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ON THE CHANGES OF SPECIES COMPOSITION OF TUNA CATCHES IN THE SENEGAL-MAURITANIA AREA

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SUMMARY

This paper is doing an analysis of the changes in tuna fisheries, PS and BB, in the fishing area of located between 12° and 22° N (later called Senegal- Mauritania area) since 1970. While total tuna catches have been high (average yearly catches 1970-2014 over 30.000 tons) and quite stable, and also fluctuating without trend during this period, two major changes have been observed during this period: first, until 2010 the rarity of Fish Aggregating Device (FAD) catches in the area and since 2011, a major development of the FAD fishery in Mauritanian waters. These sudden major catches of tunas associated to FADs remain widely unexplained. Secondly, a major decline of the local abundance and catches of large yellowfin since the mid nineties. This decline appears to be widely excessive in comparison of the size of the yellowfin adult stock. The paper discusses the various potential reasons that could explain this local decline but without firm conclusion. Further research would be needed in order to clarify these major scientific questions.

RÉSUMÉ

Le présent document fait une analyse des changements survenus dans les pêcheries thonières (canneurs et ligneurs) dans la zone de pêche située entre 12° et 22°N (la zone sénégalo-mauritanienne) depuis 1970. Même si les prises totales de thons étaient élevées (moyenne des prises annuelles de 1970 à 2014 supérieure à 30.000 t) et relativement stables, et fluctuant également sans tendance au cours de cette période, deux changements majeurs ont été observés pendant cette période : d'abord jusqu'à 2010, la rareté des prises réalisées sous les dispositifs de concentration du poisson (DCP) dans la zone et, depuis 2011, le grand essor de la pêcherie de DCP dans les eaux mauritaniennes. Ces grandes prises soudaines de thonidés associées à des DCP demeurent largement inexpliquées. Deuxièmement, on assiste à une chute brutale de l'abondance locale et des prises des gros albacores depuis le milieu des années 90. Cette chute semble être largement excessive par rapport à la taille du stock d'albacores adultes. Le document discute des diverses raisons potentielles pouvant expliquer cette chute locale sans pour autant parvenir à une ferme conclusion. Davantage de recherche serait nécessaire afin de clarifier ces importantes questions scientifiques.

RESUMEN

En este documento se realizó un análisis de los cambios en las pesquerías de túnidos, cerco y cebo vivo, en la zona de pesca situada entre 12° y 22° N (denominada posteriormente zona Senegal- Mauritania) desde 1970. Aunque las capturas totales de túnidos han sido elevadas (el promedio anual de capturas en el periodo 1970-2014 se situó en más de 30.000 t) y bastante estables, también fluctuaron sin una tendencia durante el periodo, observándose dos cambios importantes durante el periodo: primero, hasta 2010 la escasez de capturas en dispositivos de concentración de peces (DCP) en la zona y, a partir de 2011, un importante desarrollo de la pesquería con DCP en las aguas de Mauritania. Estas súbitas capturas importantes de túnidos asociadas con DCP siguen sin tener una explicación. En segundo lugar, se produjo un importante descenso en la abundancia local y en las capturas de rabil desde mediados de los noventa. Este descenso parece ser muy excesivo en comparación con el tamaño del stock de adultos de rabil. En el documento se debaten las diferentes razones potenciales que podrían explicar este descenso local, pero no se llega a una conclusión firme. Se tienen que realizar más trabajos de investigación para aclarar estas cuestiones científicas importantes.

KEYWORDS

Catch composition, temporal distribution, spatial variation, geographical distribution, yellowfin tuna

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1. Introduction

It has been noticed by fishermen as well as by tuna scientists that the species composition of tropical tuna catches by purse seiners (PS) and by baitboats (BB) has been showing in the Senegal-Mauritania area drastic fluctuations and a steady decline of yellowfin catches. This spectacular variability of species composition remains poorly studied by scientists. On the opposite, it was noticed that the changes in the local species composition occurred slowly and at a lower rate in the other fishing zones of the Guinea Gulf, for instance in the other major fishing zone off Cape Lopez. As the same stocks of yellowfin, skipjack and bigeye are exploited in the Guinea Gulf, it is important to understand how much of the major changes in species composition observed in the Senegal-Mauritania area are due to changes in stock status, to changes in catchability or size selectivity and in fishing mode, or/and to changes in the local environmental conditions or to other reasons.

This study will examine the changes in the ICCAT TASK2 data (monthly catch, effort and sizes by 1° squares) observed in the Senegal-Mauritania area since the early sixties. These observed changes will be discussed with known changes in fishing modes, in the estimated stock status and in the local environment.

The final goal of this paper will be to explain the local variability of catches and CPUEs and catches by species, and to evaluate if the yellowfin CPUEs from the Senegal-Mauritania area should be used as being realistic indicators of the yellowfin stock biomass.

2. Material and methods

Data used in this work are primarily the ICCAT TASK2 fishery data from the ICCAT data base: catch and effort by 1° squares and month of all the BB and PS fisheries active in the studied areas and size data by 5° areas and month of the same fleets. It should first be noted that this data base is fairly comprehensive and based on a large proportion of log book data: since 1969 for the BB fishery and since 1980 for the PS fishery. It could be considered that the fishery data from the surface fisheries of the Senegal-Mauritania are probably among the best ones in the Atlantic, because very few IUU or poorly documented fleets have been active in this area and because tuna resources in this area have been actively and permanently studied by scientists since the early fifties. However 3 factors should be kept in mind in the ICCAT data set available today in the ICCAT data base and the data used in this study:

1) While the Spanish fleet of PS was already very active in the Senegal-Mauritania area since the early sixties (Pereiro et al 1975), there is no TASK2 data available for this fleet until 1972, and the log book coverage of the fleet remains quite low during the 1973-1979 period, at an average rate of only 28% of total catches. As a consequence the PS catches in the area remain widely underestimated before 1980 in the ICCAT TASK2. Our study will be based on corrected Spanish data during the 1970-1980 period (as described in annex 1) allowing to estimate the total catches of the fleet by species in the Senegal-Mauritania area. CPUE were not used because of (a) the today difficulties in effort standardization and (b) because of a great heterogeneity of ICCAT Spanish PS efforts depending of the year: fishing days, fishing hours, standardized or not, days at sea

2) The type of sets, FADs or free schools, have been fully identified in the PS task2 only since 1991 for the French fleet. However, it could be hypothesized that catches on natural logs and on FADs were rare before 1991 in the Senegal-Mauritania area, as natural logs tend to be rare in this area and historical times they were quite inefficient to concentrate tuna schools. This conclusion is for instance based (a) on the rarity of large rivers in the area and on the absence of FAD catches identified for the PS fleet fishing in the area during the 1977-1982 period (Ariz et al 1992) and (b) on the low average rate of 14% of FAD/log catches observed during the 1991-2011 period.

3) The historical landing data of BB in the Senegal-Mauritania area during the 1960-1968 period are not available in the ICCAT data base (IRD data); these IRD landing data were used in our analysis, based on the hypothesis that all the BB yearly landings in Dakar were caught in the Senegal-Mauritania area (probably a reasonable hypothesis taking into account the small size of most of the BB in this early fishery). However, it should be kept in mind that during this early period, skipjack catches were most often discarded because of their very low or null value in the Dakar canneries during this period.

It will analyze the regional temporal changes during the period 1960 to 2014 observed in the species composition of the catches by PS and by BB and the yearly size distribution of the tuna caught. This analysis will be mainly focused on the Senegal-Mauritania area, and it will also examine in a comparative study the fishery data of the

PS fisheries active in the Cap Lopez area. This paper will also take into account the results of recent stock assessment analysis done by SCRS. It will also examine various environmental data from the Senegal-Mauritania area in order to describe the time and space environmental variability and to identify yearly changes and trend in this local environment that could have produced a variability in the species composition of the tuna resources exploited in the area.

3. Tuna fisheries in the Senegal-Mauritania region

3.1 Overall and yearly catches

The task2 C/E data allow to identify the Senegal-Mauritania and also Cap Lopez areas, that have been selected in order to study the variability of seasonal composition in the catches of surface gears: these 2 areas are the major areas that have been permanently exploited in the Gulf of Guinea since the beginning of the surface fisheries in the early fifties (Senegal) and early sixties (Cap Lopez). It will also be possible and interesting, also based on the TASK2 data, to compare the Senegal-Mauritania fishing operation to the fishing operations in other parts of the Eastern Atlantic. Senegal-Mauritania and Cap Lopez are the 2 core areas of the surface fisheries that are easily identified as being 2 major fishing zones that are well visible on **Figure 1** showing the average catches by species of surface gears during the 1980-2014 period. The total yearly catches by species estimated in the Senegal-Mauritania region are shown by **Figure 2** for all the surface fisheries combined and by **Figures 3** and **4** for the BB and PS fisheries. These catches should be placed in the context of the total yearly catches of tropical tunas in the Atlantic that are shown by **Figure 5:** this comparison is for instance showing that an average of 10% of the yellowfin total catches were caught by surface fisheries in the Senegal-Mauritania area during the 1970-1985 period, while this percentage was reduced to only 3% of total yellowfin catches in the Atlantic, during the last 10 years. This comparison is also showing that an average of 14.4 % of the skipjack total catches were caught by surface fisheries in the Senegal-Mauritania area during the 1970-2014 period, showing a percentage of 15% of total catches during the 1970-1985 period and a high percentage of 21 % during the period 2012-2014 (entirely on FADs). On the opposite the percentage of bigeye caught by surface fisheries has always been low: an average of only 3.8 %. This comparison between tuna catches by surface fisheries in the Senegal-Mauritania area and total Atlantic catches is showing well the sustained great importance of this area for skipjack fisheries and the its historical importance for yellowfin fisheries.

It is striking to note on the figure of total catches that these yearly catches in the Senegal-Mauritania area have been reaching an average catch of 30.000 tons during the 1970-2014 period, but showing very little variability of these total catches during the period (**Figure 2**): keeping note that the lower catches during the 2006-2011 period (an average of 18.400 tons) were due to the closure of the Senegalese EEZ, while the peak of catches during the 2012-2014 period was due to the development of a new and very efficient FAD fishery in the Mauritanian EEZ by Spanish PS (analyzed by Delgado and al 2014). The reasons explaining why FADs were inefficient in the area until 2010 and very efficient later on in the studied area remain totally unknown. Another important point to note in these yearly catches is the major decline observed in the yellowfin catches in the area during the last 20 years: while yellowfin was a major species during the 1960-1995 period, its total catches are now very low in the Senegal-Mauritania area (**Figure 2**). This major question will be studied in chapter 3-5. Another striking point to note concerning the tuna fisheries in the Senegal-Mauritania area was also that after a long history of PS fisheries without a significant use of FADs (**Figure 6**), these very large amounts of tunas, predominantly skipjack (92%, vs only 2.5 % of yellowfin and 5.5% of bigeye) were caught since 2012 associated to FADs between 16°N and Cap Blanc at 21°N. As a result, the yearly catches of skipjack during each of the 3 years (2012 to 2014) in the coastal 5° square between 15° and 20°N produced the highest yearly catches of skipjack ever recorded in the history of skipjack catches by 5° squares in the Atlantic: 30000 t. in 2013, 24000 t in 2014 and 22400 in 2012. Furthermore these 3 gold, silver and bronze medals of highest skipjack catches in the history of Atlantic tuna fisheries, are associated to a coastal 5 square (415015) were solely caught in the 12 one degree squares fished during the period. The average catch per positive FAD set and the average numbers of FAD sets per fishing day in the Senegal-Mauritania area and in the other fishing zones are also 2 interesting. These basic results are shown by **Figures 7** and **8**. During the 1991-2010 period the average catch per set was lower in the Senegal-Mauritania area than in the other areas, 26 t. vs 31 t, the very low FAD catches in the area being mainly due to the low number of FAD sets. However, it should be noted that this catch per sets were very large during some years, for instance in 1993 and 1995 (much higher than in other areas). During recent years and after 2011, the average catch per FAD sets were much higher than in the other fishing zones (42 t *vs.* 27t). The analysis of the number of positive sets of FADs is showing a steady marked increase between a flat level at only 0.07 sets per day during the average period 1991-2007 (**Figure 8**), followed by an average high level of 0.44 sets per day since 2008 (reaching peaks over 0.6 sets per day since 2012). On the opposite, the average number of daily sets was much higher in the other fishing areas during the early 1991-2007 period: 0.24 FAD sets per day, and this level has been permanently increasing and reaching 0.42 sets per day during the 2008-2013 period. It should then be noted that since 2008 the average number of daily FAD sets was at similar levels in the Senegal-Mauritania area (0.44 sets/day) and outside of it in the main fishing areas (0.42 sets/day).

3.2 Biology of tropical tunas in the Senegal-Mauritania area: a reminder

The biology and movement patterns of tropical tunas in the Senegal-Mauritania areas have been studied since the early fifties by various scientists (among them Postel, Collignon, Champagnat, Bard, Cayré, Diouf) and these investigations allow to build a quite consistent qualitative biological knowledge on these species that can be summarized as following:

- The 3 species of tropical tunas (yellowfin, skipjack and bigeye) are a seasonal component and northern fractions of these 3 stocks that have been heavily exploited in the Guinea Gulf since 1950. As a consequence, the local abundance of tunas in the Senegal-Mauritania area should somehow follow the changes in each of the stock size biomasses.
- The studied area is clearly and each year a major feeding area for the 3 species: the seasonal migrations observed in the area are clearly conditioned by the large amount of food available in the area, this potential food being a combination of coastal species that are heavily exploited in the area (reaching total yearly catches over 1 million tons), but also of a wide range of demersal and of pelagic species (fishes, pelagic crustaceans as well as cephalopods, often small or very small, adults and larvae), and of macro zooplankton that are very abundant in the region in the upwelled waters off Senegal and Mauritania.
- the studied area is also clearly a potential spawning area for yellowfin and also for skipjack (Cayre 1998), but only during the summer period and mainly in the southern range of the area (off Senegal) when and where SST > 25°C are observed, the northern area being for instance permanently too cold for the tuna spawning and the larvae survival (potential spawning occurring in a spatio temporal window shown by **Figure 9**). The overview of the basic knowledge and hypothesis on the spawning of yellowfin was well summarized by Cayre 1988, see **Figure 10**. However this Senegal-Mauritania spawning area tend to be considered as being of minor quantitative importance, compared to the major larger spawning area during the first quarter in the equatorial area of the Guinea Gulf. On the other side, it should be noted that bigeye that are caught only at small or medium sizes by surface fleets in the Senegal-Mauritania areas, and most of them are not spawners, but feeding tunas.
- The apparent movement/migration pattern of tunas between the Guinea Gulf and the studied area is also well shown by the average monthly catches of adult yellowfin by Japanese longliners in their historical period of activity, during the period when the yellowfin stock was permanently and heavily exploited by Japanese longliners (1958-1966): the major concentrations of adult yellowfin were observed during the 1st quarter in the equatorial area of the Eastern Guinea Gulf, while the main yellowfin fishing zones were seasonally moving towards the north eastern Atlantic, and close to Senegal during the May to August period (see **Figure 11**). Furthermore, it was also hypothesized by Champagnat 1974 that the small and medium size yellowfin caught in the Senegal-Mauritania area were also migrating from the southern central Atlantic, and not solely from the Guinea Gulf; this hypothesis should be kept in mind by scientists.

As a conclusion, it should be hypothesized that the massive seasonal movement of yellowfin and skipjack targeting the Senegal-Mauritania area do correspond to a combination of spawning and of feeding migrations during late spring and early summer, while the movement of small and medium bigeye is solely driven by a feeding seasonal migration.

3.3 Fishing seasons

It should be noticed that these 2 BB and PS fisheries are highly seasonal in the Senegal-Mauritania area, and taking place mainly during the same fishing seasons, during the summer period, and in warm surface waters, following the windy upwelling season and the cold surface waters observed in the area between November and May because of the strong trade winds and of subsequent upwelling (**Figures 12** and **13**). A marked seasonality of monthly catches has been permanently observed in the region for the BB and for the PS fisheries, in direct relation with this environmental seasonality. This seasonality of monthly catches in the Senegal-Mauritania region is shown for BB and PS on **Figure 14** and **15.** These 2 figures are also showing that this seasonal pattern tend to be quite distinct for PS and for BB, and also quite variable between years and periods. It should for instance be noted that while there was until 2000, a marked seasonality in the BB fishery catches that were then dominated by yellowfin catches, the BB fishery has been since 2003 steadily fishing all year round, its catches being widely dominated by skipjack.

3.4 Fishing areas

It should be noted that the location of the studied fishing zone off Senegal and Mauritania tend to be:

- closed at its northern frontier at the level of Cap Blanc (21°N), because of environmental reasons: there is a permanent absence of any coastal tuna fishery active between Cap Blanc and Canary Islands. The ecological frontier at the level of Cap Blanc (21°N) is probably due to the strong upwelling off this cape, keeping in mind that the 3 species of tropical tunas are commonly fished by other fisheries in the northern areas off Canary, Madeira and Azores islands, but far north of this Cap Blanc.
- our southern frontier artificially chosen at 12° N is quite open in the south and quite artificial, but voluntarily positioned in an area of low tuna catches (compared to the higher catches off Senegal and off the Guinea dome (south of 10°N).

It should be noted that the core tuna fisheries in the Senegal-Mauritania area are mainly coastal for both gears, being located quite close from the continental shelf. It should also be noted that the fishing zones tend to be quite distinct between BB and PS (see **Figure 16** and **17**), and quite variable, depending of the periods concerning each of the 2 fishing gears. It should already be kept in mind that this geographical variability of the regional fisheries could be due to two main potential causes:

- This Senegal-Mauritania fishery mainly takes place in two EEZ belonging to Senegal (south of 16°N) and to Mauritania (North of 16°N): then, the availability or the lack of fishing agreements between the EU and Senegal (for instance since 2006 the lack of fishing agreement) or Mauritania, for BB and/or for PS, will widely or totally condition the tuna fisheries in each of these 2 EEZ (keeping in mind that potential private agreement may also be active for some vessels).
- The availability of potential tuna resources in the region will also widely condition the local fishing effort in Senegal and/or in Mauritania and also the relative abundance of yellowfin, skipjack or bigeye as well as the sizes tunas available and caught in the strata. This availability of the tuna resources will also be conditioned by the local environmental conditions, physical environment (for instance SST, subsurface oxygen, etc), as well as the condition of the local ecosystem and of the more or less large amount of coastal food available in the area for the tuna resources.

These questions will be discussed in chapter 6, based on the observed changes in the tuna fisheries and their environment.

3.5 Changes in species composition of BB and PS catches

Another important point easily visible in the figure of total yearly catches (**Figure 2**) was the major steady decline in the percentage of yellowfin in the total catches: while there was an average amount of 37 % of yellowfin (11.100 t.) in the total catches during the early period 1970-1989, there was only since 1996 an average of only 10 % of yellowfin (3200 t.) in the tuna catches caught in the area. Both gears have been showing this marked decline of their yellowfin catches, see figure 18. This major variability and trend in the yearly species composition of the tuna catches may be due to a combination of factors that will be discussed in chapter 5. It can already be noted that this large variability of species composition appears to be widely distinct from the moderate variability of the species composition observed in the other regions of the Gulf of Guinea, for instance in the Cap Lopez area, where the species composition of PS catches has been also showing a decline in the YFT catches, but much less than in the studied area (**Figures 19** and **20**), since decline being mainly due to the increase of the FAD catches. The species composition of PS catches in the Senegal-Mauritania area is also well shown by the Definetti plots showing the frequency of each ternary species composition observed in the PS samples[4] where each individual was randomly sampled independently of its specie s. It should also be noted that these Definetti plots contains an additional and valuable information concerning the size categories of the tuna sampled: the blue sector of each pie showing the proportion of large tunas in weight (here, predominantly yellowfin) for each frequency of species composition. These ternary plots have been done during 3 periods:

[4] While these ternary plots cannot be done for the BB catches because following a sorting f the catches, each species is sampled independently during the landing.

1) Period 1980-1990 combining FAD and free schools sets in an unknown proportion, when the type of schools was not identified in the samples

2) Period 1991-2011: the period without major FAD fishing in the Senegal-Mauritania area

3) Period 2012-2014: the recent period of major FAD fishing off Mauritania

These plots are showing that during the period 1980-1990 a majority of the samples were caught on pure large yellowfin sets (29 % of samples) or on pure skipjack sets (50%), and also on a mixture of yellowfin and skipjack at variable rates of mixture (a total of only 21 % of these samples). **Figures 21, 22 and 23 are** showing that the species composition of FAD and of free schools samples available since 1991 tend to be very distinct for FAD and free schools samples, but quite homogeneous for each fishing method during the entire period 1991-2014 (then the very large FAD catches observed since 2012 off Mauritania are also showing a quite stable ternary plot compared to the average species composition during the 1991-2011 period). An interesting point to note concerning the species composition during the period 1980-2014 is that the pure schools of large yellowfin were frequently sampled while they are now very rare during recent years in the free schools samples. It should also be noticed that this local decline in the yellowfin catches was somehow similar to the major historical decline that was observed in the Angola BB fishery during the 1959-1970 period (this decline remains unexplained by scientists).

3.6 Sizes caught

This analysis has been mainly done on the yellowfin catch at size by PS and BB (shown by **Figures 24** and **25**). As the changes in skipjack sizes are minor ones and less interesting, and as bigeye is not an abundant species in the area, **Figures 26** and **27** are only showing the average total CAS of skipjack and of bigeye that are typical for BB and PS catches from the Senegal-Mauritania area. Changes of the average weight of yellowfin caught by PS and by BB are shown by **Figure 28**, a figure showing a major decline and an increasing year to year variability of the average yellowfin weight caught by PS during the studied period 1980-2014. On the opposite the average weight of yellowfin landed by BB are permanently lower and stable because of the size selectivity of this gear. The comparison of the average yellowfin CAS by PS during the early and recent periods is showing that the decline in average weight was in fact due to the today lack of large yellowfin, showing now a rarity of large yellowfin caught at sizes over 10kg (or 80 cm) that are typically mostly caught in free schools sets (**Figures 21** and **24**).

4. Environmental variability in the Senegal-Mauritania area

This point will be limited to a short overview of the local environmental conditions in the Senegal-Mauritania area, primarily based on the literature and also on the COADS SST obtained from merchant ships and made available by NOAA and based on some selected papers from the environmental literature. The main environmental characteristics that is typical of the area is the seasonality of its surface waters, showing 2 major alternate warm and cold seasons, the cold seasons being conditioned in winter time by strong trade winds and subsequent upwelling. This seasonal pattern of SST in the studied area is for instance well shown by **Figure 13** (based on merchant ships COADs data, courtesy of NOAA). However it should be noted that this environmental pattern is not homogeneous in the studied area, the upwelling being mainly active on the continental shelves of Senegal and Mauritania, and never homogeneously covering the studied area. This basic geographical characteristics of the upwelling is for instance well shown by a satellite image of the area, see **Figure 12a** (kindly provided to us by H. Demarcq). It should also be noted that these cold waters are also producing a local increase in the biological chlorophyll productivity (see **Figure 12b** kindly provided to us by H. Demarcq). This high local productivity also explain the large biomass and large catches of coastal pelagic fishes in the Senegal and Mauritania areas (total catches reaching levels > 1 million tons) and the large catches of small pelagic species by coastal fisheries in the area. There is no doubt that this large biomass of small pelagic species is a major factor explaining the large tuna biomasses seasonally concentrated in this area. Another point concerning SST in the area is that they have been showing during recent years a small increase, this increase of SST being observed during every months of the year (**Figure 13**).

It should also be kept in mind in the analysis of the tuna fisheries in the area that this area is typically an anoxic area showing very low rates of dissolved oxygen at shallow levels, for instance rates of dissolved oxygen lower than 3 or 2 ml/l at a moderate depth of 100 m (see **Figure 29** from Merle, 1978). As most tuna species (for instance yellowfin and skipjack) cannot inhabit these deep anoxic waters, this lack of oxygen tend to concentrate the habitat of tuna in the shallow waters and also to increase their catchability to the fishing gears. Furthermore, it should also be noted that these low rates of oxygen tend to be shallower during recent years (Stramma et al., 2011), then potentially the habitat and food chain available to tunas, and again reducing the habitat of yellowfin and of skipjack tunas and increasing further their catchability. Another point to examine concerning the environmental changes is the trend in the biomass of food available to the tunas, an important parameter as the Senegal-Mauritania area is clearly a feeding zone for tunas. One of the potential indicator of the biomass of tuna food available in the area is given by the yearly catches of small pelagic species: even if these catches are not proportional to the biomass, they are somehow indicative of the biomass of food available because any potential major biomass change of these stocks would necessarily produce a major change in their yearly catches. In this context, the total catches of the 2 species of Sardinella (*S. eba* and *S. aurita*) by the artisanal Senegalese fisheries may be an indirect indicator of the biomass of these 2 major species. **Figure 30** is showing that these yearly catches of small pelagic species by these fisheries were quite stable since the early nineties, a trend probably indicative that there was not major change of this biomass occurring during recent years.

5. Discussion: why such major changes in the tuna fisheries

5.1 Overall

The analysis of tuna fisheries in the Senegal-Mauritania area has been showing 2 types of major scientific questions that should carefully be discussed and answered by scientists. These two major questions can be summarized as following:

1. Why such major increase today of the FAD catches, in an area where the use of drifting FADs by PS was inefficient and seldom used until 2010.
2. Why the catches of large yellowfin have been vanishing from the Senegal-Mauritania area since the late nineties?
   These two questions will be discussed in the following chapters

5.2 Why such an efficient FAD fishing since 2012?

The very high catches and CPUEs associated to FADs that have been observed each year since 2012 in the northern part of the Senegal-Mauritania area are a striking and poorly studied event. On one side, the very large amount of skipjack caught by PS since 2012 in this area was not a real surprise, as very large catches had been observed in the area in previous years. There was no doubt that the Senegal-Mauritania area is one of the best in the Atlantic for the productivity of its tuna fisheries and especially for skipjack (always the dominant species in the Senegal-Mauritania area). However, on the other side, there is no doubt that FAD fishing was not efficient in the Senegal-Mauritania area: FADs have been often seeded by PS since the beginning of FAD fishing and the PS fisheries have been active in the area during most years, but there was only an average 15% of the tuna catches of PS caught on FADs in the area during the 1991-2010 period, while this average percentage of FAD catches was reaching 55% in the fishing grounds south of 12° North. The very large catches of FAD associated catches observed since 2012 in the Mauritania area remain totally unexplained.

5.3 Why vanishing yellowfin catches in the Senegal-Mauritania area?

5.3.1 Overall

There is no doubt that while the total yearly catches were quite stable in the Senegal-Mauritania area since the early seventies, the yearly catches by species and by gear have been permanently showing a major variability. As the commercial value of yellowfin has been variable but always high during the entire period, it should not be hypothesized that this decline of yellowfin catches was due to its discards or to its a reduced targeting or to a reduced efficiency of the PS and BB fleets: this marked local decline of the yellowfin catches was probably due to the marked decline of the abundance of adult yellowfin.

On the opposite, it can be noted:

(1) That the tuna catches in the other major fishing zones, for instance off Cap Lopez, have been showing an important variability of yearly total catches but a great stability of species composition (Simply showing a declining percentage of total YFT catches due to increase catches on FADs).

(2) That the decline of yellowfin catches in the Senegal-Mauritania area is much larger that the decline of stock biomass estimated by SCRS: the most recent results have been estimating in 2011 that the adult stock was showing a quite stable trend during the period, its absolute level being quite uncertain and depending of the model used (**Figure 31**). None of the yellowfin adult biomass estimated by the assessment models in 2011 has been showing the brutal decline visible in the catches and CPUEs of large yellowfin observed since the mid nineties in the Senegal-Mauritania area. This result is also well and easily confirmed by the stable trend of most of the yellowfin fisheries indicators (CPUE and catches) of various fleets in most fishing zones (for instance purse seiners in Cap Lopez area) and longliners.

(3) That the yellowfin catches in the Guinea Dome fishing zone south of the Senegal-Mauritania area during the 3rd quarter have been increased during recent years: possibly an indication that this southern area is now the equivalent of the historical concentration in the Senegal-Mauritania area (**Figure 32**).

Based on these observations, our conclusion is that these vanishing catches of large yellowfin in the Senegal-Mauritania area probably correspond to a vanishing biomass of large yellowfin in the area but also that this change is a local event due to changes in the local "conditions". Our conclusion is that it should be of major interest for scientists to understand this major change in the local yellowfin stock and fisheries geographical distribution (surprisingly this important question has never been studied or even discussed by ICCAT scientists….). This recommended study should for instance cover the following topics.

5.3.2 Changes in local environmental conditions or in the food available to large yellowfin?

The analysis of sea surface temperature in the area has been showing a minor increase during the studied period: effect of global warming. However this small increase in SST cannot explain the vanishing biomass of adult yellowfin. It was also noted that there was an increase of anoxic waters in the area, but it is difficult to envisage that this change would eliminate large yellowfin from the Senegal-Mauritania area, without having a visible impact on skipjack and on small. A potential decrease in the food available to large yellowfin in the Senegal-Mauritania area should be further studied, but the preliminary information available from catches by coastal fisheries would indicate that there was no major decline in the exploited coastal resources during recent years. Furthermore, it should be kept in mind that the total productivity of the tuna fisheries was quite stable during the recent period, while the 3 species of tropical tunas tend to eat similar preys (most often mesopelagic preys, sometimes coastal ones) and taking note that total tuna catches were + or – stable during recent years.

5.3.3 Shrinkage of the distribution of the eastern Atlantic yellowfin stock in relation with its reduced biomass?

It has been often observed that major declines in stock biomass, for instance due to their overfishing, were often associated to a logical shrinkage of the area covered by the stock. In this hypothesis it should be envisaged that the today lack of adult yellowfin could be due to a shrinkage of the stock habitat following its declining biomass (keeping in mind that most estimates of adult biomass have been quite stable during recent years, **figure 31**). In this hypothesis, the yellowfin spawning zone that was positioned off Senegal and in the Cape Verde islands in summer time, would now be limited to the spawning zone identified by Cayré 1988 at southern latitude, for instance between 5° and 10°N at 15°W, an area where the today catches and abundance of large yellowfin has been stable or increased during recent years. It should be kept in mind the catches of large yellowfin were observed only in April and May, then before the traditional fishing season in the Senegal-Mauritania area. The small amount of gonad index data available from this area 10°-5°N at 15°W would indicate high gonad index, but only in April (while GI are low in the equatorial area) (Chassot personal communication). More gonad samples from this area would be necessary to evaluate the potential spawning in this area south of 10°N and north of 5°N.

5.3.4 Genetic loss of a vanishing Senegal-Mauritania area yellowfin sub population?

If the study of yellowfin gonad status from the Guinea dome catches is showing that these tunas are not in spawning condition, it could mean that a sub population of yellowfin that was spawning every year in the Senegal-Mauritania area, is now vanished and lost. This potential loss of a given sub population could possibly be due to local overfishing of this sub population at one stage of its life. This hypothesis remains of course totally questionable, but it would be worth to study it, as such genetic erosion could reduce the potential fecundity of the yellowfin stock.

5.3.5 Negative impact of FAD fishing in the intertropical areas altering tuna movements?

It has been hypothesized by Marsac *et al.* (2000) that large numbers of drifting FADs seeded in an area could somehow modify the natural movement pattern of tunas associated to FADs that are trapped under networks of dense drifting FADs: the ecological trap hypothesis. As very large numbers of FADs: today, about 17000 FADs (Fonteneau *et al.*, 2014), have been seeded in the Eastern Atlantic in 2013, and this large number of FADs may have indirectly modified the historical movement pattern of yellowfin. This hypothesis could be envisaged, but it does not appear to be a realistic one to explain the recent lack of large yellowfin in the Senegal-Mauritania area, because large yellowfin are seldom associated to FADs in the Atlantic.

6. Conclusion

This study was a first preliminary attempt to examine and to explain the major changes in the species composition of the tuna catches in the Senegal-Mauritania area. It has been showing that there was a major decline of the abundance of large yellowfin in the area since the mid nineties. This decline could be explained by a combination of various causes that have been discussed, but its real causes remain difficult to evaluate. On the other side, there is little doubt that this major decline has nothing to do with the trend of the adult stock of yellowfin in the Atlantic Ocean. As a consequence, local yellowfin CPUE of the Senegal-Mauritania fisheries should be used carefully in any analytical works done by SCRS: they are probably indicative of a combination of local events in the Senegal-Mauritania area at the NE frontier of the yellowfin stock, but not at all representative of the entire stock. Another point emerging from this study would be to promote various research actions that should be developed as possible in order to study better and to explain the major changes observed in the Senegal-Mauritania area: for instance analyses based on log book and on observer data on the recent efficient use of FADs, on the local environmental changes and on their potential effect on large yellowfin, on the today potential spawning of yellowfin south of 10°N, etc. Our recommendation is that this regional question is of great scientific interest and that it should be actively studied by ICCAT scientists (for instance scientists from Senegal, Mauritania and the EU). The EU should be a logical source of funding in support of these investigations, because of the great importance and long history of the EU fisheries in the area in relation with multiple fishing agreements between EU and Senegal or Mauritania

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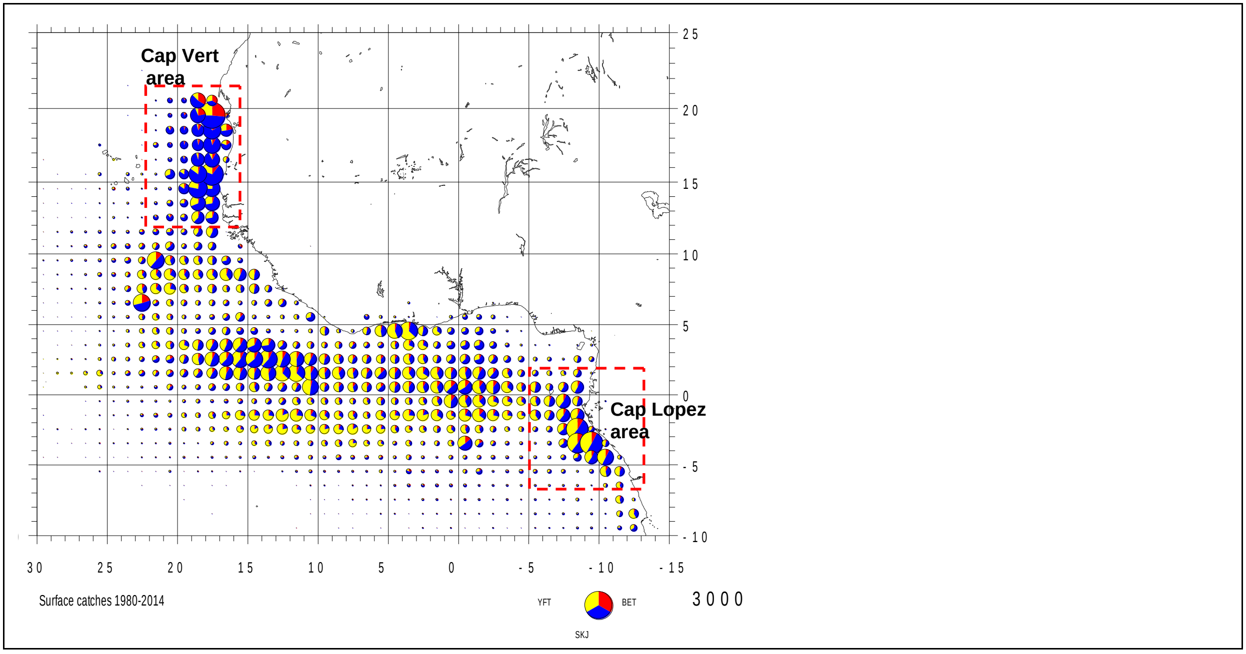

Figure 1. Average catches of surface gears by species during the period 1980-2014 and location of the 2 main fishing zones off Senegal-Mauritania and off cap Lopez that have been selected to analyze the yearly variability in species composition

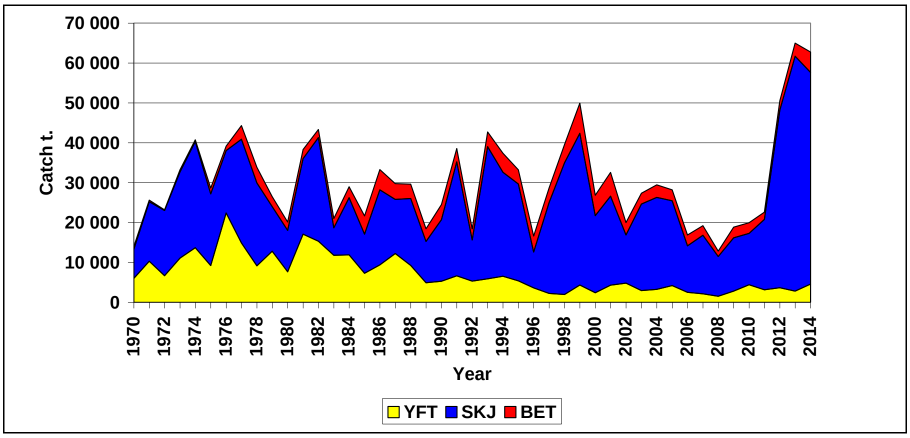

Figure 2. Yearly total catches by surface gears in the Senegal-Mauritania area (as declared in the ICCAT TASK2: Spanish PS catches in the area being estimated during the 1970-1979 period based on IEO data).

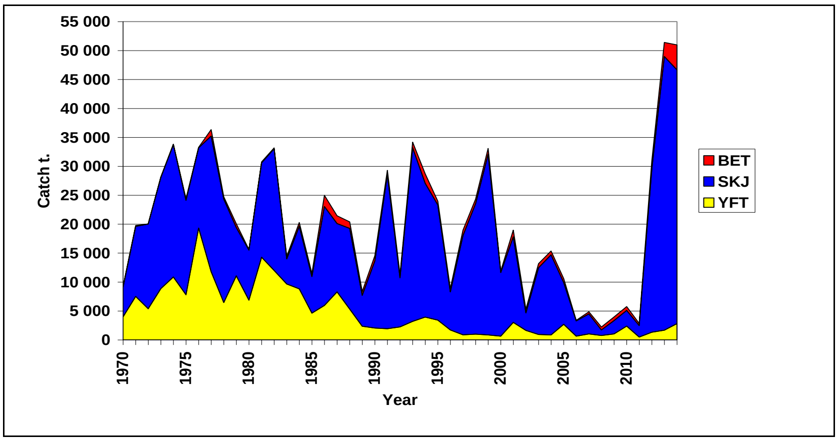

Figure 3. Yearly catches by PS in the Senegal-Mauritania area (declared in the TASK2: Spanish PS catches corrected during the 1970-1979 period).

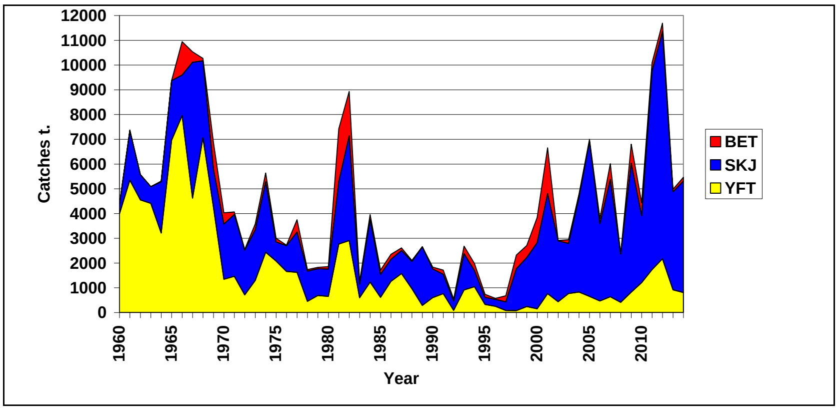

Figure 4. Yearly catches of BB in the Senegal-Mauritania area.

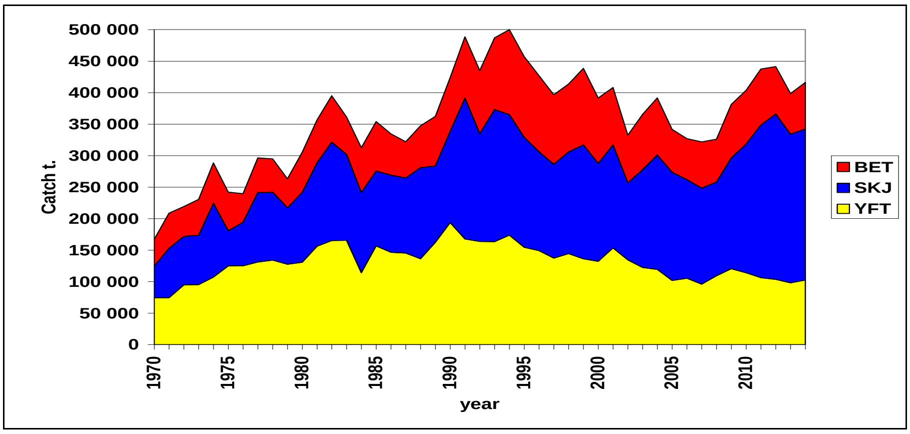

Figure 5. Total yearly catches of tropical tunas in the Atlantic.

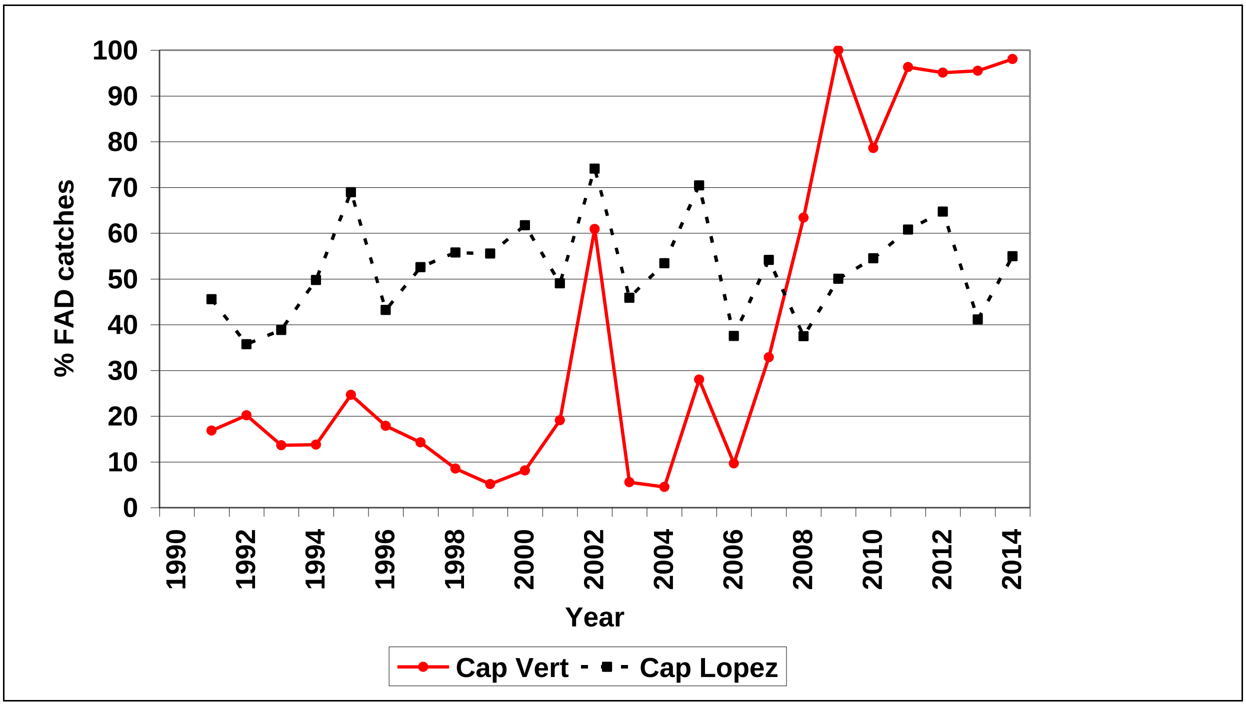

Figure 6. Yearly percentages of catches associated to FADs in the Senegal-Mauritania and in the Cap Lopez areas.

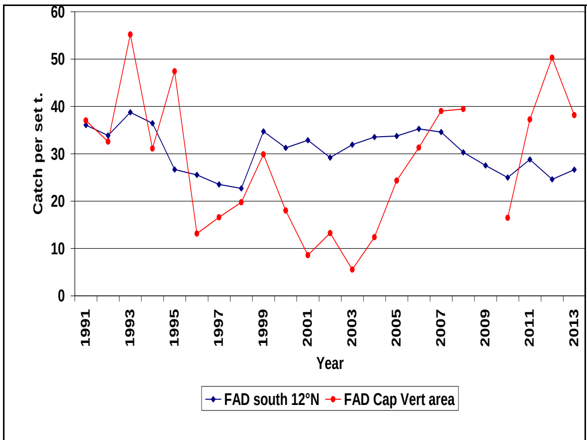

Figure 7. Average total yearly catch per FAD set in the Senegal-Mauritania area and in the rest of the Eastern Atlantic, south of 12°N.

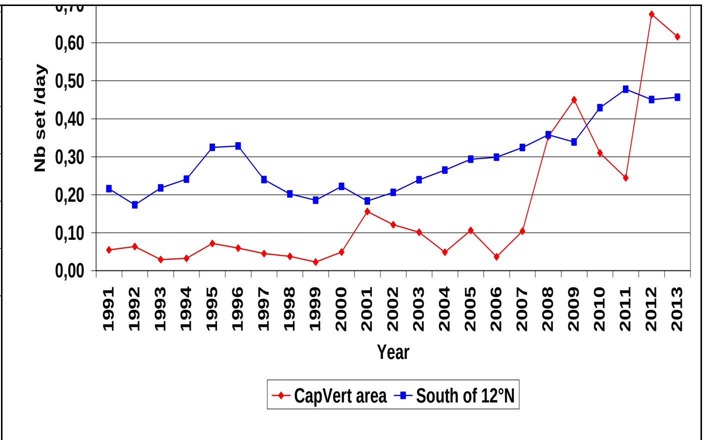

Figure 8. Number of positive FAD sets per fishing day in the Senegal-Mauritania area and in the rest of the Eastern Atlantic, south of 12°N.

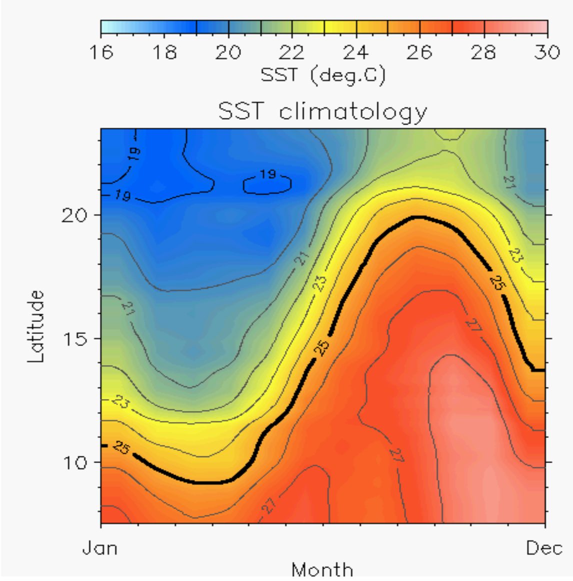

Figure 9. Diagram of average monthly Sea surface temperature as a function of latitude in the studied area. Isotherm corresponding to a 25°C SST, i.e. a minimal temperature for tuna spawning, shown in red (based on ICOADS data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/*).*

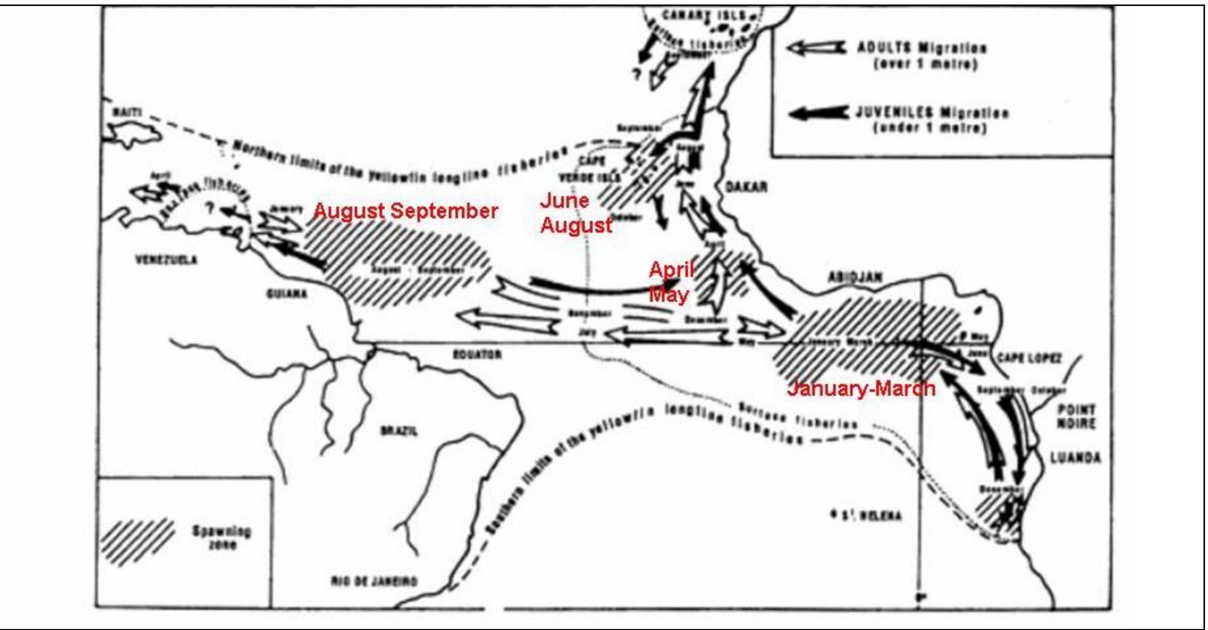

Figure 10. Overview of hypothetical movement pattern of adult and juvenile yellowfin proposed by Cayre 1988.

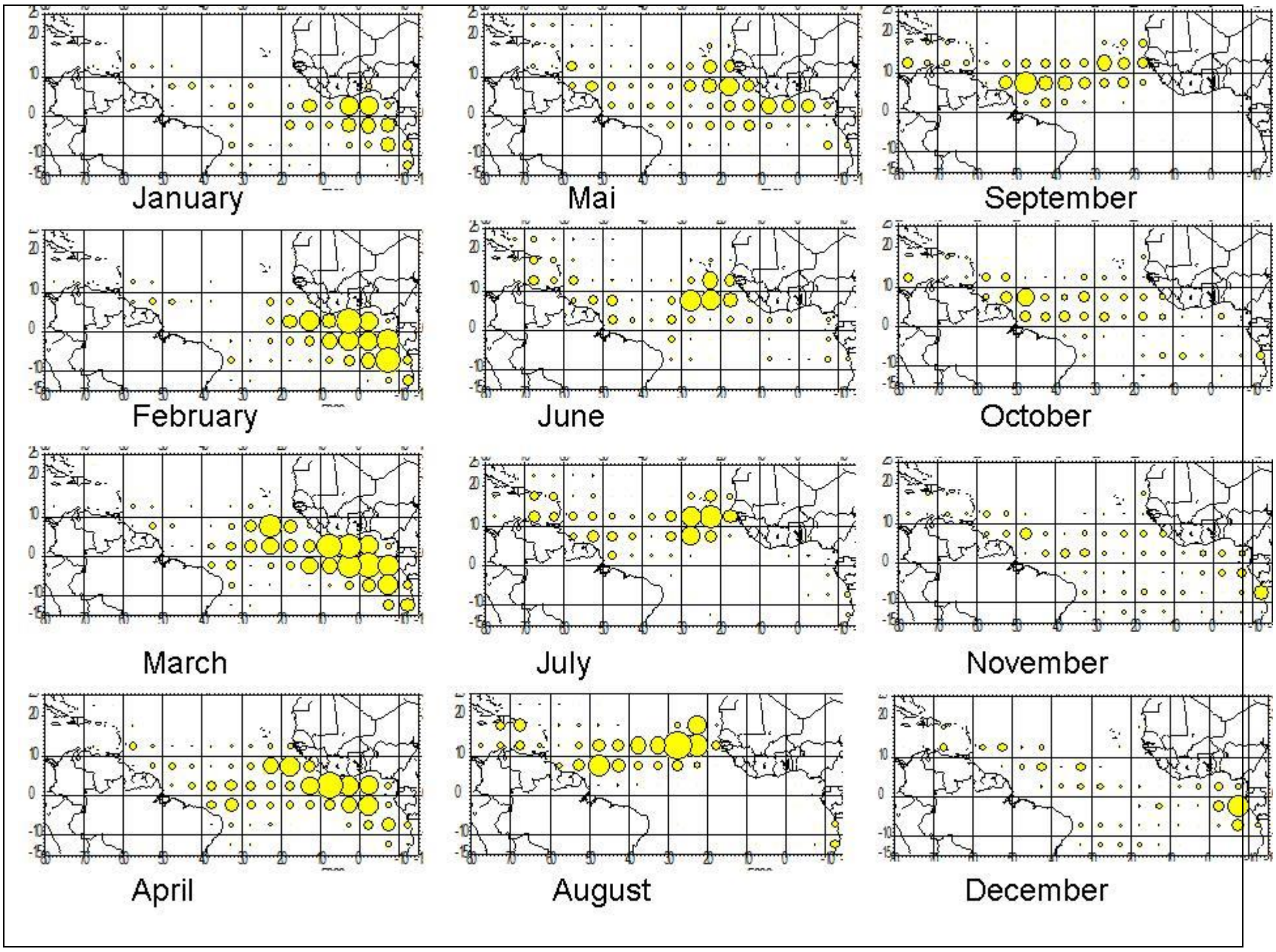

Figure 11. Monthly average catches of yellowfin by Japanese longliners during the period 1958-1966…. *Indicative of seasonal tuna movements/migrations.*

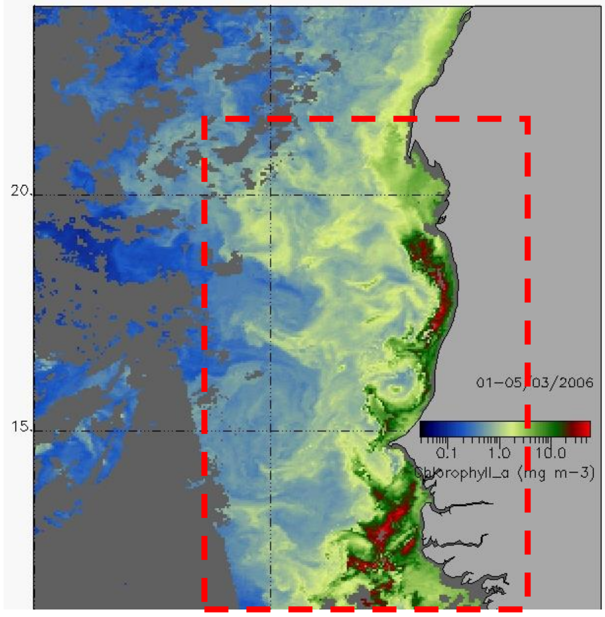

Figure 12a. Typical pattern of chlorophyll satellite image in the studied area showing the spatial heterogeneity of productivity pattern (courtesy of Hervé Demarcq, IRD).

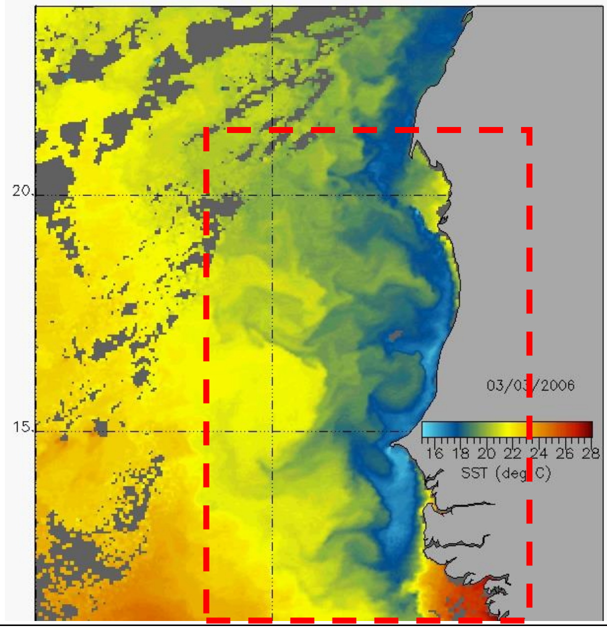

Figure 12b. Typical pattern of Sea surface satellite image in the studied area showing the spatial heterogeneity of temperature in relation with localized coastal upwelling (courtesy of Hervé Demarcq, IRD).

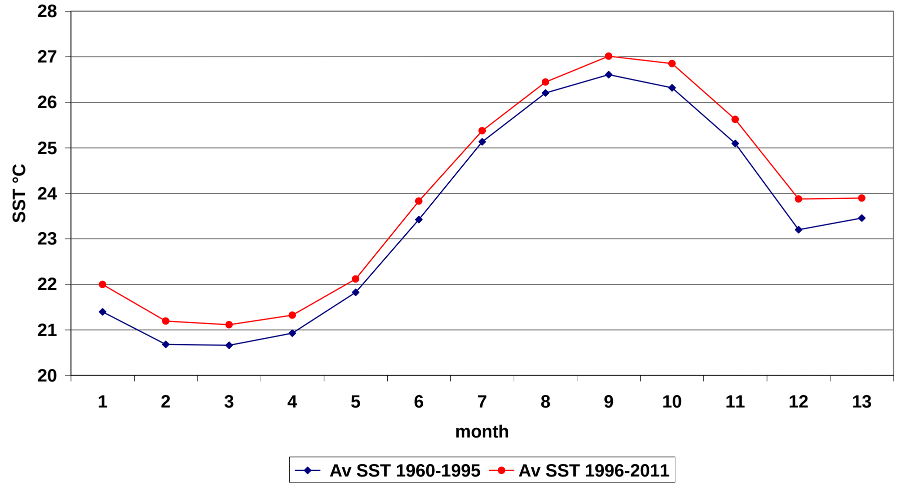

Figure 13. Average sea surface temperature in the studied area during the 1960-1995 period and during recent years, period 1996-2011 period (COADS data).

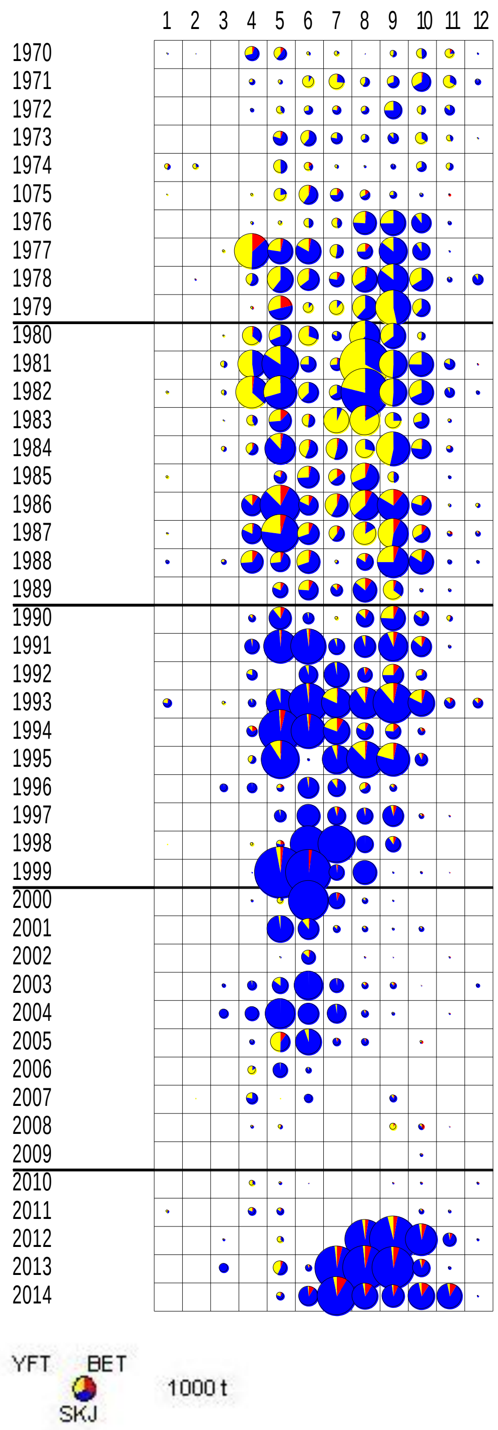

Figure 14. Monthly catches of PS fisheries, by species, in the Senegal-Mauritania area (widely underestimated during the 1970-1979 period due to incomplete TASK2 Spanish PS data).

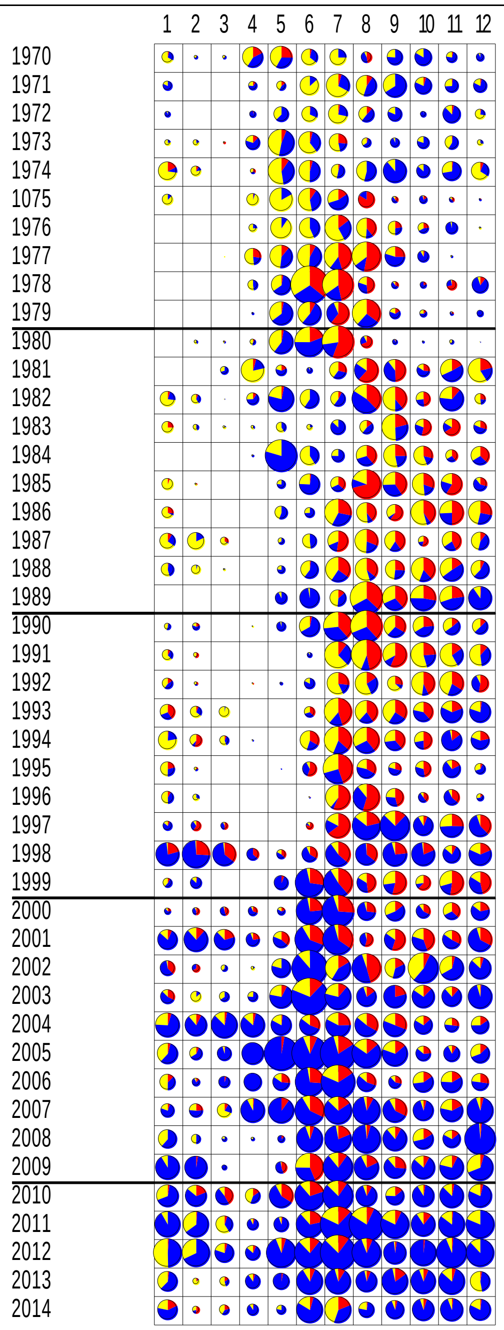

Figure 15. Monthly catches of BB fisheries, by species, in the Senegal-Mauritania area.

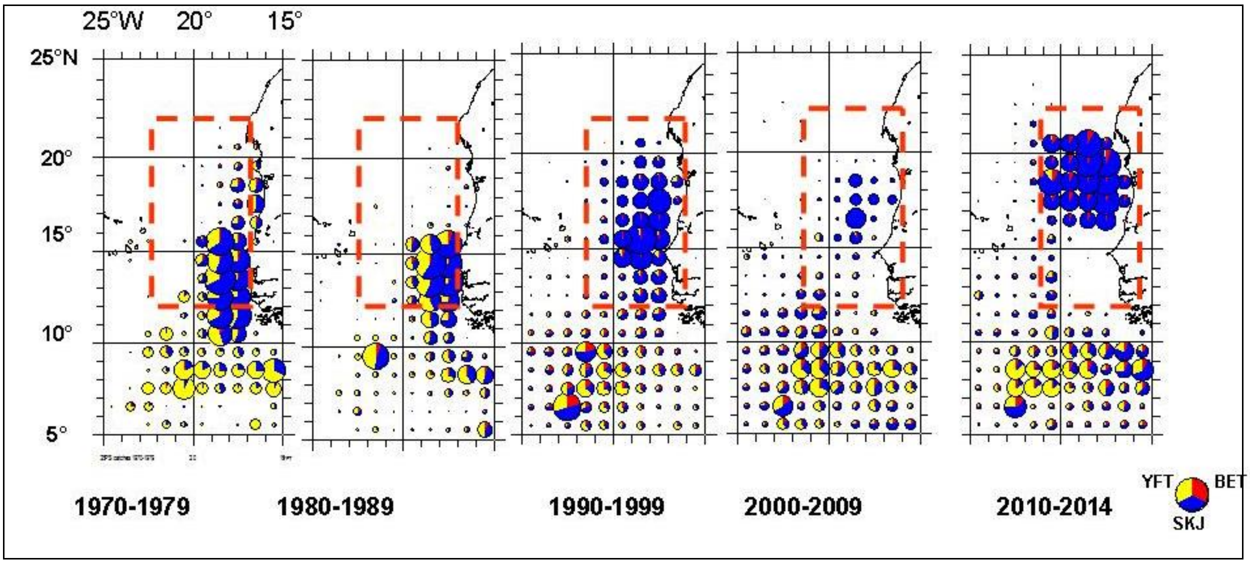

Figure 16. 1970-2014: average catches of PS during 5 periods.

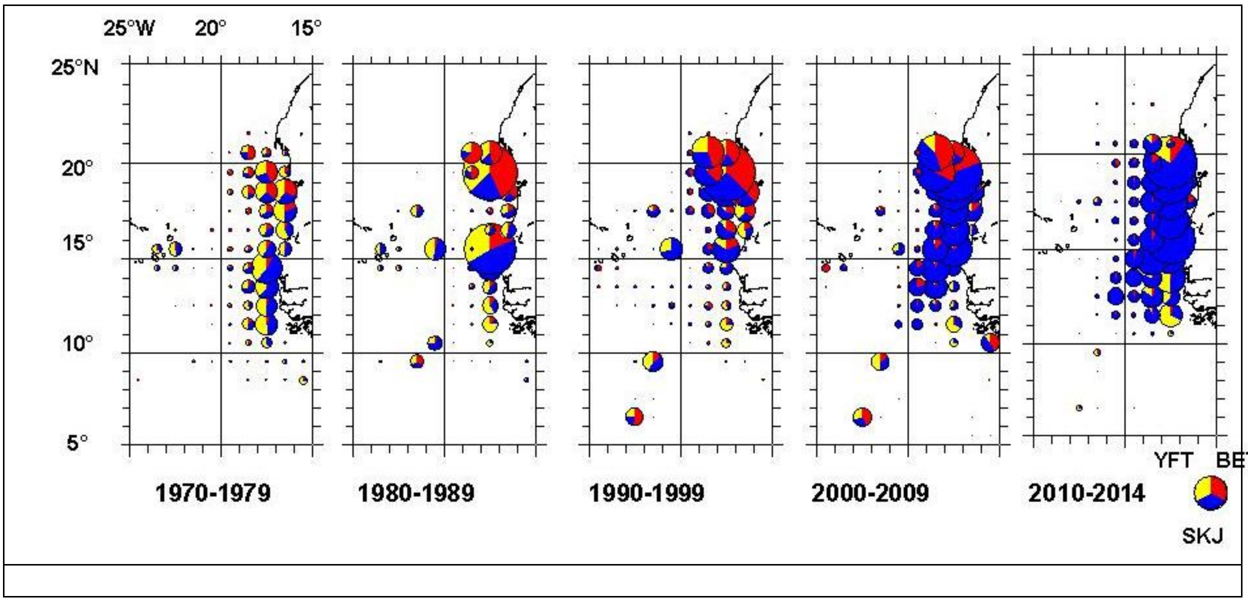

Figure 17. 1970-2014: average catches by 1° squares of baitboats during 5 periods.

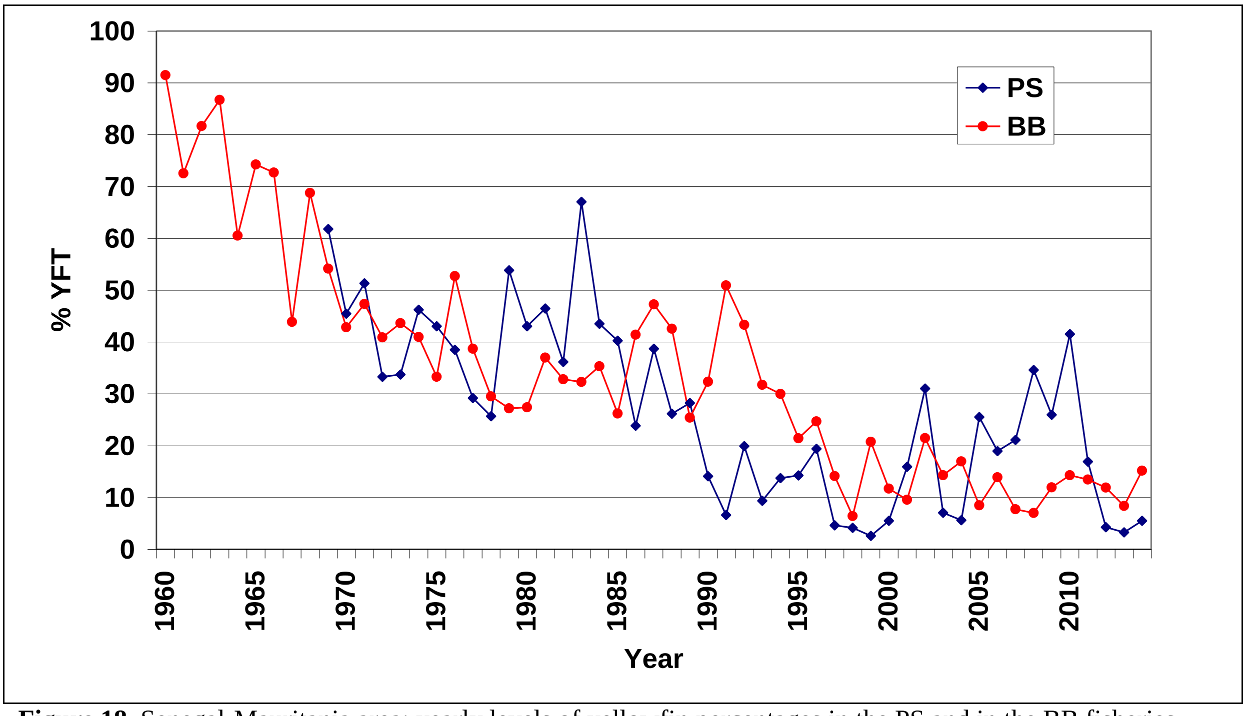

Figure 18. Senegal-Mauritania area: yearly levels of yellowfin percentages in the PS and in the BB fisheries

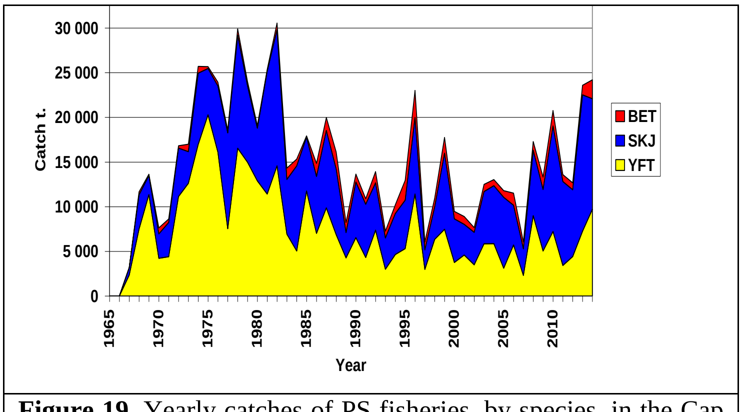

Figure 19. Yearly catches of PS fisheries, by species, in the Cap Lopez area.

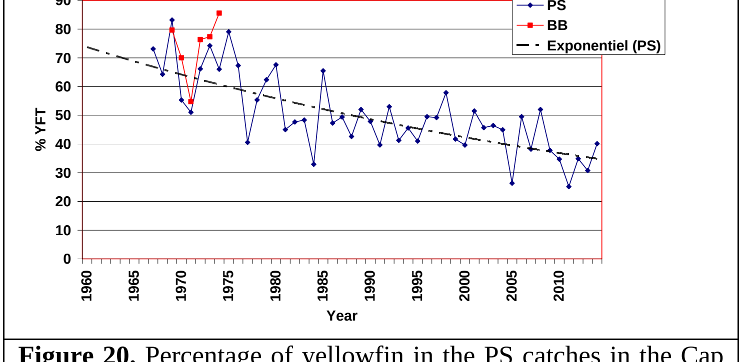

Figure 20. Percentage of yellowfin in the PS catches in the Cap Lopez fisheries.

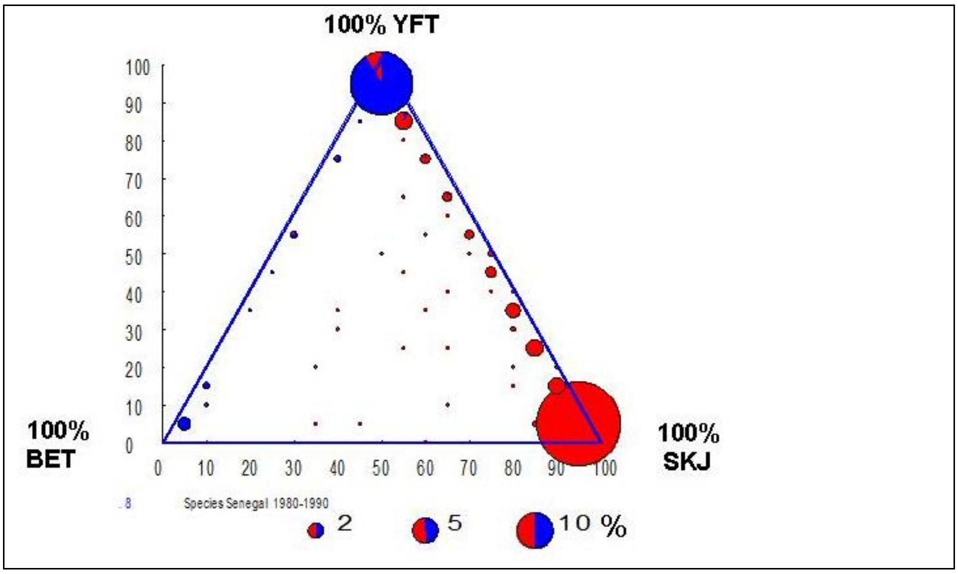

Figure 21. Frequency of the species composition of the 687 samples (predominantly on free schools) during the 1980-1991 period from the Senegal-Mauritania area (in blue: % of large tunas >10kg, in weight).

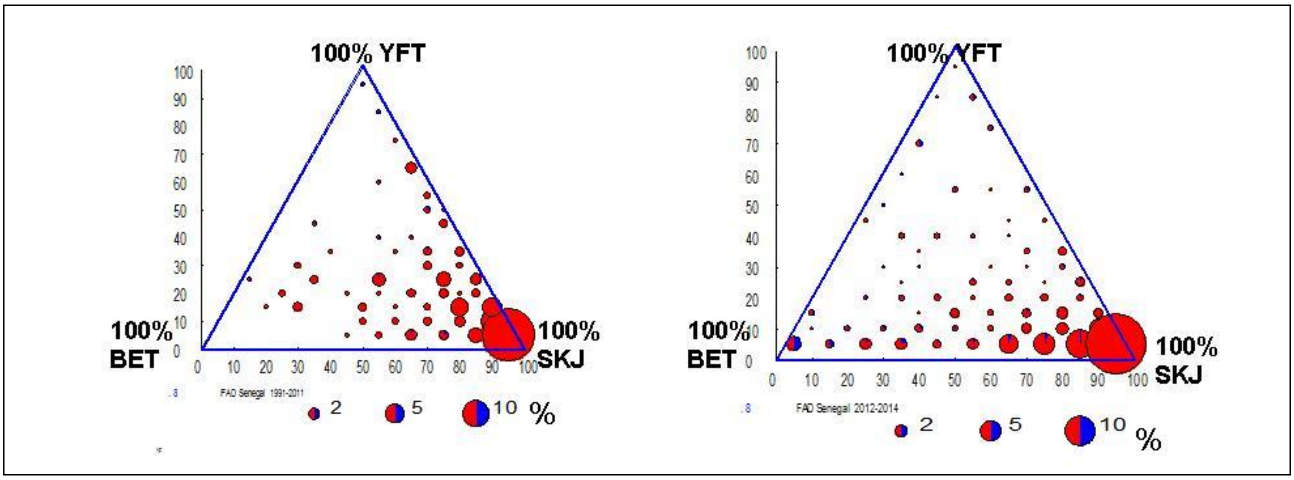

Figure 22. Frequency of the species composition of the 261 FAD schools samples during the 1991-2011 period (left) and on the 579 samples during the 2011-2014 period from the Senegal-Mauritania area.

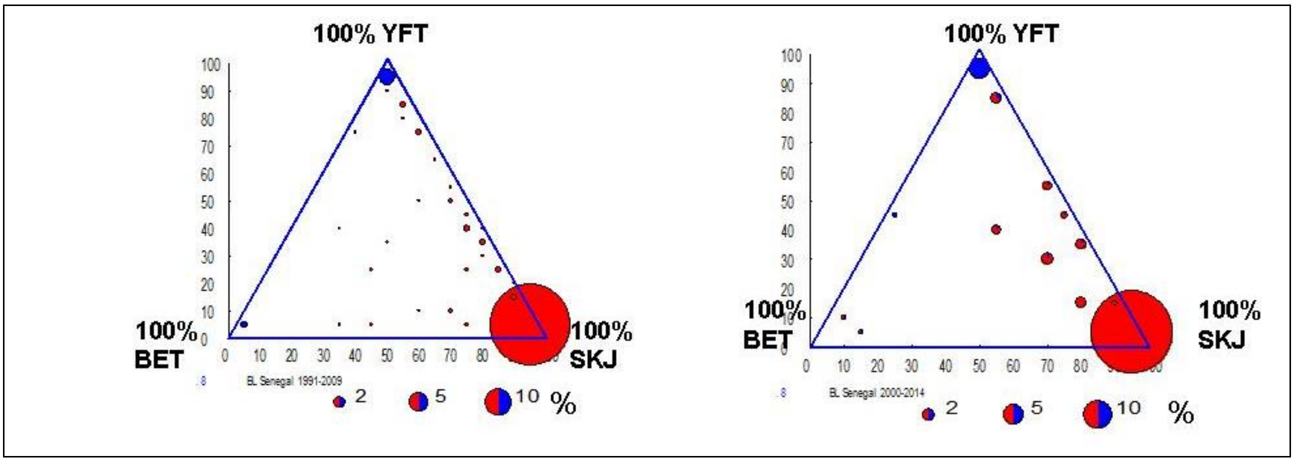

Figure 23. Frequency of the species composition of the 597 free schools samples during the 1991-2011 period (left) and on the 250 samples during the 2011-2014 period from the Senegal-Mauritania area.

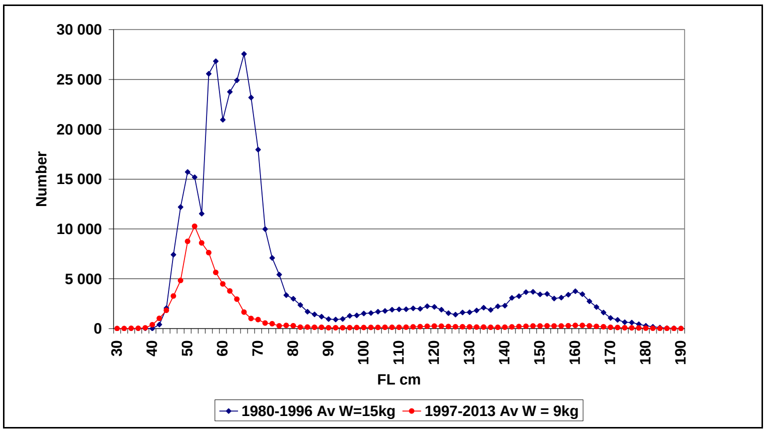

Figure 24. Average numbers of yellowfin caught by size by PS in the Senegal-Mauritania area, during 2 periods: 1980-1996 high abundance and 1997-2014 of low abundance.

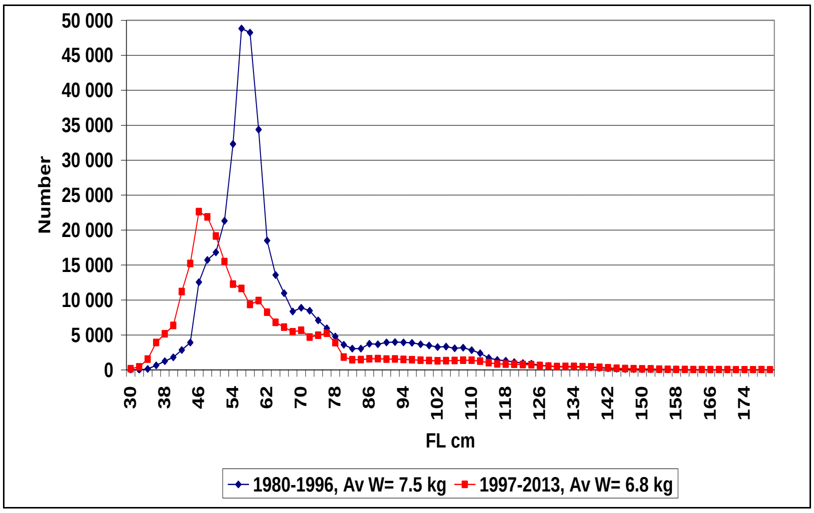

Figure 25. Average numbers of yellowfin caught by size by BB in the Senegal-Mauritania area, during 2 periods: 1980-1996 high abundance and 1997-2014 of low abundance.

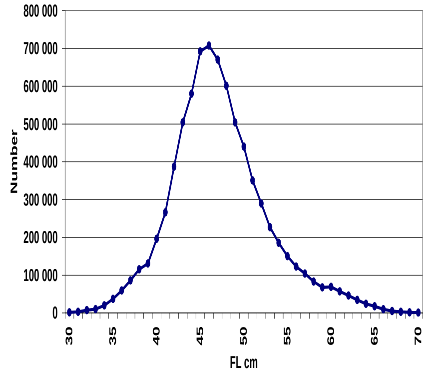

Figure 26. Average catch at size of skipjack caught by BB and PS in the Senegal-Mauritania area (1980-2013).

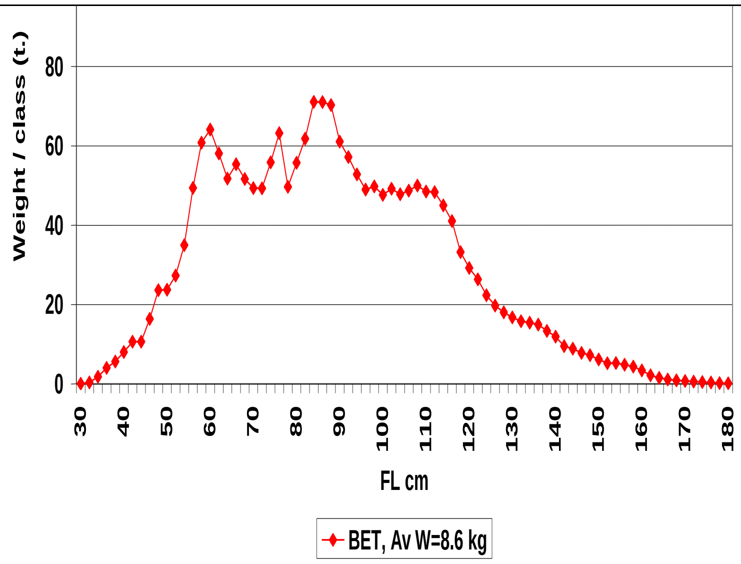

Figure 27. Average catch at size of bigeye caught by BB and PS in the Senegal-Mauritania area (1980-2013).

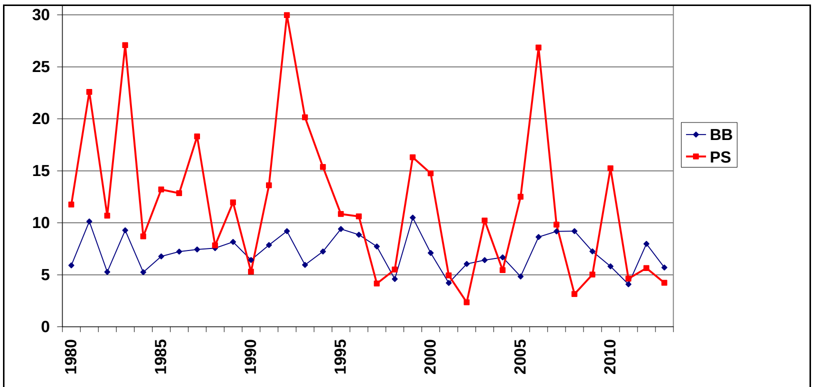

Figure 28. Average weight of yellowfin caught by BB and PS in the Senegal-Mauritania area.

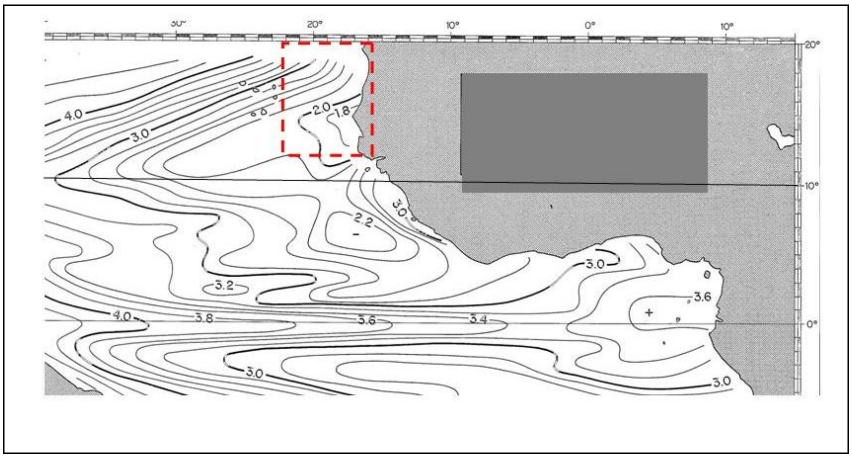

Figure 29. Average rates of dissolved oxygen at a depth of 100 m (studied area in red) (from Merle 1978).

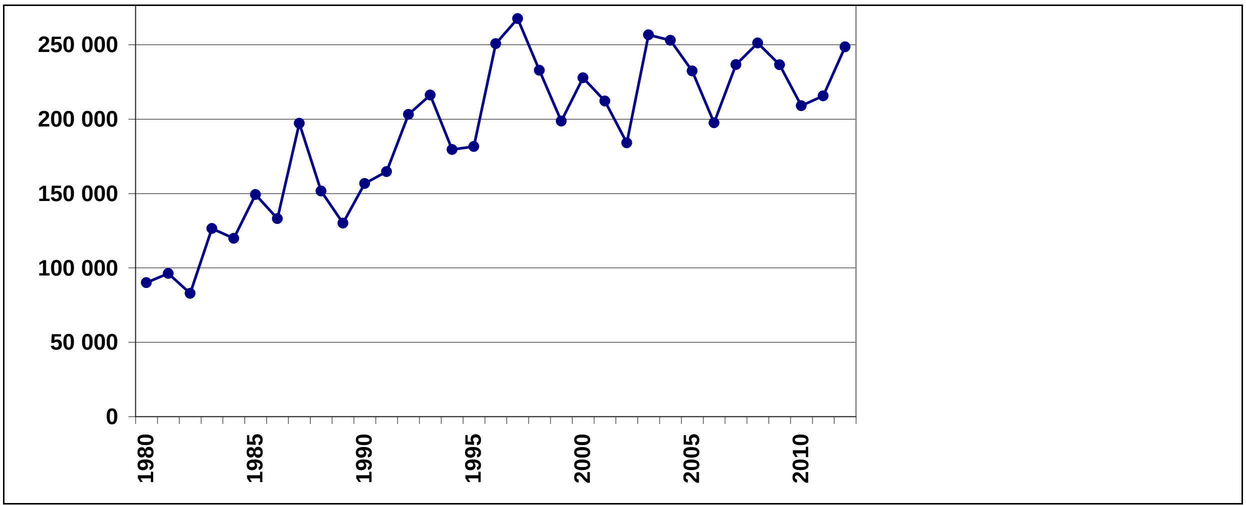

Figure 30. Yearly catches of Sardinella by Senegalese fishermen (predominantly by artisanal fisheries).

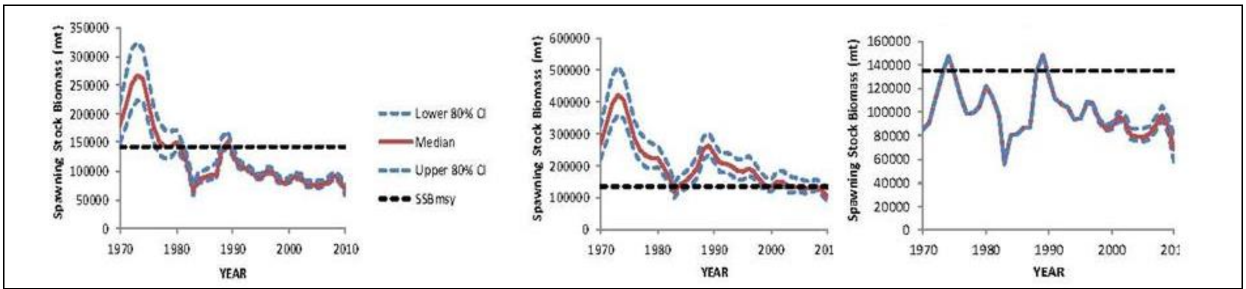

Figure 31. Biomass of the adult yellowfin stock estimated by 3 types of VPA during the 2011 SCRS stock assessment.

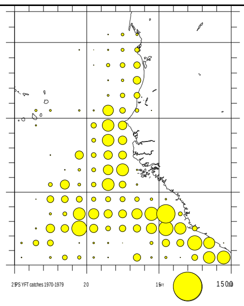	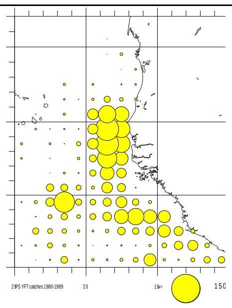	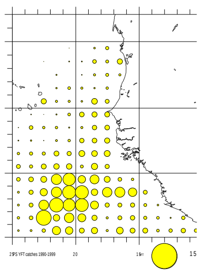	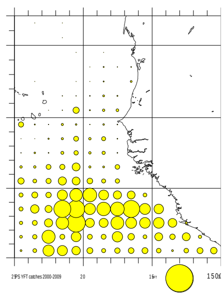	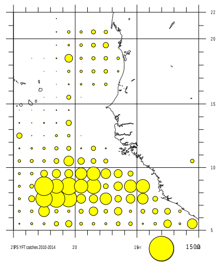
Figure 32a. yellowfin catches by PS 1970-1979	**Figure 32b.** idem 1980-1989	**Figure 32c.** idem 1990-1999	**Figure 32d.** idem 2000-2009	**Figure 32e.** Idem 2010-2014

Annex 1

Estimated catches in the Senegal-Mauritania area by Spanish PS during the 1970-1980 period

The comparison of the yearly catches in the TASK1 and TASK2 reported by Spain is showing (1) that there was no coverage of Spanish log books data in the early period 1963-1973 and (2) that this coverage of log book has been steadily increasing during the 193-1980 period to reach a level close to 100% after 1980, see **figure 1**. As a consequence, while the total catches by Spanish PS have been a steadily increasing and an important component of the PS fisheries, see **figure 2**, these Spanish catches are widely under estimated in the ICCAT TASK2 during the seventies.

In such a context, we have made an attempt to estimate the yearly catches in the Senegal-Mauritania area by Spanish PS. These estimates were obtained following these rules:

1. Period 1970-1975: various SCRS papers by Spanish IEO scientists (Pereiro et al 1975, Fernandez 1973) have been providing quantitative estimates of their quarterly catches in the so called Dakar .It has been assumed that this area was equivalent to our Senegal-Mauritania area, and these catches have been kept in our study.
2. Taking note that there are no bigeye catches in these 1970-1975 catch statistics, because Bigeye catches were misclassified as yellowfin in all the Spanish log books. It was assumed in our today corrected series that bigeye catches were mis-classified as yellowfin, and that there was the same percentage of Bigeye in the Spanish purse seine catches as in the other fleets from France, Senegal and Cote d'Ivoire.
3. Period 1976-1980: it has been assumed that the TASK2 data was randomly and well covering the activities and fishing zones of this PS fleet. Then the TASK2 catches from the Senegal-Mauritania area have been multiplied by the ratio between TASK1 and TASK2 yearly catches, based on data shown by figure 1.

As a result our total yearly catches by the Spanish PS fleet estimated in the Senegal-Mauritania area and used in our study are shown by **Table 1**.

Table 1. Yearly catches by species of Spanish PS estimated in the Senegal-Mauritania area.

Year	YFT	SKJ	BET	Total
1970	2 237	3 579	*321*	6 137
1971	4 035	9 122	*193*	13 350
1972	3 868	11 768	*87*	15 723
1973	7 751	18 320	*383*	26 454
1974	9 033	21 526	*715*	31 274
1975	5 043	14 378	*911*	20 332
1976	17 962	11 804	1 976	31 742
1977	6 762	16 490	1 977	25 229
1978	3 419	9 330	1 978	14 728
1979	7 573	5 546	1 979	15 099
1980	4 690	6 357	1 980	13 027

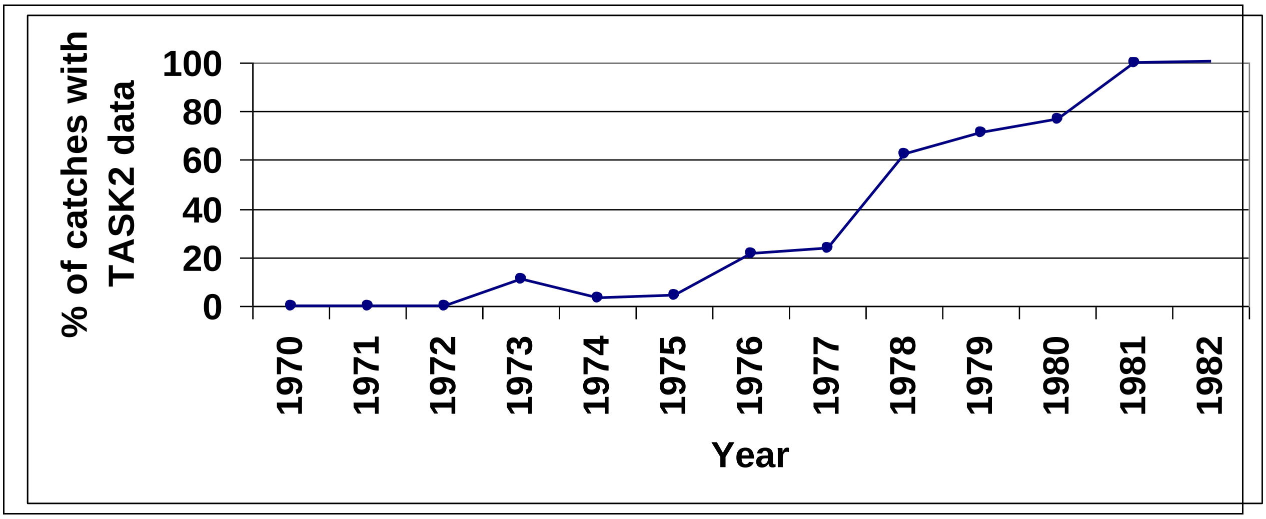

Figure 1. Percentage of Spanish PS catches reported to ICCAT in the task2 by 1° and month.

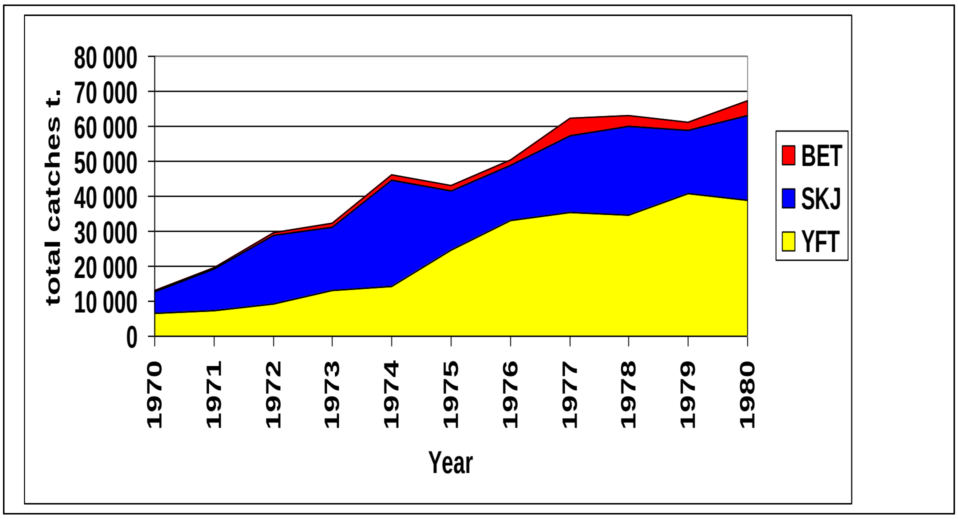

Figure 2. Yearly total catches by Spanish PS during the 1970-1980 period.