Document IOTC-2007-WPTT-04

Results obtained from the biological sampling of large bigeye tuna caught on free schools by purse seiners in the Indian Ocean

By Michel Potier[1], Nanet Bristol[2] and Alain Fonteneau[3]

Summary

This document analyses some biological characteristics observed on two small samples of large bigeye tunas caught on free schools by purse seiners in June 2003 and Mai 2007 in the area west of Seychelles. This paper shows the importance and peculiarities of this fishing strata where large bigeye have been commonly caught by purse seiners during recent years. The length-weight and sex ratio at size relationship of these tunas are described and compared to data from the literature. This paper also makes a comprehensive analysis of the stomach contents of these sampled tunas. All these large bigeye were caught in warm surface waters (over 25°C), but all females had very low gonad index. Then the 2 samples would indicate that this strata was a feeding one and not a spawning strata.

Résumé

Cet article analyse quelques caractéristiques biologiques observées sur deux petits échantillons de gros patudos capturés en bancs libres par des senneurs en Juin 2003 puis en Mai 2007 dans la zone Ouest Seychelles. Cette note montre l'importance et les particularités de cette strate de pêche dans laquelle des gros patudos ont été régulièrement capturés par les senneurs à cette saison durant les années récentes. Les relations longueurs-poids et sex ratio par taille sont décrites pour ces poissons et comparées à la littérature. L'article fait aussi un examen des contenus stomacaux de ces patudos. Tous ces gros patudos ont été capturés dans des eaux chaudes (>25°C), mais toutes les femelles avaient des indices gonado-somatiques très faibles. Au vu des 2 échantillons disponibles, cette strate apparaît donc comme étant une zone trophique et pas une zone de ponte.

[1] Michel Potier, IRD scientist, B.P. 172 97492 Sainte Clotilde , La Réunion, France
[2] Nanet Bristol, SFA scientist, PO Box 449, Victoria, Seychelles
[3] Alain Fonteneau, IRD scientist, CRH, BP 171, Sète, France

1-Introduction

Bigeye tunas are seldom caught by purse seiners on free schools (an average of only 4.3 % during the period 1990-2006), a fishing mode where yellowfin tuna is more often the dominant species (70% of yellowfin in the free school catches during the period 1990-2006). The analysis of the time and space distribution of these catches shows that these large bigeye caught on free schools are sometimes caught in given strata and for instance in the West Seychelles area.

This fishing area located West of Seychelles Islands (Figure 1) is an area where the fishing activities by purse seiners takes place more or less all year round since the beginning of the fishery (Figure 2a) and catching nearly half of its tunas on free schools (47 % of total catches during the 1990-2006 period). It can be noted that these large bigeye tunas are significantly caught in this area during each year, June being the month showing the highest bigeye catches during most years (see Figure 2b). The goal of the present study was to conduct a biological sampling of these large bigeye, in order to evaluate their biological condition, their reproductive status and their feeding state. The pending question is to determine if these seasonal concentrations of large bigeye tunas in the West Seychelles areas were linked to spawning or to feeding concentrations of these tunas.

2- Material and methods

Two small samples of 25 large bigeye caught by purse seiners in June 2003 and of 25 bigeye caught in May 2007 were collected and analyzed. These fishes were measured (in fork length and in predorsal length) and weighed (at the nearest 100 g.). The sex of these fishes was noted and the gonads were weighed. The stomachs of each of these tunas were collected, weighed and their contents were carefully analysed. These biological information on the sampled fishes have been later examined and the main components of this seasonal fishery of large bigeye west of Seychelles Islands are also analyzed.

3- Fishery data in relation with bigeye caught on free schools in the West Seychelles area

3-1) Fishing zones

Figure 3 shows the average fishing zones where bigeye tuna have been caught by purse seiners during recent years on free schools. This map shows that the West Seychelles area is the area where bigeye have been predominantly caught by purse seiners on free schools during recent years. The average fishing map of purse seiners of free schools during the month of June (2003 sample) is shown for bigeye tuna on Figure 4. It should be kept in mind that such map is based on an average species composition within each quarter and within each area, for each size category of caught fishes. This method tend to smooth the geographical distribution of bigeye over the entire time and area strata, when possibly the time and area location where bigeye have been caught may be more restricted (see Fonteneau et aL. 2007).

3-2) Bigeye catches and CPUE in the West Seychelles area

The yearly catches of bigeye tuna taken by purse seiners in the different fishing zones and in the West Seychelles area are shown in Figure 5a and 5b. This figure shows that the BET catches in the West Seychelles area amounted for 50% of free schools bigeye catches during the last 20 years (an average total catch of 4500 tons). The monthly seasonal pattern of these yearly catches is shown for the combined species on Figure 2a and for bigeye only on Figure 2b, while Figure 6a shows the average bigeye monthly CPUE in the purse seine free school fishery during the last 10 years. These figures tend to show that the free school fishery is quite active permanently in the area, when catches of large bigeye taken on free schools are mainly important during the 1st quarter and in June of each year. The highest average cpue of these large bigeye taken on free schools by purse seiners are observed in June, followed by the lower CPUE observed in February. On the opposite the bigeye CPUE of longliners in the area West of Seychelles do not show any clear pattern, the June CPUEs being at an average level (Figure 6b)

3-3) Sizes of bigeye caught by purse seiners on free schools in the West Seychelles area

The average sizes of bigeye tuna caught by purse seiners on free schools in this area are shown on Figure 7. Figure 8 exhibits the yearly average bigeye weights taken on free and on FAD associated schools, showing that during most years, but not always, these bigeye are large fishes. It appears that most of these large bigeye are taken at sizes over the size at first maturity (in a range between 90 and 110 cm for bigeye), when FAD associated bigeye caught in the same area are always small.

3-4) Environmental data: SST

Sea surface waters in the area are always warm in the West Seychelles area in June, the major fishing period for bigeye: an average SST of 27℃ has been measured by French purse seiners in this strata during the period 2001-2006 (in a range between a minimum at 25°and a maximum at 30° C (see Figure 9). Such warm waters are considered to be potentially suitable for the bigeye spawning activities (Schaefer 2005)

4-Basic biological parameters of the large bigeye sampled

4-1) Sizes caught

The histograms of the sizes collected in the 2 samples taken in 2003 and in 2007 are given by Figure 10a. This figure shows that the fishes sampled in 2003 were in a range 101-150 cm (average length 135 cm), while the 2007 sampled bigeye were in a range of smaller sizes (101-131 cm, average length 114 cm)

4-2) Weight at size of the bigeye caught

The sizes distributions of both samples are given Figure 10b. This figure shows that fishes sampled in 2003 were in a range between 38 and 82 kg (average weight 57 kg), while the 2007 sampled bigeye were in a range of smaller weights between 26 and 55 kg (average weight of 36 kg).

These individual weights of our samples were compared to the basic length weight relationship used by EU scientists in their processing of their bigeye catch at size data. This comparison shows that the weight of most of these large bigeye tunas sampled are heavier than expected. However these observed weights are in close agreement with the theoretical average weights that are assumed by the IOTC relationship for large bigeye (Figure 11). This question remains unclear: it is possible that the sampled bigeye had high condition factors (being in a feeding concentration), but it is also highly possible that the average length weight relationship used by EU scientists underestimates the real weight of the average large bigeye (this technical point should be clarified and corrected!).

4-3) Sex ratio at size of bigeye caught

This result is only of minor indicative interest, due to the very small size of the collected samples. It can be noted that the overall sex ratio in this sample of 50 fishes was showing a rate of 44 % of males and 56% females (Figure 12), and without a clear dominance of males, even at the very large sizes (for instance over 1,4m) at which males are often dominant in the bigeye catches (Miyabe 2005). On the other side, this sex ratio at size is quite similar to the pattern recently shown by Ariz et al 2006 on large bigeye (1097 individuals) taken by longliners in the southern Indian Ocean (same Figure 12).

4-4) Gonad index of bigeye caught

The gonad index (gonad weight/Fork length^3*10^4) has been calculated for 24 females sampled in 2003 and 2007. These gonad indexes are always low or very low, in a range between 0.8 and 2.2 with an average level of 1.34. None of these gonads went beyond the threshold of 3, at which tuna spawning tend to be occur (Kikawa, 1962). Furthermore the visual examination of these gonads confirms that they were reproductively inactive. These results would indicate that these fishes were not caught in relation with their spawning activities.

5- Stomach content analysis

5-1) Stomach filling

The number of empty stomach was very low (only one occurrence in each sample). The average wet weight of the June 2003 sample was 235.2 ± 116.7g (range 64-684g). Food sample of May 2007 weighed on average 164.8 ± 78.9g (range 42-376g) (Figure 13). However, the index of stomach fullness (ISF – computed as the weight of the stomach content over the weight of the predator, in %) was very similar between the June 2003 and May 2007 samples (0.42 ± 0.33 and 0.44 ± 0.25, respectively). A Kruskal-Wallis test on this index showed no difference between the two samples (H=0.389, p=0.533).

5-2) Diet composition

We used three indices for each identified prey items: the frequency of occurrences in the stomachs (O defined as the percentage of all the non-empty stomachs examined), the mean proportion by number (MN) and the mean proportion by reconstituted weight (MRW). MN and MRW were calculated by taking the proportions of each prey species (or category) found in the individuals stomachs, and then calculating the average of the proportions found in all the stomachs. We thus treated individual fish as the sampling unit, allowing us to compute standard deviations. The three diet indices were also calculated by broad classes (cephalopods, crustaceans, fishes).

11 families and 1151 prey items were counted in the stomach of the 38 bigeye tuna sampled. On average 34.6 (June 2003) and 28.0 (May 2007) preys were found per stomach.

Fishes were founded in 13 samples (100%) in June 2003 and in 24 samples (96%) in May 2007. They contributed respectively to the diet 93.4% and 88.6% by MN and 98 and 91% by MRW. The bigeye cigarfish (*Cubiceps pauciradiatus*) dominated the diet. It was ranked first in the two samples by MN (93 and 89%) and by MRW (47% and 85%) (Table 1). It was recovered in more than 85% of the stomachs in June 2003 and 96% in May 2007.

Table 1. Frequency of occurrence, mean proportion by number (MN) and mean proportion by reconstituted weight (MRW) of prey species or categories recovered from stomach contents (13 samples (June 2003) and 25 samples (may 2007)) of bigeye tuna.

JUNE 2003		MN%±SD	MRW%±SD	O%
Fishes		**93.4±7.8**	**98.4±2.73**	**100**
Nomeidae	*Cubiceps pauciradiatus*	70.15± 35.30	65.78± 38.15	84.6
Scombridae	*Auxis thazard*	22.6± 32.71	29.29± 38.49	61.5
Gempylidae	*Rexea promethoides*	0.32± 1.16	3.08± 11.11	7.7
Myctophidae	*Diaphus sp.*	0.27± 0.99	0.21± 0.76	7.7
Crustacea		**6.64± 7.82**	**1.64± 2.73**	**76.9**
Portunidae	*Charybdis smithii*	6.64± 7.82	1.64± 2.73	76.9
MAY 2007				
Fishes		**88.76±28.6**	**90.6± 27.7**	**96**
Nomeidae	*Cubiceps pauciradiatus*	87.94± 29.15	87.16± 31.14	96.0
Diretmidae	*Diretmichthys parini*	0.11± 0.57	0.05± 0.26	4.0
Omosudidae	*Omosudis lowei*	0.06± 0.29	1.89± 9.45	4.0
Myctophidae	*Diaphus sp.*	0.19± 0.68	0.21± 0.74	8.0
	Electrona risso	0.06± 0.28	0.07± 0.36	4.0
Scopelarchidae	*Scopelarchus analis*	0.11± 0.57	1.13± 5.66	4.0
	undetermined fish	0.09± 0.45	0.06± 0.28	4.0
Crustacea		**1.45±5.40**	**0.45± 1.7**	**8**
Caridae	undetermined carids	0.45± 2.27	0.11± 0.56	4.0
Odontodactylidae	*Odontodactylus scyllarus*	1± 5	0.33± 1.67	4.0
Cephalopods		**9.79±24.11**	**9.0± 26.2**	**36**
Ommastraphidae	*Ornithoteuthis volatilis*	0.22± 1.11	0.10± 0.52	4.0
	Sthenoteuthis oualaniensis	9.51± 24.06	8.88± 26.20	28.0
	undetermined octopods	0.06± 0.29	0.0009± 0.005	4.0

The frigate mackerel (*Auxis thazard*) was the second prey item of the June samples by MN (22.6%) and MRW (29.2%) (Figure 14), but it was absent from the stomach contents of the May 2007. Other fish species did not exceed 0.3% each by MN and 3% by MRW. All were mesopelagic fishes belonging to the families of Myctophidae, Gempylidae, Omosudidae, Diretmidae and Scopelarchidae.

Cephalopods were absent in the June 2003 samples but they were recovered in 36% of the Mai 2007 samples and they contributed to the diet 10% by MN and 9% by MRW. The flying squid *Sthenoteuthis oualaniensis* was the main cephalopod prey. It was ranked second by MN (9%) and by MRW (9%) in the diet of the May samples. Other species were *Ornithoteuthis volatilis* and an undetermined specimen of octopods.

Crustaceans were rarely observed in May 2007 (less than 1% by MN and <0.5% by MRW). In June 2003, the swimming crab *Charybdis smithii* was observed in 77% of the stomachs, but was not a dominant prey, neither in MN (6%) nor in MRW (1.6%).

5-3) Comparison of feeding regime

In addition, the degree of trophic overlap between both June and May samples was estimated by computing one indice of niche overlap: the simplified Morosita index C_{mh} proposed by Horn (1966) which is the appropriate overlap index for prey weight. It is calculated from the following formula:

$$C_{mh} = \frac{2\sum_{i=1}^{S} p_{A,i} \times p_{B,i}}{\sum_{i=1}^{S} p_{A,I}^2 + \sum_{i=1}^{S} p_{B,I}^2},$$

where C_{mh} = the Morosita-Horn index, S = total number of identified prey species (or category) in the feeding habits of lancetfish in both seasons, $p_{A,i}$ and $p_{B,i}$ = proportion resource i is of the total resources in sample A and in sample B, respectively. C_{mh} ranges from 0 (no prey in common) to 1 (complete overlap).

Result was close to one (0.890) which means that the bigeye tunas caught in June 2003 and May 2007 fed on similar concentrations of preys, almost exclusively constituted of the bigeye cigarfish (*C. pauciradiatus*).

5-4) Size of preys.

Standard length (SL) of fishes and dorsal mantle length (DML) of cephalopods were measured when prey was still in good stage. The size of the pelagic crab *Charybdis smithii* was expressed as the carapace Heigth (H). When prey items were partly digested, equations relating hard parts (otolith, dactylopode, and beak) to size were used to estimate the prey size. Size dimension of the prey was expressed in cm.

Whatever the species, the size of the individual prey was small (Table 2). The largest ones were observed in June 2003 when large bigeye tunas were sampled.

Most of the bigeye cigarfish recovered in the stomachs of the bigeye tuna in June and May were of a similar size. However, some large specimens (12.5 cm) were recovered in the stomachs contents of June 2003 (Figure 15).

Predator-prey size ratios were calculated by taking the ratio of each individual prey to the size of its predator. We thus treated individual prey as the sampling unit allowing us to compute standard deviation. Size ratios were always high. With *C. pauciradiatus* size ratios varied from 16.4 ± 2.68 in May 2007 to 18.7 ± 2.6 in June 2003. The greatest ratio was observed in June 2003 with the swimming crab (*C. smithii*) (105.6 ± 10.27).

Table 2 Mean size and size range for the main prey found in the stomachs of the bigeye tunas. For fish prey values are expressed in Standard Length (SL: cm), for cephalopods in Dorsal mantle Length (DML: cm) and for Crustacean in height of carapace (H: cm).

Predator		Min	Max	Mean
Thunnus obesus (FL : cm)	June 2003	118	146	134
	May 2007	105	131	114.5
Prey species				
Charybdis smithii	June 2003	1.1	1.4	1.3
Cubiceps pauciradiatus		4.6	12.5	6.7
Auxis thazard		4.7	15.6	10.7
	May 2007			
Cubiceps pauciradiatus		4.6	8.6	7.1
Sthenoteuthis oualaniensis		2.8	7.3	4.3

6- Conclusion

The two small biological samples conducted on large bigeye caught by purse seiners around Seychelles in warm surface waters allowed us to conclude that these tunas were not reproductively active and that they were actively feeding on abundant fish and crustacean prey with a high number of prey per stomach. Bigeye tunas are known to be opportunistic top predators (Ménard et al 2006). The stomach content analyses evidenced that these fishes fed at the surface (and not in deep waters as longline caught bigeye) on a restricted number of prey species: one main prey counted for more than 50% of the reconstituted mass. Such results have already been highlighted for the yellowfin tuna in the western Indian Ocean (Potier et al., 2002, 2007). Once a prey concentration of one target species is detected, tunas can feed on this concentration until satiation (Ménard et al 2003). In our study, the bigeye cigarfish played this role. It does not constitute an unusual event as the same species was already observed in great numbers in the stomachs of the bigeye tunas caught with purse seine by the Soviet sampling programs in the 1988-1990's east of Seychelles (Romanov pers. com.). During this program, 83% of the prey mass was constituted of *C. pauciradiatus.*

The bigeye tuna caught in June 2003 and May 2007 feed on the epipelagic part of the cigarfish population. Most of the bigeye cigarfish observed in the stomachs were small individuals. Salekhov (1989) noted that juveniles of the bigeye cigarfish remained in the epipelagic zone of 30-90 m, forming schools near the surface.
Subsurface predators exhibit different feeding behaviour with a larger prey spectra, a number of prey per stomach smaller and a prey mass distributed among three to four main prey species. In the western Indian Ocean, 44 families of prey have been recorded in the stomachs of the yellowfin and 18 in the bigeye tunas stomachs recovered from subsurface individuals (Potier et al., 2004). We thus believe that such shallow concentrations of large bigeye tuna are related to the detection of favoured aggregated prey.

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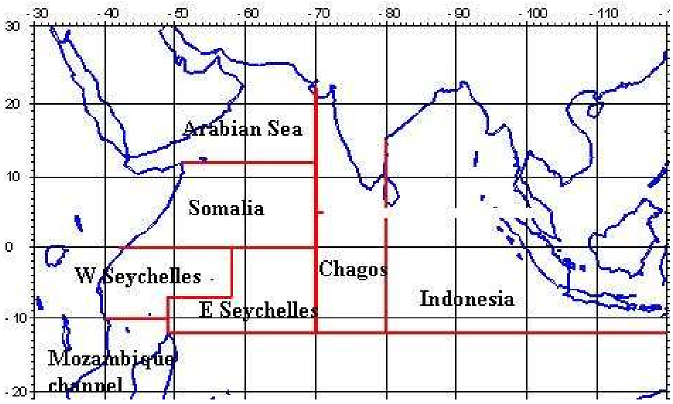
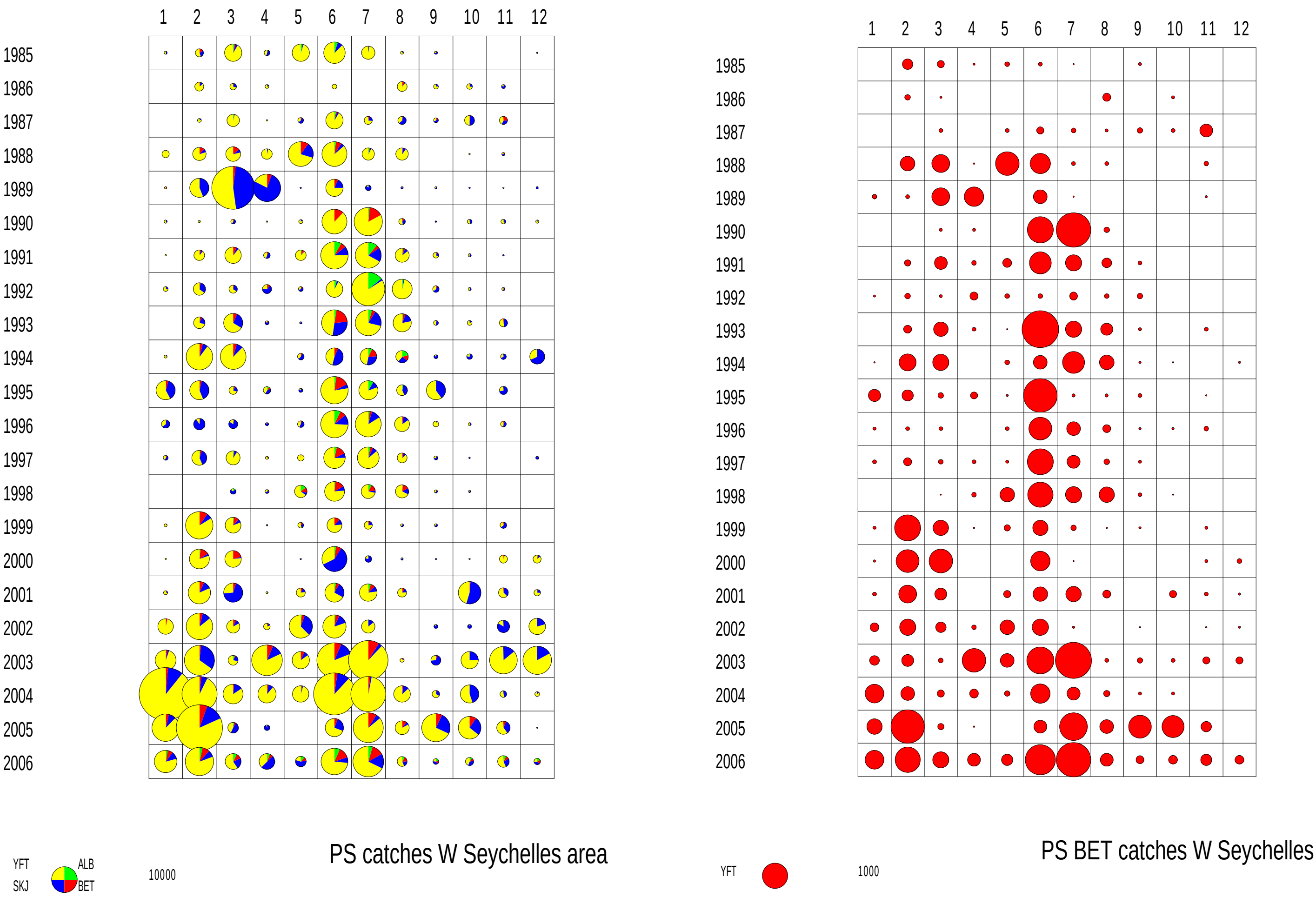


Figure 1: Fishing zones used for the analysis of purse seine caught tunas in the present analysis



2a) combined species

2b) bigeye tuna

Figure 2: Monthly catches of tunas (by species) taken on free schools in the West Seychelles area during the period 1982-2006.

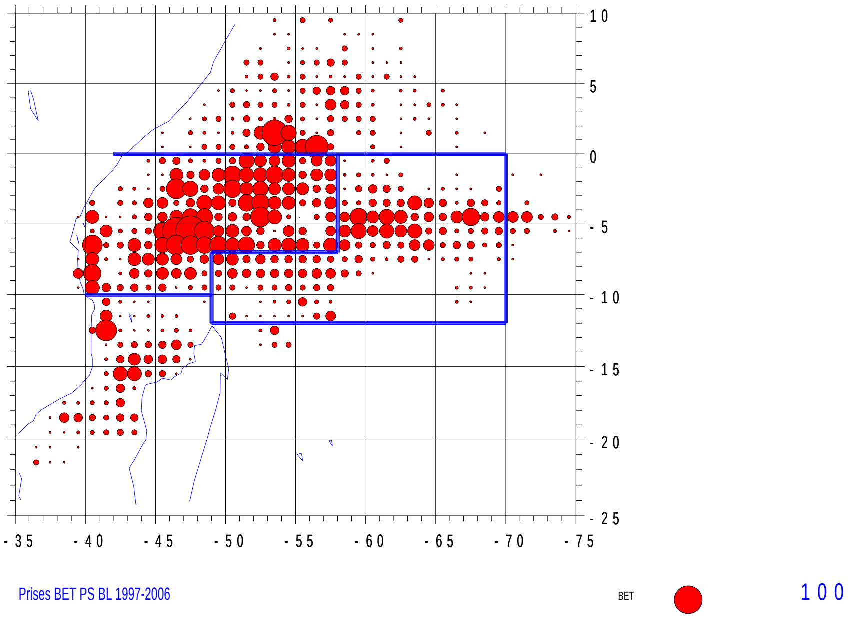


Figure 3: Bigeye catches taken by purse seiners on free schools during the month of June (average between the last 10 years 1997-2006)*NB: these locations of bigeye catches have been obtained by a species composition scheme, and they may not be representative of the real catches due to a smoothing effct of the area-quarter stratification used*)

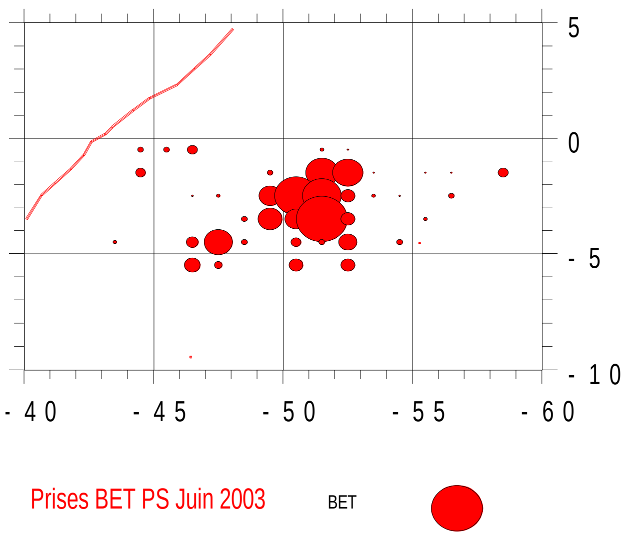


Figure 4: Bigeye catches taken by purse seiners on free schools during the month of June 2003

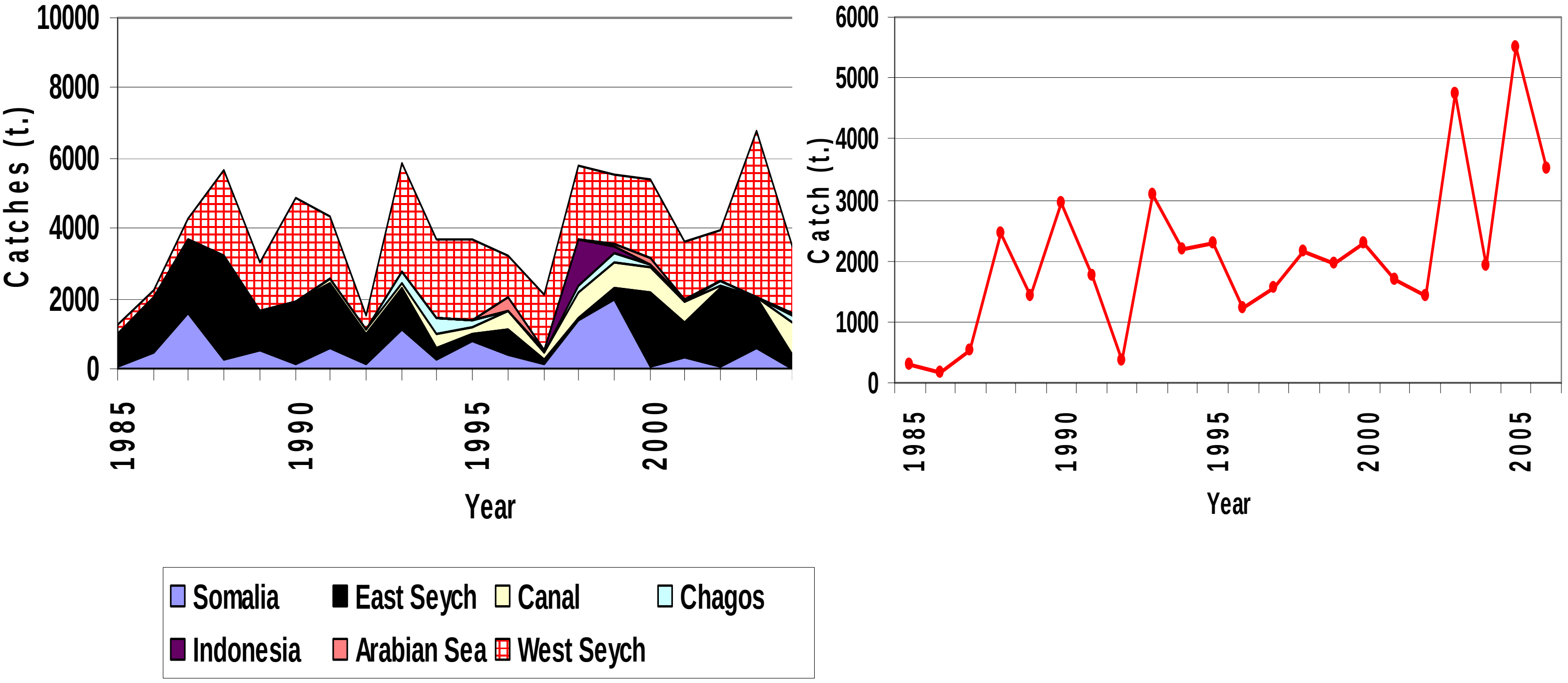


Figure 5: Yearly catches of bigeye tuna taken by purse seiners on free schools in each of the figure 1 fishing zones (left, 5a) and yearly catches in the West Seychelles area (figure 5b right).

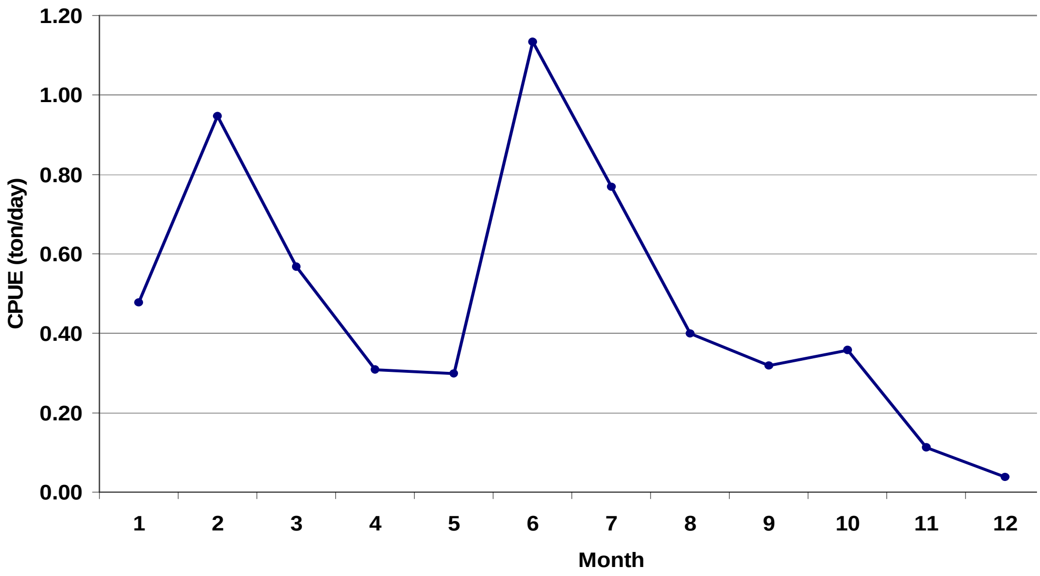


Figure 6a: purse seiners

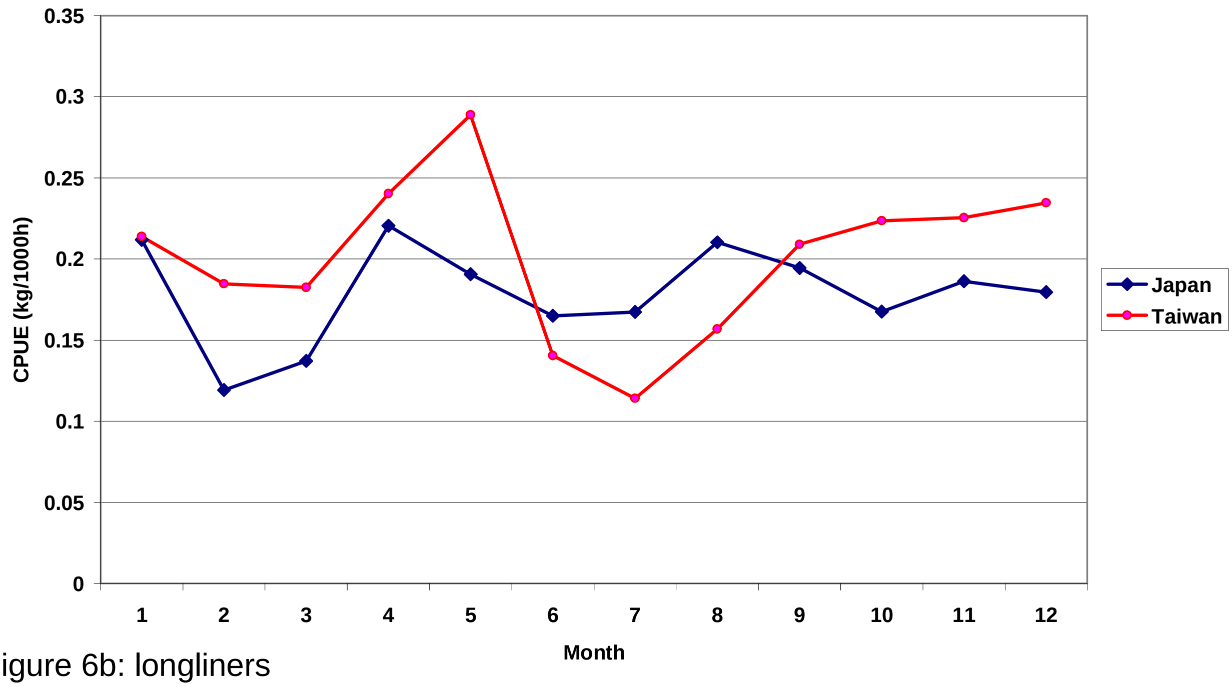


Figure 6b: longliners

Figure 6: Average monthly CPUE of bigeye for the purse seine fleet (period 1996-2005, figure 6a) and for Japanese and Taiwanese longline fleet in the area West of Seychelles (figure 6b)

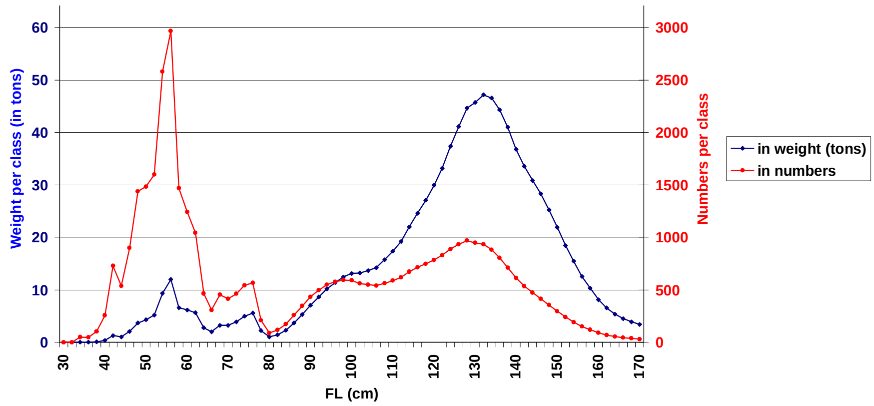


Figure 7: Average size distribution (in number and in weight) of bigeye caught on free schools in the West Seychelles area (period 1991-2007)

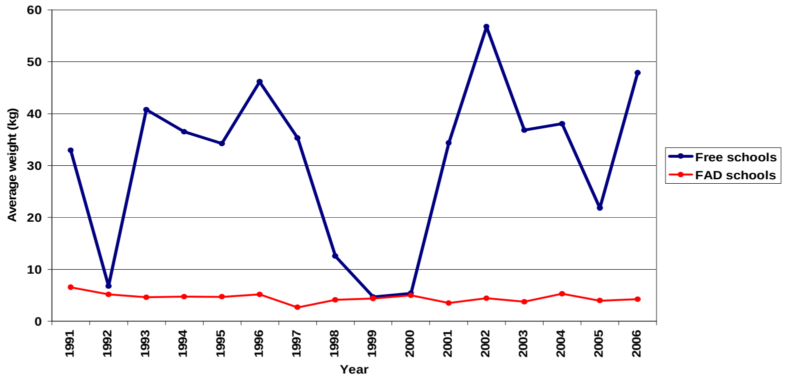


Figure 8: Yearly average weight of bigeye caught on free and on FAD schools in the West Seychelles area during the period 1991-2007.

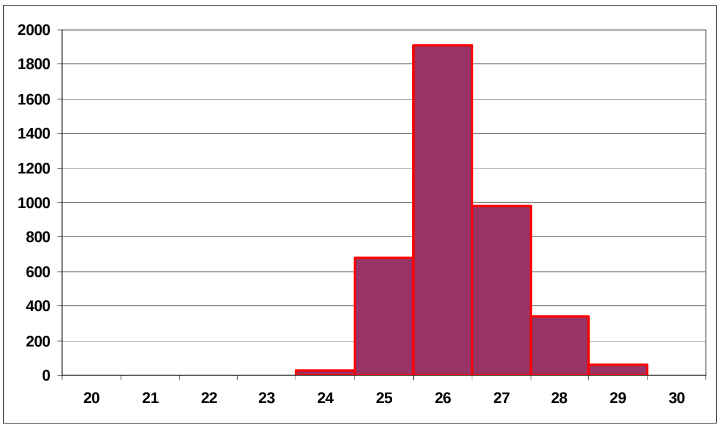
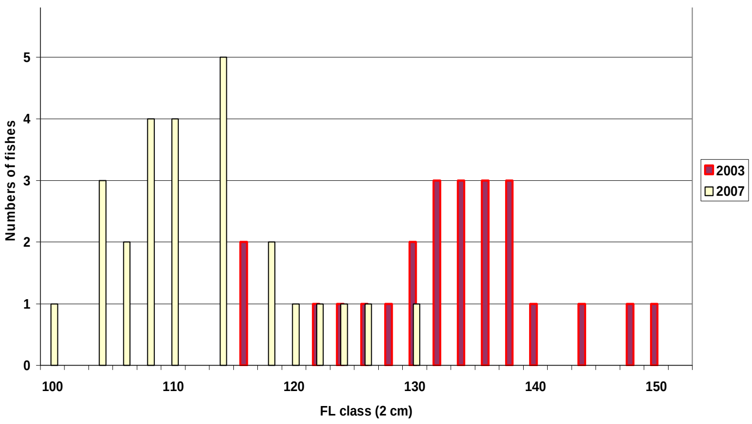


Figure 9: Frequency of sea surface temperatures collected by French purse seiners in the West Seychelles area during the month of June (period 2003-2006)



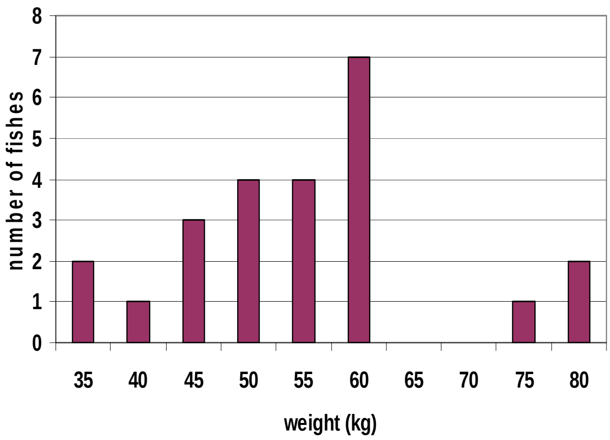


Figure 10: Size frequency of the 2 bigeye samples collected in 2003 and in 2007 (in length figure 10 a left, and in weight figure 10b right)

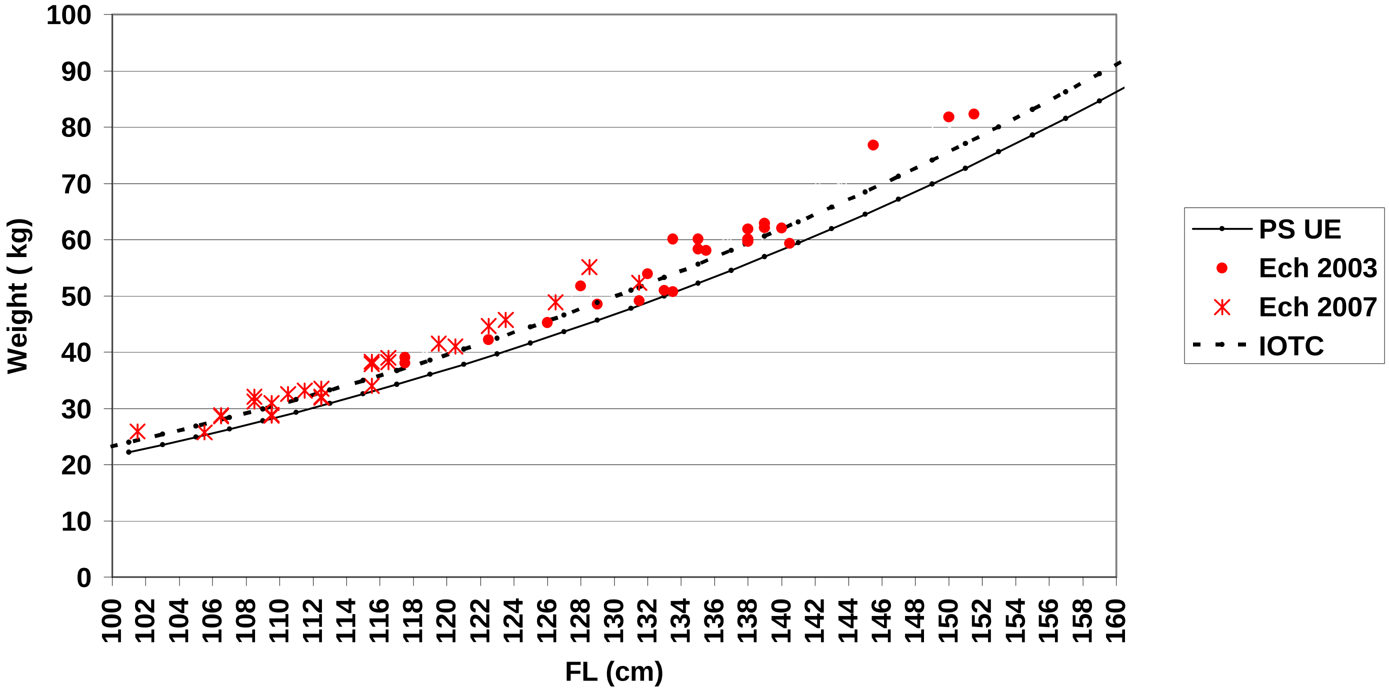


Figure 11: Length and weight observed for each of the bigeye tunas sampled in 2003 and 2007, compared to the average length weight relationship presently used by EU scientists in the processing of their bigeye size data.

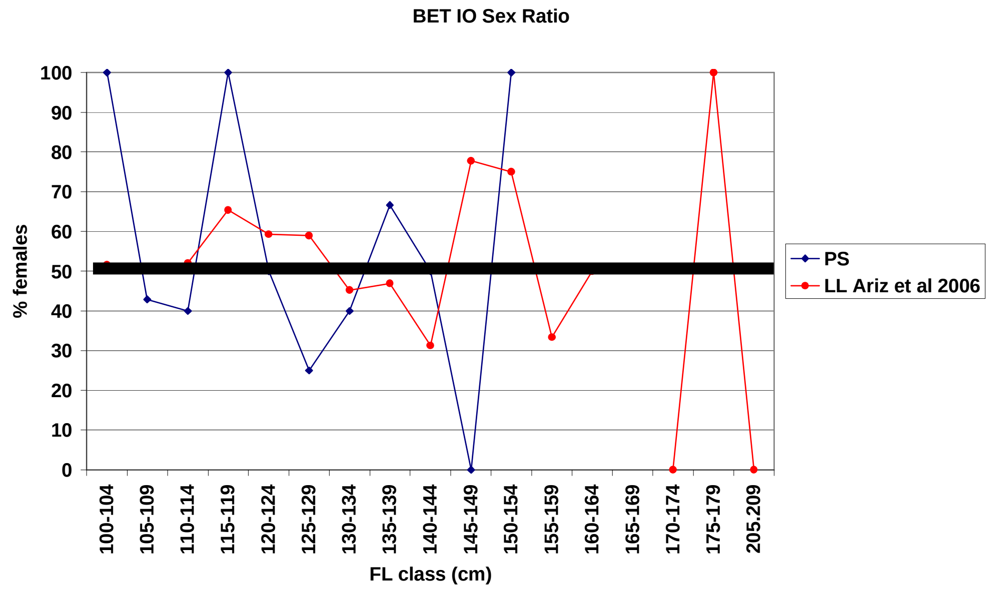


Figure 12: Sex ratio at size in the 2 samples collected in 2003 and 2007 and sex ratio obtained by Ariz et al 2006 on a large sample of bigeye caught by longliners (1097 individuals).

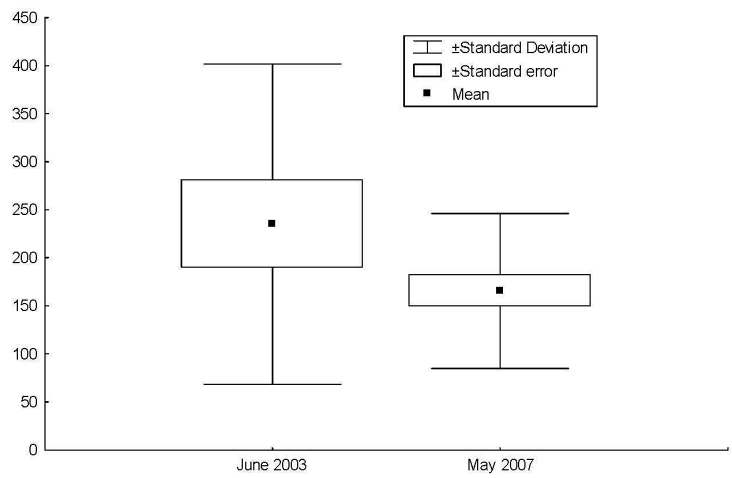
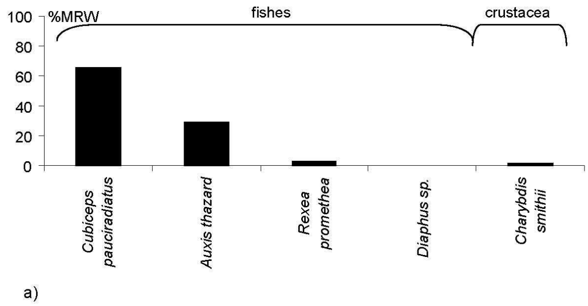


Figure 13. Distribution of the stomach content weight observed for bigeye tuna in the 2 samples of June 2003 and May 2007.



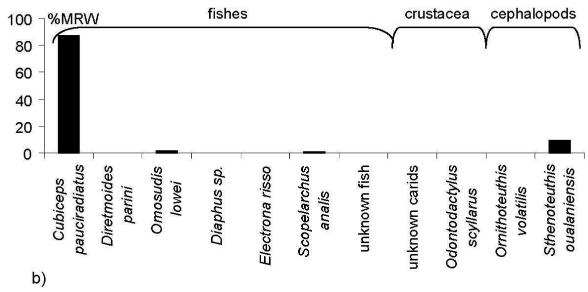


Figure 14. Contribution of the prey to the mean proportion by reconstituted weight (MRW) in diet of bigeye tuna in 2003 (a) and 2007 (b).

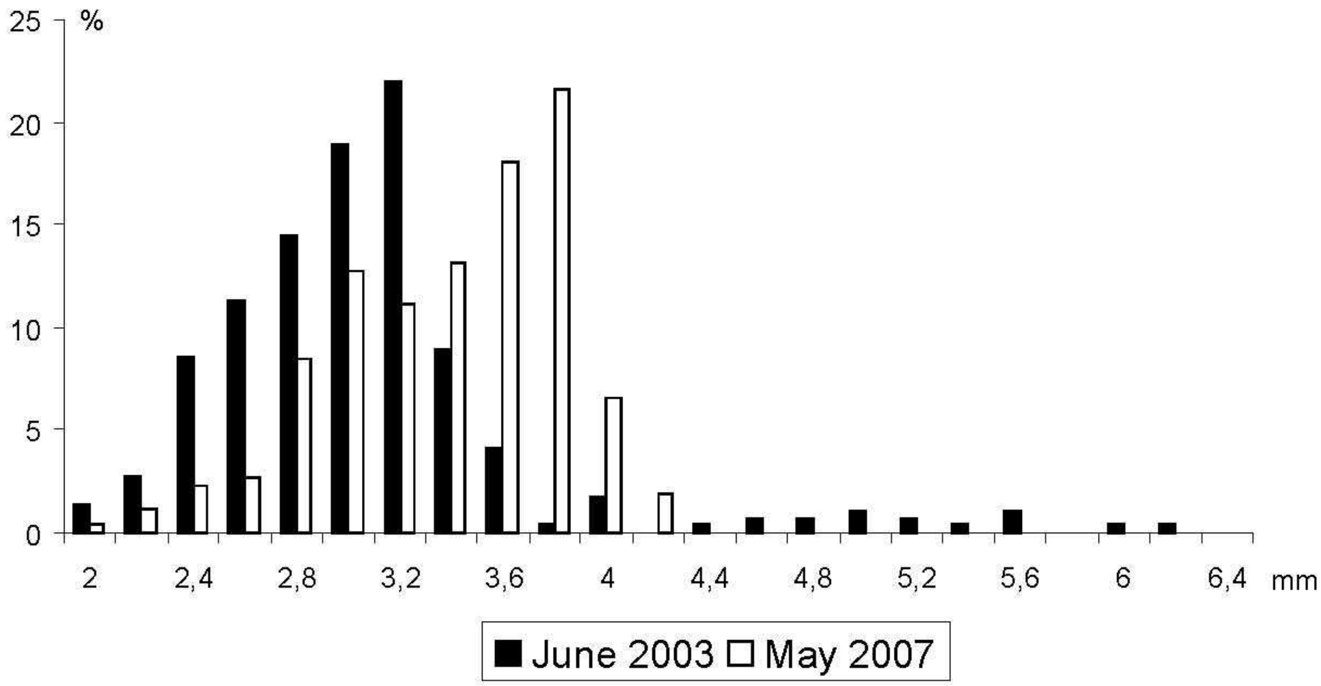


Figure 15. Prey size distributions of *Cubiceps pauciradiatus* (otolith length in mm) recovered from stomachs observed in June 2003 and May 2007.