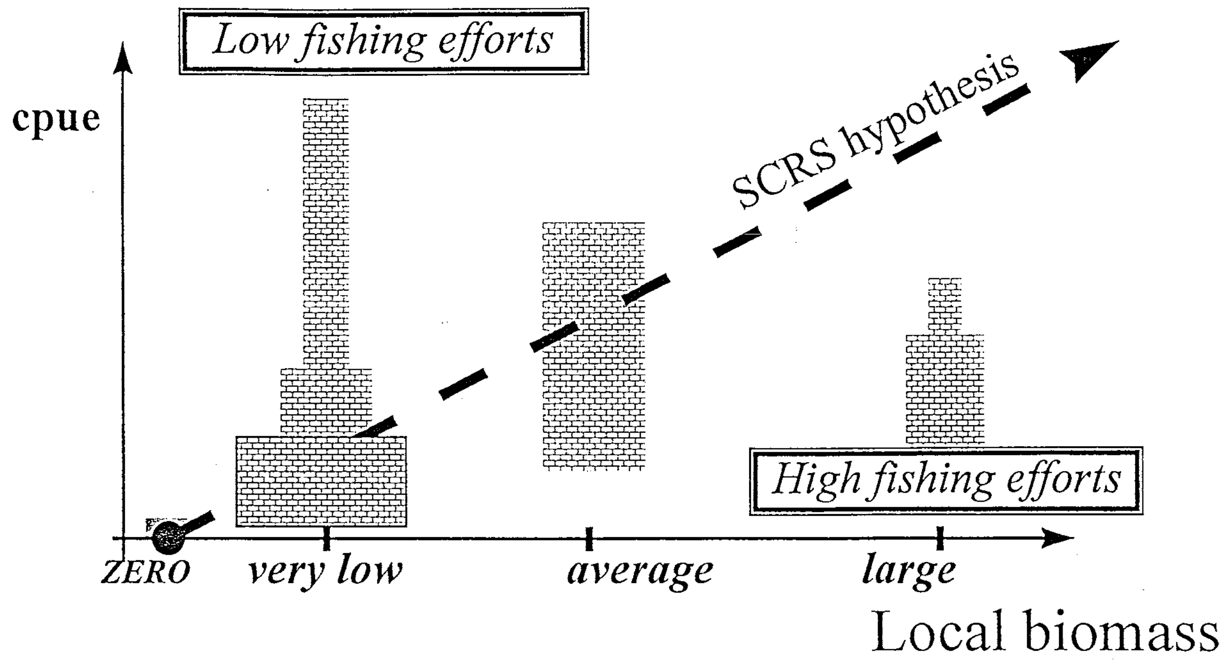


Figure 11 : Theoretical relationship at a local level between biomass and cpue : expected relationship and observed cpue at low, medium and high levels of local biomass (exploited by a mobile and large fleet of purse seiners).

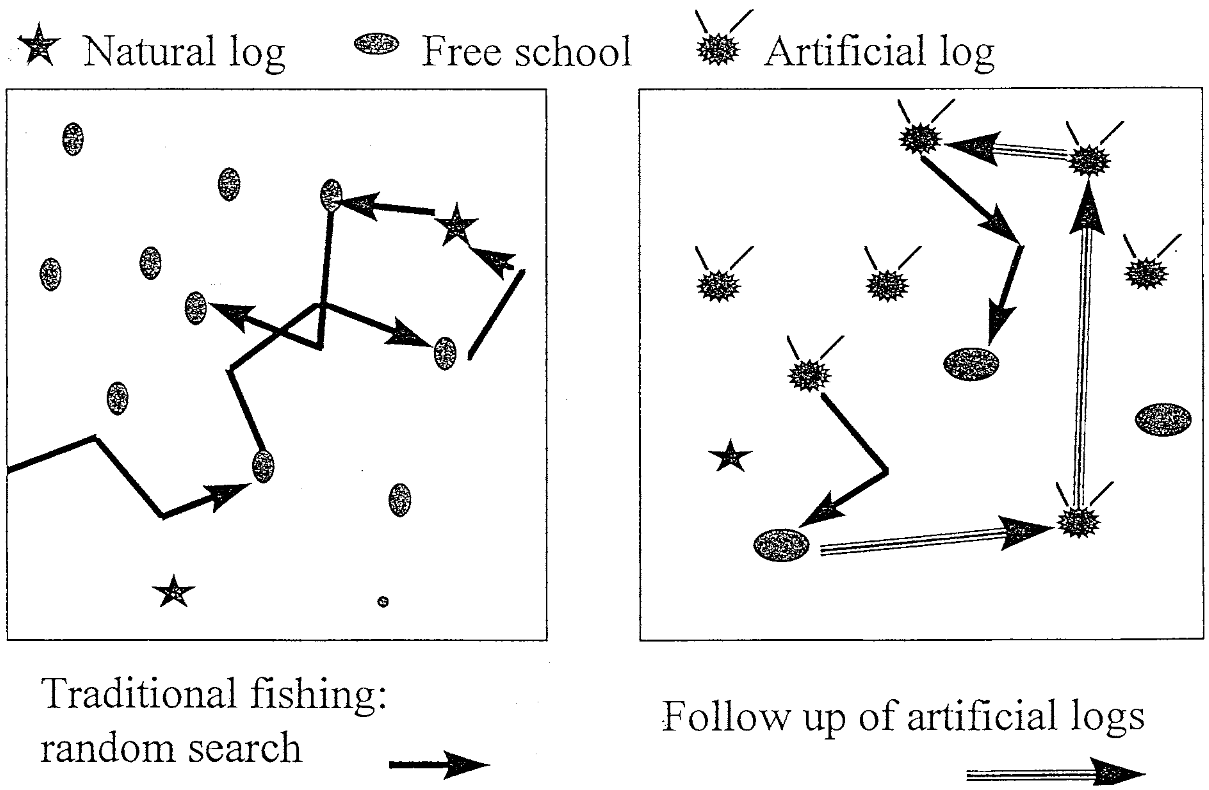


Figure 12 : Change in the effort pattern between a free school purse seine fishery (in the Atlantic, before 1990) and in a combined free and artificial log fishery (after 1990)