Meso-scale exploitation of a major tuna concentration in the Indian Ocean

By Alain Fonteneau[1], Vincent Lucas[2], Alicia Delgado[3] and Hervé Demarcq[4]

Summary

The paper analyzes the meso-scale fishery data of the purse seine fleet fishing in the western Indian ocean in February 2005 when a major concentration of tuna has been heavily exploited by this surface fishery. This event took place during a short period of only 12 days in a small area of about 3500 nautical miles^2 , located west of the Seychelles EEZ. This small spatio and temporal strata produced a record total catch of 22.000 t. Sets were made mainly on free schools (93% of total catches) and 78% of the catch was composed by large yellowfin tuna (average weight of 38 kg). The average CPUE and the average catch per set were very large, 68 tons per day at sea and 91 tons respectively. This fishing event took place in an area where high concentration of chlorophyll was observed by satellite, at least 9 days before the fishing event, and then this concentration was probably related to its feeding on a large biomass of preys.

Résumé

Cet article analyse les données à méso-échelle de la flottille de senneurs qui a exploité en Février 2005 une très importante concentration de thons. Cet événement s'est déroulé durant une courte période d'environ 12 jours seulement, située à l'ouest de la ZEE des Seychelles. Cette petite strate spatio temporelle a ainsi permis une capture record de 20.000 tonnes. Les calées ont été surtout réalisées sur des bancs libres (93% des prises totales) et en majorité sur du gros yellowfin (78% des prises totales, avec un poids moyen de 38 kg). Durant ce événement la PUE moyenne était très élevée ((68t/jour) de même que la prise moyenne par calée (91 tonnes). Cet événement a eu lieu dans une zone où de forte concentrations de chlorophylle avaient été observées par satellite au moins 8 jours avant le début de la pêche des thons. Cette concentration était probablement de type alimentaire, les thons se concentrant sur une forte biomasse locale de proies.

[1] Alain Fonteneau, IRD scientist, CRH, BP 171, 34203 Sète Cedex, France, (E Mail : alain.fonteneau@ird.fr)

[2] Vincent Lucas, SFA scientist, Victoria, Seychelles

[3] Alicia Delgado de Molina, IEO scientist, Centro Oceanografico de Canarias, Santa Cruz de Teneriffe, Canary Islands, Spain (E Mail : alicia.delgado@ca.ieo.es)

[4] Hervé Demarcq, IRD scientist, CRH, BP 171, 34203 Sète Cedex, France, (E Mail : herve.demarcq@ird.fr)

1- Introduction

Tuna are highly migratory species whose spatial distribution covers large areas in the world ocean. However, due to the discontinuities in their suitable habitat, large fraction of tuna catches are often caught during short periods of time in very small areas. These ephemeral spatial and temporal strata, called "tuna concentrations" or "tuna patches", are actively searched by fishermen as these hot spots can easily allow to entirely filling the wells of various purse seiners within short periods of time. This type of meso-scale fishing events have been analyzed various times in the Atlantic (Fonteneau 1986, Ravier et al 2000), but has never been conducted in the Indian Ocean, although the fishery data shows that they are also often observed and heavily exploited in this ocean. Using the information provided by log book data and size sampling done during landing, the goal of this paper is to analyze the meso-scale fishing activities of the purse seine fleet, which exploited such major tuna concentration west of the Seychelles EEZ in February 2005.

2-Material and methods

Fishery data

This analysis is primarily based on the log book information and size sampling done on the European Union and Seychelles fleets of purse seiners. Catches by this fleet corresponds to a great majority of the fishing activities in the selected area (e. g. an average 86 % of the total purse seine catches during the period 2000-2004), when none of the other purse seiners fleets fishing in the Indian Ocean was noticed in the area during the studied fishing event. Detailed log book data as well as the size sampling done during the landing were primarily used in this analysis.

A first exploratory analysis of the 2005 fishery data set was done showing that a very large quantity of tunas had been taken in February 2005 in a given 1° square (figure 1b). An analysis of the meso-scale fishing activities of the fleet was then done on daily fishing maps and on the daily changes in catches in the area in order to identify the duration and geographical extension of this fishing event. It can be seen that the concentration mainly took place during a period of 12 days (February 9th to 20th) within a small fishing zone of approximately 1° square (figure 3).

With the aim of analyzing the meso-scale dynamic of the exploitation of this tuna concentration, the main variables characterizing the purse seine activities and their corresponding catches in the area were analysed on a daily basis: number of fishing vessels operating in the area, daily fishing effort, catches by species, numbers of sets and estimated duration of these sets, size of the area explored each day, type of fishing modes (e.g. FADS sets, non-associated school sets, etc), species composition of the catch and sizes of fishes taken. The daily size distributions of the three species caught within this strata were obtained from a high sampling rate of these catches, with a total of 7565 tunas sampled during landings in Victoria (table 2). The levels and trends of each of these parameters will be examined and discussed in comparison with the typical patterns observed in similar hot spots of the purse seine fishery as they have been described in the Atlantic.

Environmental data

The average environmental conditions in the area during the period were taken from the Levitus and Boyer 1994 word atlas (figure 12), and compared to satellite information (colour of surface waters) obtained on this area before and during the fishing event, in order to evaluate if this "hot spot" fishing event could be linked with some visible environmental anomaly.

3- Fishing event

The fishing event took place in the offshore waters west of the Seychelles EEZ in an area that has been historically fished at this season by the purse seine fishery (figure 1a). This map shows that the area where the fishing event took place was not identified as being a major fishing zone, when very large catches have been taken in the area during February 2005 (figure (1b). This strata, dominated by catches of large yellowfin, has been classified by Stequert et al 2001 as being a typical spawning zone for the adult yellowfin (e.g. fishes larger than 1 meter). The environmental conditions found in this area during the month of February are typically a suprathermoclinal layer of about 100 meters, reaching an average shallow temperature of 27°C.

This tuna concentration has been exploited by a large fraction of the EU purse seine fleet (Spanish and French) as well as by Seychelles flags vessels (own by Spanish interest and handled by Spanish crews)

The analysis of the fishery data shows that a record catch of nearly 22000 tons of tuna, (78.2 % of yellowfin, 16 % of skipjack and 5.8 % of bigeye, estimates based on the corrected species composition), has been taken in a very small area centered at 5°40'South and 47°30' East (table 1 and figure 3). An estimated surface of about 3500 nautical miles^2, e.g. smaller than a 1° square at the Equator, has been exploited during a period of only 12 days. Until now, such high level of localized catches has never been observed in historic development of purse seine fisheries operating in the Indian Ocean, in the Atlantic Ocean or in the Eastern Pacific Ocean.

If the fishing event had a very short duration (see daily changes in catches in figure 4 and location of the catches in the figure 3), a large fraction of the purse seine fleet, with a maximum of 32 vessels simultaneously fishing the same tuna concentration at the end of its exploitation.

The analysis of daily species composition of the catches (figure 2 and table 1) indicates that yellowfin tuna has been permanently and by far the main species targeted and caught, most of these fishes being taken on free swimming schools (93% of total catches). The average rate of unsuccessful sets on free schools was close to 57 % (a quite high percentage typical of this fishery). These yellowfin caught were predominantly large fishes as shown by their size distribution given by figure 7 with an estimated average weight of 38 kg (figure 6). This weight can be compared to the average typical weight of also 38 kg, caught by purse seiners during the first quarters of the period 1995-2004 on free schools in the Equator-10°South area, west of 50°E.

The analysis of the daily sizes of yellowfin caught and sampled (figure 7) shows that very few immature yellowfin smaller than 90 cm were taken during the fishing event (only 7.5% of the total numbers caught). Large yellowfin caught can be classified in two categories:

- small adults in a range between 90 and 120 cm of fork length that were mainly caught during its second half
- very large fishes larger that 120cm, than have been caught every days over the time duration of the fishing event.

A small proportion of bigeye was also taken in these free schools dominated by yellowfin (estimated at 5.7% of yellowfin catches, possibly underestimated), and these large bigeye were caught at sizes similar to yellowfin at an average weight of 37,6 kg.

The average catch per successful set observed on the 224 positive sets during the fishing event was very high, 91 tons/per set, and it can be noticed that 31.3 % of these sets produced a catch larger than 100 tons. The maximum catch per set has been reaching an

estimated weight of 400 tons (figure 8). Based on linear equations between the catch per set and the setting time, the total duration of these sets was estimated at 1372 hours (including positive and negative sets). This total duration, a period when the vessels were not able to search, represented 39% of the fishing time exerted by the fleet. The daily number of sets was quite stable at a relatively low level of 18,7 positive sets per fishing day, keeping in mind that the total effort exerted locally by the purse seine fleet has been constantly increasing during the period (figure 4).

CPUE: The catch per unit of effort (CPUE) for yellowfin caught in free school sets was calculated using three types of units of effort (figure 10):
(1) numbers of hours at sea,
(2) fishing hours
(3) estimated searching hours.
It appears that the three CPUE indices were highly correlated during the entire period. On the 5th of February, these three series of CPUE started to be to be quite high in the area, e.g. 4 days before the date that has been selected for the analysis as being the day 1st of the fishing event (However, during these first 4 days before February 9th the total effort and catches in the area were still limited). The most interesting CPUE to consider is probably the free school CPUE of yellowfin stratified by two size categories: small adults (90 - 120 cm FL) and large adults (> 120 cm FL). The CPUE of larger fishes shows a severe declining trend during the first 8 days of exploitation (with a CPUE reaching nearly zero during the last 2 days), when on the 18th of February, there is a new major increase of the yellowfin CPUEs (and of the subsequent catches) for both groups of small and large adults (figure 9). Notice that after February 20th, a large number of vessels have been still exploring the area, even though the indices of CPUE (and then of catches) being at very low levels.

4- Environment

Sea surface temperatures collected during the fishing operation by purse seiners indicate that all tunas were caught in warm surface waters in a range between 26° and 30° C, with an average temperature of 28,6°C (figure 13). This temperature is typical of this stratum (figure 12) with a layer of warm surface waters above a thermocline at about 100 m. This range of temperature typically corresponds to the warm shallow waters that are observed in the area at this season that are suitable to allow the maturation and spawning of yellowfin tuna (among other species) (Hassani and Stequert 1991).

The satellite information shows that a major environmental anomaly, namely a very dense (over 50 mg/m^3) and highly localized of chlorophyll concentration was repeatedly observed by satellite in the area before and during the fishing event. This major environmental anomaly was first identified on the satellite image taken on January 23th and fully confirmed on January 26th by the image shown by figure 14 (e.g. 14 days before the major fishing events). This bloom was located close to a marked thermal front, with surface waters at <26° in the North and over 28°C in the south. Unfortunately, it will remain impossible to determine the original date of this environmental anomaly because of a high density of clouds in the area. This anomaly has been also observed and followed in the same area during several weeks, and at least until February 13th when it disappeared from the satellite images.

It should also be noticed that several skippers of purse seiners have been informed of this highly visible environmental anomaly well before the fishing event, but it is difficult to associate the discovery of the concentration to the circulation of this satellite information among the skippers of the purse seine fleet.

5- Discussion

Bearing in mind the importance of its catches and the reduced size of the fishing strata, it appears that the fishing event presently analysed was very unique in the history of the world purse seine tuna fishery. Such meso-scale event is obviously of great importance for tuna fishermen, as it allows to get very high CPUE and to fill the wells of the boats within a very short period of time. These fishes were probably fished on a feeding concentration, keeping in mind that these large yellowfin were possibly in spawning condition (being caught in a typical spawning strata). Unfortunately there was no biological sampling done on the gonads or stomachs of these yellowfin and this question will remain a pending one.

The daily fishing maps done during the period (figure 11) are showing that the daily fishing zones were highly concentrated each day in a very small peculiar area with an estimated superficy estimated between 100 and 200 nautical miles^2. It can also be noted that these small areas of daily high catches have been showing some small scale apparent movement, possibly due to a fishes displacement. An overview of this apparent movement is given figure 11. Based on the declining catches and CPUE generally observed during the exploitation of various tuna concentrations in the Atlantic Ocean, it was suggested that many of them were suffering very high local exploitation rates (Fonteneau 1986). In such cases of very high exploitation rate, the total catches tend to be just a bit lower than the local population. As a consequence, knowing the total catches allows one to estimate the initial local biomass. In the present study, such a typical quick decline can be observed for the CPUE of large yellowfin CPUE during the February 9th to 17th period (figure 9). This decline may indicate that the local biomass of large yellowfin, at least its fraction previously followed and exploited by the fleet, was reduced to nearly zero on February 17th. However, the major increase of both medium and large yellowfin adults CPUEs on February 18th suggests a new local recruitment of fishes of these categories. This “fresh” biomass was then heavily exploited by more than 30 vessels in an area very close to the previous ones (at an eastward distance of about 40 miles), and only during 3 days (72 positive sets and a total yellowfin catch of 6600t). The fact that after February 20th, the CPUE has been reduced again to nearly zero, when purse seiners were still exerting a high level of searching activity, could suggest that most tunas suddenly vanished from the area on this day, but without a visible indication on the numbers of these survivors.

One major pending question upon such concentration is to explain it, and two types of biological explanations are explaining most of these concentrations: they are linked either with a feeding concentration of tunas targeting a concentration of preys, or they are linked with spawning concentrations of spawning tunas in favourable environmental strata and conditions

There is a high probability that the dense levels of chlorophyll observed north of the fishing zone during several weeks have produced a large local concentration of food available to tunas. This food concentration probably explains the subsequent concentration of tunas in the area, but its species composition will remain unknown. Fishermen and scientists have recently reported that tuna schools have been often seen and caught in the Western Equatorial Indian Ocean in feeding frenzy, while targeting large schools of *Natosquilla spp (*a pelagic crustacean) and such feeding on *Natosquilla* has often been highlighted as a potential cause of high CPUE by purse seiners in recent years (Fonteneau et al, 2004). However such presence of Natosquilla in the area has not been reported to us.

With respect to the assumption related with a spawning concentration, it is clear that this stratum is typically a spawning stratum for yellowfin. The literature devoted to this topic for yellowfin (Karpinski and Hallier 1988, Hassani and Stequert 1991) indicates that during the 1st quarter the fishing areas around Seychelles have been well identified as being the best

spawning strata for yellowfin (although these authors have identified other spawning activities in the Eastern side of Seychelles). It can then be hypothesized that this concentration, located in an area with optimal SST (in a range between 26 and 30°C) and low winds, was a spawning concentration. This assumption could be reinforced by the fact that large yellowfin in reproductive stages may tend to be highly vulnerable to the purse seine fisheries, in relation with their shallow and schooling behaviour during spawning.

These spectacular and ephemeral "fishing hot-spots" are definitely very interesting ones for scientists as well as for fishermen, although they have been too seldom studied and analysed by scientists. This type of meso-scale analysis of fishery data can be very interesting to better understand the biological, behavioural and environmental processes at the origin of such tuna concentrations. Furthermore, the interaction between these tuna concentrations and the fishing effort exerted by the purse seine fishery is also of great interest. As an example, there is evidence that the early purse seine fishery that was fishing in the same fishing area during the early eighties would have caught much smaller quantities of yellowfin, this lower expectation of catches being simply been due to various additive causes such as:

- ✓ the lower fishing efficiency of the old nets, sets over 100 tons were very difficult to handle and seldom observed, while during this fishing event, 64% of total catches has been taken by these sets larger than 100 tons.;
- ✓ furthermore, the freezing capacity during the early eighties was not sufficient for many boats to catch and to freeze these very large sets in a short time.
- ✓ the lower average capacity of each purse seiner (average capacity was at about 1200 m3 during the mid eighties, over 1800 m3 nowadays): each boat can exploit the same fish concentration during a larger period of time before being filled up by its load of tunas,
- ✓ the increased efficiency in handling large quantities of tunas: in the sets observed on the present fishing event, the gain is setting time between the early eighties and nowadays can be estimated (based on observer data) at a level of 18%. Such gain of setting time, correspondingly increases the potential searching time of the fleet.

As a result, the increasing efficiency developed to locate and to exploit these tuna concentrations tend to increase the fishing power of a given fleet (increased q factor).

At least two recommendations could be made following this study:

1) On the need for port samplers to identify in real time such potential large scale tuna concentrations, and when such event is identified, to obtain all accessory potential information on the event from fishermen and to sample the gonad index and the stomach content of these tunas.
2) On the need to identify and to analyse in the history of the Indian Ocean purse seine fishery (period 1983 to now) the occurrence and exploitation patterns of these tuna concentrations. This study should necessarily be done on the combined purse seine fleet. The *ad hoc* software made by IRD (Ravier et al 2000) does allow to automatically identify in the log book data all these exploited concentrations, and this software could be made available to conduct this analysis

5-Conclusion

The present fishing event appears to be by far the most spectacular and important in the history of world purse seine fisheries. The available data allows to make a quite comprehensive analysis of this event that was probably linked with a major environmental anomaly and a local concentration of food available for tunas. The detailed causes of the event, such as the food involved or the potential spawning activity of the tunas fished will remain questionable, but the analysis of this event widely confirms the importance for the

purse seine fleet of such fishing events. Analyzing the dynamic of this meso-scale event has confirmed that a large fleet of efficient purse seiners presently active in the Indian Ocean can now exert a strong fishing pressure upon this type of tuna concentrations. It can be assumed that such meso-scale event has frequently occurred in the past in the world ocean, but remaining unnoticed to scientists (lack of ad hoc analysis or low exploitation rate). In the present case, the tuna concentration became highly visible because there was a large fleet of highly efficient purse seiners exploiting this tuna concentration. It would then be worth to better study the changes in the meso-scale exploitation patterns and rates exerted by purse seiners during the history of the Indian Ocean purse seine fisheries, as these events play an increasing role in the dynamics of tuna stocks exploitation by purse seiners.

Acknowledgments

This analysis was made possible by the very good cooperation by all the skippers who have been submitting to us detailed information upon their activities. We want to sincerely acknowledge their highly positive work and cooperation. Furthermore, the efficient work done in Victoria harbour by the multinational team of technicians from SFA, Spain and France, who have been permanently sampling the species and size composition of these catches, should also be greatly recognized and acknowledged by us. Their very efficient work has provided valuable input to our study.

Our acknowledgements are also given to Daniel Gaertner who made very useful comments on the draft of this text. We want to also give our most sincere thanks to Gildas Bodilis from the French company Chevanne Merceron Baillery, as he kindly offered to us all the satellite images that he has been collecting and analyzing before and during the fishing event.

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Tableau 1: Daily catches identified in the log book of purse seiners in the area shown by figure 2

Day	YFT	SKJ	BET	Total
3	399	48	34	481
4	204	42	10	255
5	494	0	115	609
6	496	21	21	537
7	1086	5	44	1134
8	209	8	25	242
9	1387	148	94	1629
10	850	67	91	1008
11	1162	359	81	1602
12	1950	18	165	2133
13	876	44	129	1049
14	1096	293	114	1503
15	1820	282	176	2277
16	1020	363	72	1454
17	410	314	32	755
18	1430	542	86	2057
19	3374	1002	159	4535
20	1824	91	66	1982
21	291	163	19	474
22	138	229	18	385
23	242	395	31	668
Total	**20758**	**4433**	**1579**	**26770**
Total 9-20th	**17198**	**3523**	**1263**	**21985**

Tableau 2: Numbers of tunas measured, corresponding to each fishing day, on the studied catches, by species

	9	10	11	12	13	14	15	16	17	18	19	20	Total
Yellowfin	509	268	118	0	472	392	315	226	201	936	2081	598	6116
Skipjack	66	0	123	0	0	60	24	219	211	309	162	5	1179
Bigeye	12	4	21	13	22	40	51	25	80	2			270
Total	587	272	262	13	494	492	390	470	492	1247	2243	603	7565

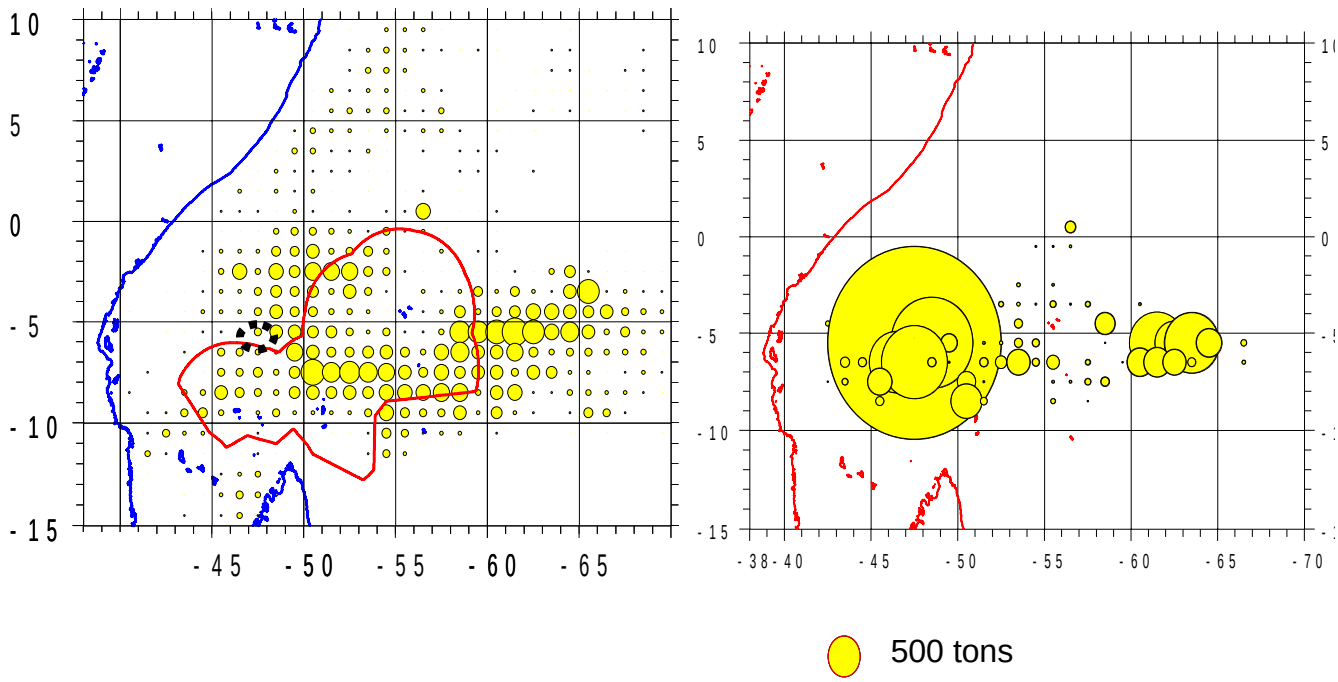


Figure 1: Average catches by species taken by 1° squares by the purse seine fisheries during the month of February (average period 1982-2003) and area of the presently analyzed 2005 fish concentration (doted line).

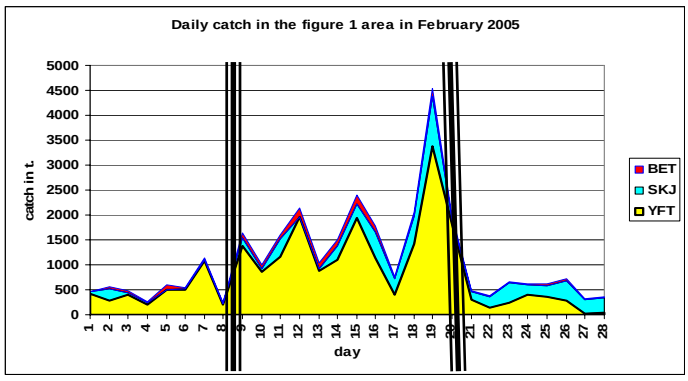


Figure 2 : Daily catches by species recorded in the area shown by figure 2 during February 2005

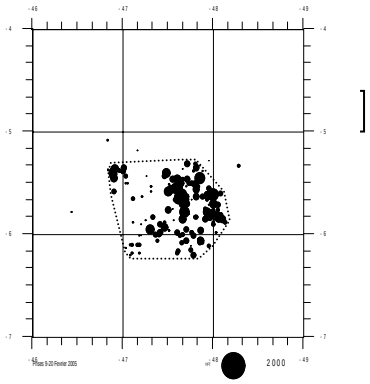


Figure 3: Geographical location of all positive sets registered between February 9th and 20th in the 4°S-7°S and 46°-49°E area

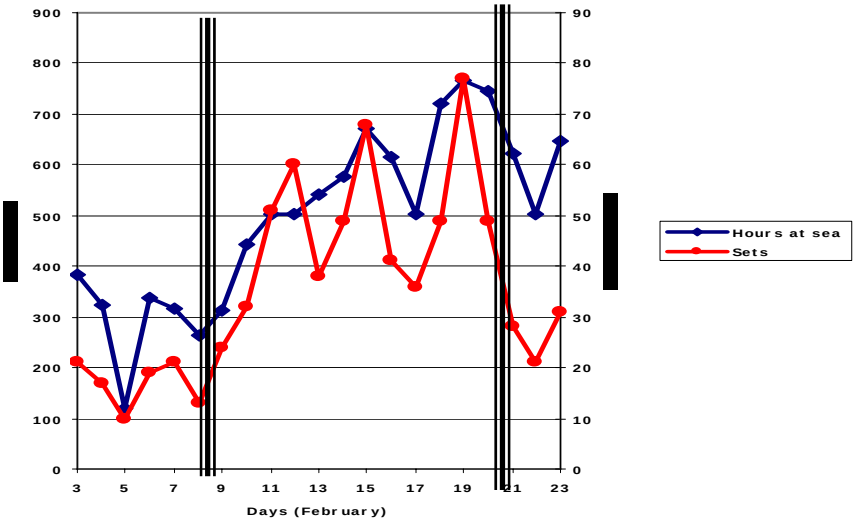


figure 4: Daily fishing activities by the purse seine fleet in the figure 2 area between the 3rd and the 23rd of January 2005, as shown by the number of fishing days and by the total numbers of sets recorded in the log books.

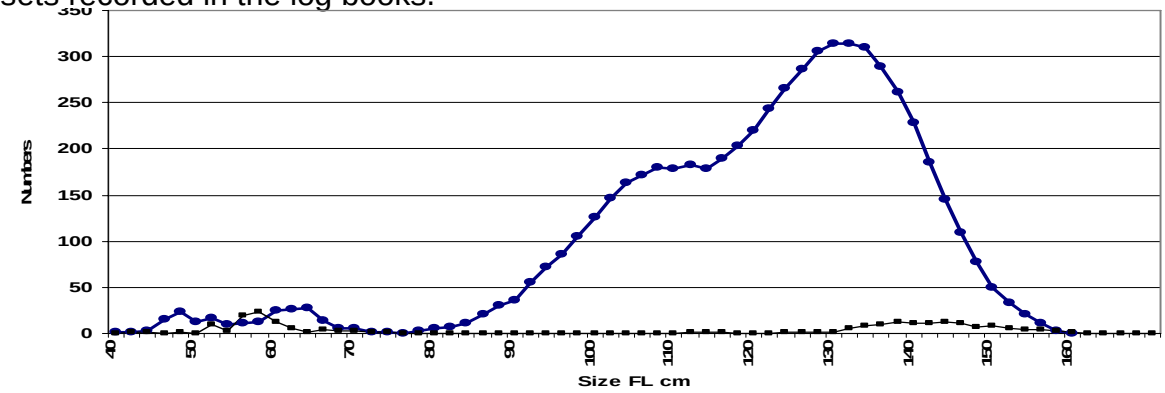


Figure 5: Size distribution of the yellowfin and bigeye caught and sampled from the studied fishing event as shown by the numbers of fished measured at each 2 cm size

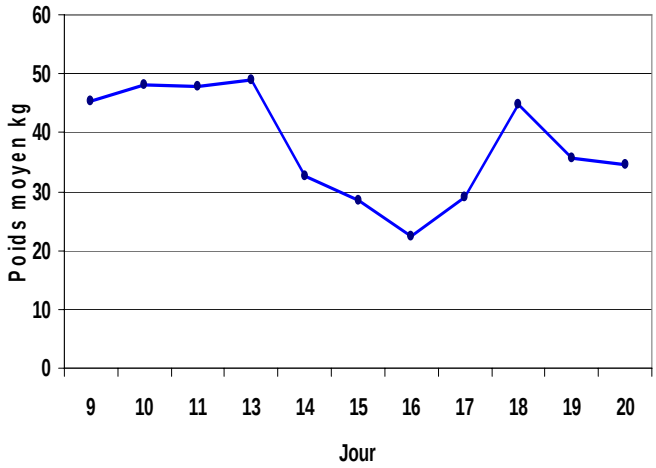


Figure 6: Average weight of yellowfin caught daily on free schools during the fishing event

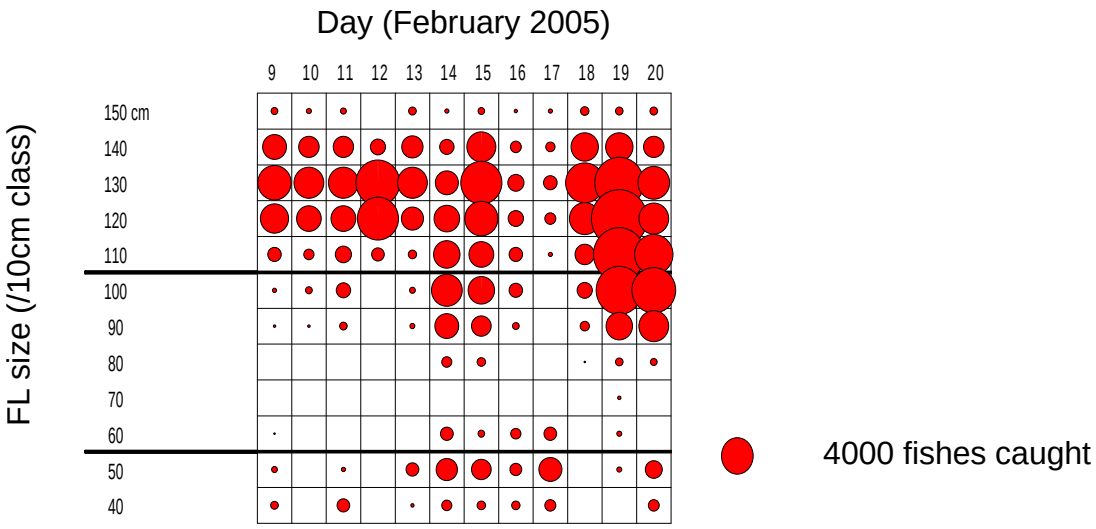


Figure 7: Diagram of daily catches at size of yellowfin tuna taken on free schools, by 10 cm classes,

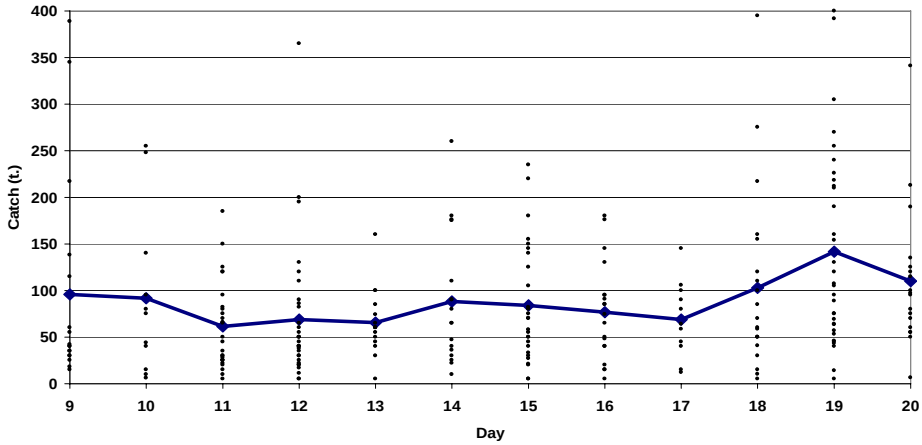


Figure 8: Catch per set of the 224 positive sets on free schools observed during the fishing event, observed catches, and average daily catch per set..

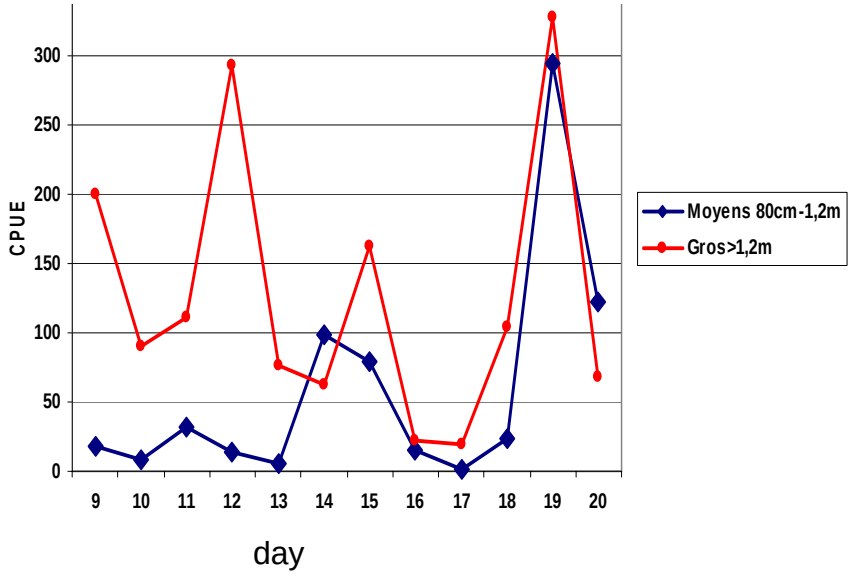


Figure 9: Daily yellowfin CPUE (free schools) expressed by size categories for small (90 to 120 cm) and large adults (120 to 160 cm) (expressed in number of yellowfin caught by fishing hour)

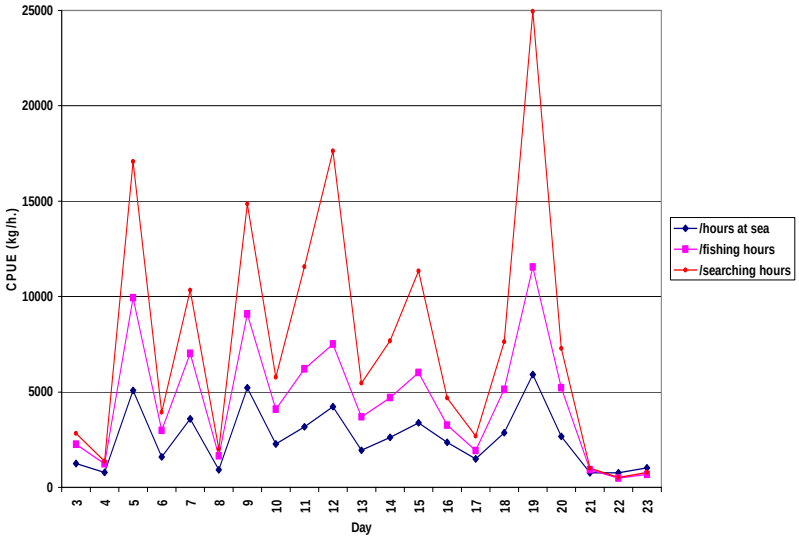


Figure 10: Daily CPUE of purse seiners on large yellowfin during the fishing event , as expressed in various units of CPUE: catch per hour at sea, per fishing hour and per searching hour.

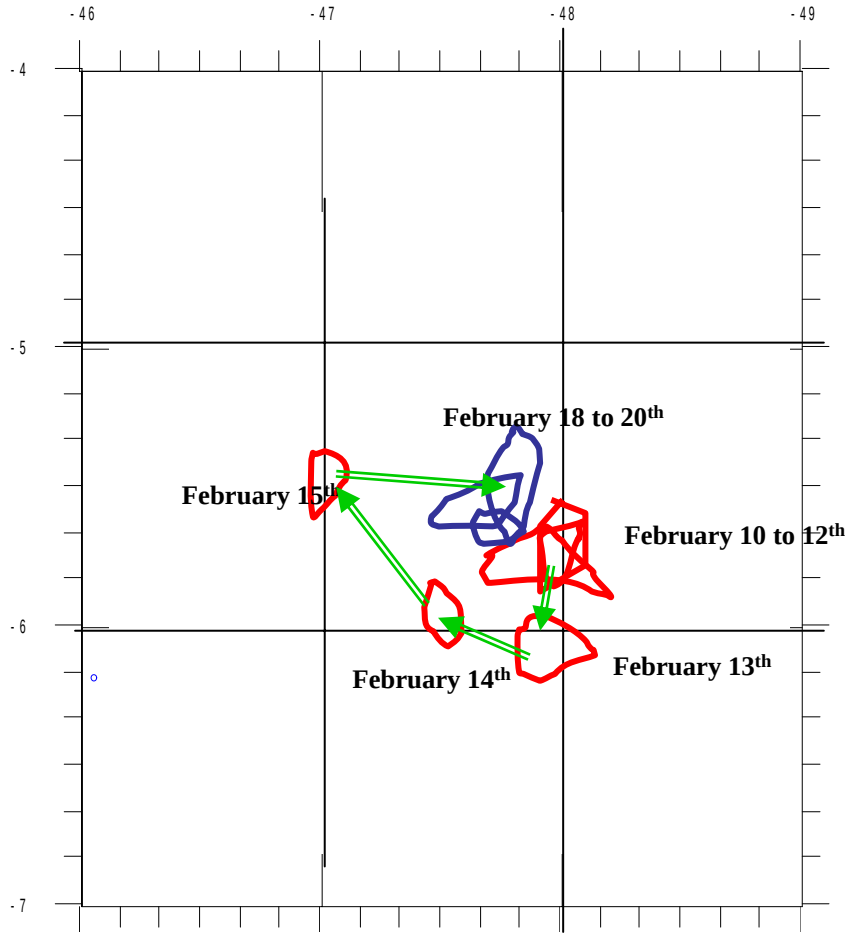


Figure 11: Daily sizes and positions of the areas fished by purse seiners during the concentration (contour estimated by eye)

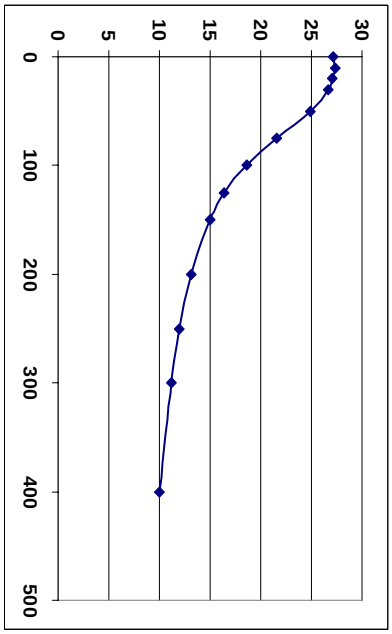


Figure 12: Average environmental condition observed in the fished area during the first quarter: temperature as a function of depth (from Boyer et Levitu world atlas)

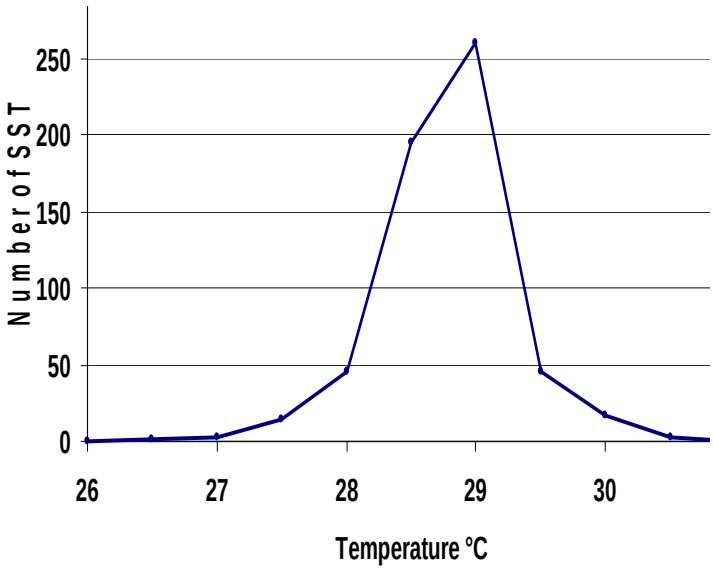
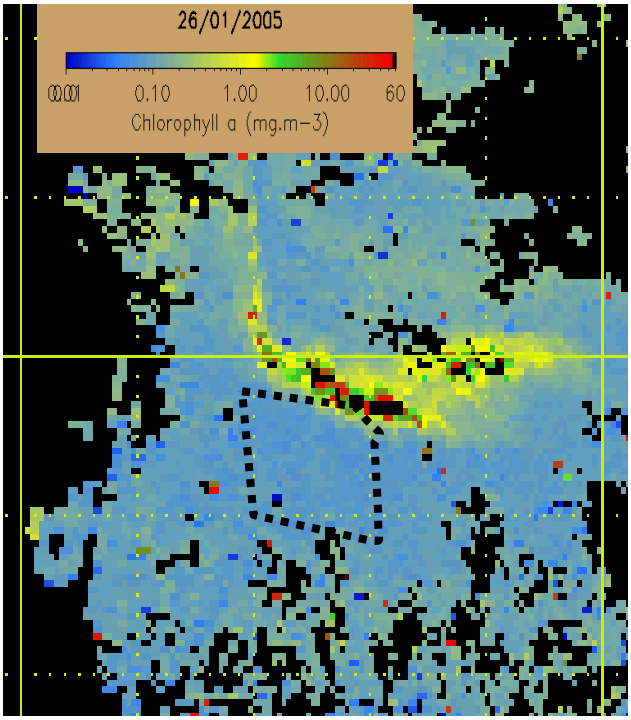


Figure 13 : Frequency of sea surface temperatures taken by purse seiners during the fishing operations (average SST=26,6°C)



5°S

45°E 50°E

Figure 14: Map of chlorophyll concentration estimated from water color (Sea Wiff) taken on January 26th and showing high concentration of chlorophyll north of the area that will be fished by purse seiners 11 days later (this fishing zone being shown by the dotted line).