Updated biological parameters for Indian Ocean yellowfin tuna and monitoring of forage fauna of the pelagic ecosystem, based on a routine sampling at the cannery in Seychelles

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Abstract

This paper aims to demonstrate the great potential of routine sampling at canneries to follow up biological parameters of tuna species and to track changes (in space and time) of the forage resources available to pelagic top predators. The present dataset pooling observations for 1984-2006 by observers at sea and at the cannery in Seychelles allows updating some of the biometric relationships used by the IOTC for yellowfin tuna. The updated equations proposed to convert first dorsal lengths into fork lengths is : $FL = 2.0759\ FDL^{1.1513}$. The updated size weight relationship proposed is : $W = 1.8860E\text{-}05\ FL^{3.0195}$. The length at first maturity is re-estimated to 104 cm (for females) from a large dataset concerning the WIO purse seine fishery. A decrease of the size at which males become dominant in the population is suggested, from 154 cm to 144 cm in the present study. The analysis of gut contents points out clear distinction between areas covered by the purse seine fishery, in terms of dominance of prey resources for pelagic top predators.

Introduction

Biometric measurements started in Seychelles from the very beginning of the purse seine fishery, by scientific observers on-board the seiners. In 1987, the sole tuna cannery operating in Seychelles was created (*Conserverie de l'Ocean Indien*). The scientific tuna sampling was pursued at the cannery until January 1991, when a restricted access rule was enforced. In 1995, Heinz bought 60% of the cannery and changed the name to IOT (Indian Ocean Tuna Ltd). After an agreement from the IOT management, biological sampling resumed in October 2003; it is still underway with some gaps mainly due to shortage in supply of large yellowfin or reduced personnel.

The cannery is processing tuna caught by purse seiners transhipping in Seychelles. The processed tuna is taken in the West Indian Ocean. The various goals of the biological sampling are to follow and update size and weight relationships (FL: fork length ; FDL: first dorsal length), monitor the reproductive cycle (GSI) and the sex ratio at size to track potential changes resulting from an increased fishing mortality. So far, the sampling work has targeted yellowfin (*Thunnus albacares*) because it is one of the two species (with skipjack) processed by the cannery. In November 2005, the collection of stomachs was implemented in addition to the other variables, in order to monitor the trophic activity of tuna and track changes in the forage resources available to surface dwelling tuna.

In this paper, we include all available information, from past to present, to update biometric relationships.

Material and methods

In Seychelles, the purse seine caught tuna are transhipped to reefers and, for a lesser fraction, unloaded frozen at the tuna processing plant (IOT). Before being processed, tuna are put to thaw out. Later, when they enter the process chain, fish are measured (FL rounded to the lowest cm, and FDL rounded to the lowest half cm), weighed (kg, accuracy 10^{-2}), sex is determined and gonad is weighed (to the nearest gram). Stomach is removed, put as a whole in a plastic bag (with a reference number) and stored in a deep freezer for further analysis. Date and location of each sample are determined *a posteriori* from a thorough analysis of the purse seine logbooks.

At the laboratory, the gut contents were sorted into main prey groups (crustacean, fish, squid, other). Then, the dominant species were determined. This is a relatively easy and quick task on purse seine fish because tuna prey upon dense patches of poorly diversified species. An index of stomach fullness (ISF), defined as the ratio between the weight of the stomach content and the body weight, was calculated to compare the fullness across the size of fish.

The gonado somatic index (GSI) is used to estimate the state of sexual maturity. GSI is calculated as follows :

$$GSI = \frac{W_g}{L^3} x100 \qquad \text{where } W_g = \text{weight of gonads, } L = \text{fish length}$$

Albaret (1977) established a relation between GSI and the stages of maturity: 11-16 for start of maturation, 24-26 for maturation, 30-50 for prespawning and spawning, 20 for postspawning, 11 for sexual resting. In our analysis, we selected the value 14 (middle of class 11-16) as a threshold to determine the start of maturation.

Three groups of data are used in this study, represented an overall 7522 yellowfin:

- measurements made at sea by IRD in 1984 and by SFA (Seychelles Fishing Authority) observers from May 1986 to October 1987
- first set of measurements made at the cannery in Seychelles (Conserverie de l'Ocean Indien) from August 1987 to January 1991
- second set of measurements resulting from 42 visits at the cannery in Seychelles (IOT Ltd) from October 2003 to July 2006, and still underway

Fish measured at sea include all sizes (29–164 cm). During the first set of operations at the cannery, the measurements were in the size range 34-164 cm. In the second set of operations at IOT, the sampled fish were much larger (79-164 cm). Data on gonad and sex survey analysed in this study are those from the second set of operations at IOT.

The three datasets were merged to update the size-weight keys. Overall number of available and checked observations by variable and by year/month is given in Table 1. The size distribution of the yellowfin sampled during these different surveys is represented in Figure 1.

Results

- *FL-FDL relationships*

The relationship between FL and FDL (Fig. 2) is established after 7036 observations. The best fit is a power regression :

$$FL = 2.0759 * FDL^{1.1513} \qquad r = 0.995 \qquad (p<0.001)$$

Table 2 lists the predicted FL for each FDL in the range of observations.

- *FL-weight relationships*

The best fit for the relationships calculated between FL and weight is a power regression. Graphic representation for FL-W is given in Figure 3. A first fit (thin line) was carried out on the current data and we noticed some deviation from the scatterplot notably in the larger sizes. The residuals appear slightly skewed on the right side. In order to minimize this deviation, we put a weight of 100 to each observation where FL is greater or equal to 140 cm. This procedure allows replicating artificially the observations in a fraction of the dataset where points are much less numerous than the size range 90-140 cm that is extensively sampled. The weights were multiplied to the squared residuals and the minimization procedure was applied to the sum of squared residuals. The parameters of the relation $W = a\ FL^{b}$ for the two fits applied on 6752 observations are:

Fit #	a	b	r	p
1: Non-weighted data	1.8382E-05	3.0195	0.9848	<0.001
2: Weighted data (FL >=140 cm)	1.8860E-05	3.0195	0.9882	<0.001

Indeed, there are very minor differences but the fit #2 gives a better 0-centered distribution of residuals. Predicted body weight for each 1 cm FL using fit #2 is given in Table 3.

- *Gonado Somatic Index*

GSI are calculated on females only. The data set contains 1088 observations (92 in 2003, 429 in 2004, 363 in 2005 and 204 in 2006). GSI is used to define the size at first maturity. Among the various definitions proposed for the size at first maturity, we consider that in which 50% of the female population is capable of reproducing (i.e. with GSI > 14). In our sample (1063 observations where GSI is associated with FL), we pooled the GSI by 2 cm size classes. A second order polynomial fit ($r = 0.877$, $p < 0.005$) is used to represent the variation of maturating females over size. The length at first maturity, i.e. the x value where the model curve crosses the 0.5 baseline, is 104 cm (Figure 4).

The current GSI dataset cannot be used to study the reproductive cycle. Available dates are those of the sampling whereas the date of catch would be necessary. A catch operation can occur 2 months before the date of sampling, although it is likely that the distribution of catch operations peaks during the month preceding the sampling. A retrospective analysis of this dataset is planned to allow allocating fishing dates (even approximate) to the samples. Analysis of the present (and uncorrected) observations sets the spawning season (GSI > 30) from January to April, which is in accordance with previous studies.

- *Sex ratio by size*

The frequency of males and females by size classes of 2 cm is used to describe the variation of the sex ratio by size. Sex ratio is calculated on a sample of 2985 fish (1547 males and 1438 females); the proportion of males at size is plotted in Figure 5. The sex ratio fluctuates without trends up to 140 cm then the proportion of males starts growing continuously. The threshold of 65% of males in the population is reached at 144 cm FL.

➢ *Stomach analysis*

The stomachs collected were distributed in three distinct fishing grounds: north of the Seychelles (area 1) for October-early December 2005, east of the Seychelles (area 2) for December 2005-January 2006, and south of the Seychelles (area 3) for the end of January and February 2006 (Fig. 6).

We pooled individual ISF by fishing area. Statistics are given in the following table (standard deviation are in brackets):

	mean	minimum	maximum
North Seychelles (area 1)	0.48 (0.44)	0.10	2.34
East Seychelles (area 2)	0.98 (0.85)	0.21	3.22
South Seychelles (area 3)	0.47 (0.38)	0.01	2.28

The highest mean (0.98%), minimum (0.21 %) and maximum (3.22%) ISF are found East of Seychelles. The north and south Seychelles are respectively second and third ranked areas. Note that the mean ISF in the East of Seychelles if two fold that of the two other areas..

In the area 1, the dominant prey group is the crustaceans, and notably the swimming crab *Charybdis smithii*. Fish preys dominate in the two other areas: the nomeid *Cubiceps pauciradiatus* in area 2; and nomeid with juvenile carangids (or engraulids, still to be determined) in area 3 (Fig. 7). Larger sizes of *C. pauciradiatus* are found in area 2.

Comparison with previous studies and discussion

➢ *FL-FDL relationship*

The FL-FDL relationship used by IOTC is that published by De Montaudoin et al (1991). Using 1714 fish measured at Victoria's cannery and on-board purse seiners, these authors tried to assess the effect of sex on the equations. No significant difference was found, leading to the conclusion that males and females can be merged into a single equation. These authors also noticed significantly different slopes and intercept when comparing subsets of "small" (< 22 cm FDL) and "large" fish (>=22 cm FDL). Therefore, a dual relationship was proposed :

Relation	Model	Parameters	Reference
# 1	N=1714	▪ for FDL < 22 cm : $FL = 3.2457 * FLD^{0.989913}$ ▪ for FDL>=22 cm : $FL = 1.9689 * FLD^{1.16472}$	De Montaudoin et al (1991)
# 2	N= 7036	All sizes : $FL = 2.0759 * FDL^{1.1513}$	Present sudy

The differences in estimating FL from FDL from the two studies are represented in Figure 8. Relation #1 always gives smaller FL estimates than relation #2 does. A maximum difference of -3.3 cm is reached for 21.5 cm FDL. Above, the difference is minor, within the range -0.8 to -0.3 kg.

The present study includes a greater number of observations and proposes a single model (instead of two) to represent the FL-FDL relationship. Even small sizes (<50 cm) are fairly well covered. This new relationship will be applied in the data processing of the T3 procedure made by IRD on purse seine length frequencies. Conversion tables integrating variance of FL estimates at each FDL will be soon available.

- *Length-weight relationship*

Unlike FL-FDL relationships, there are a substantial number of past studies addressing the size-weight issue for yellowfin in the Indian Ocean. Somvanshi (2002) made a review of the available relationships. These are plotted in Figure 9, where longline (LL) and purse seine (PS) fisheries are considered separately. The equations used by IOTC for yellowfin taken with the purse seine are those proposed by De Montaudoin et al (1991). There are two sets of parameters for the power regression, according to the fish length (< or >= 64 cm FL). Taking the new PS curve (fit #2 on weighted data) proposed in this paper as a reference, the difference in weight can reach 15 kg with a composite (average) LL curve and 4 kg with the curve presently used by IOTC. In all cases, the curve of the present study gives higher weights at size.

De Montaudoin et al (1991) noticed minor but significantly different parameters in the relation when sex is considered. However, as it is not possible to identify sex externally, a composite curve, such as that proposed in this paper, should be used.

Fish weighed at the cannery have been frozen in brine and we might consider some difference with fresh fish because of a “drying” effect caused by the freezing process. However, some authors (Caveriviere 1976, Bard 1983) who addressed this issue consider this effect as minimal. The accuracy of the measurement is likely to offset the potential bias caused by freezing.

- *Size at first maturity*

Two previous studies estimating the size at first maturity (SFM) with the 50% threshold of mature females are found for the Indian Ocean yellowfin. Maldenya and Joseph (1987) reported a SFM at 101 cm FL in Sri Lanka (1432 females examined between 60 and 135 cm FL) whereas Hassani and Stequert (1991) reported a SFM at 32 cm FDL (= 113 cm FL using our FL-FDL relation) from a sample of 795 females (23-41 cm FDL, 77-149 cm FL). The value found in the present study (104 cm, N = 1088, 78-160 cm FL) is closer to the Maldenya and Joseph estimate. We can note that Hassani and Stequert pooled their GSI into 2 cm FDL classes that introduce a strong uncertainty when lengths are converted into FL (6 cm FL classes). Original data used by Hassani and Stequert should be included in the most recent dataset for PS and reprocessed with smaller size intervals expressed in FL.

- *Sex ratio by size*

The larger proportion of males in the large sizes has been observed in all three oceans (Capisano 1991, Schaefer 1998, Timochina 1992). In the Indian Ocean, Hassani and Stequert (1991) locate the shift to a dominance of males at 41 cm FDL (149 cm FL). Maldenya and Joseph (1986) show a growing divergence between the number of males and females starting at 111 cm FL. More recently, Fonteneau (2002), using a corrected data set corrected from that of Hassani and Stequert, reports that males start to be dominant at 154 cm, and notes that the dominance of males appears at large sizes in the Indian Ocean compared with other oceans (134 cm in the Pacific and 146 cm in the Atlantic). In the current updated data set, 65% of the population is male at 144 cm FL. This new estimate is much lower than the previous one (Fonteneau 2002). This decrease should be kept as an indicator reflecting a high fishing mortality on the older age classes during the last decade.

Females are dominant in the size range 115-125 cm, a characteristic already noticed in the Atlantic (Capisano 1991). This is likely to be the consequence of differential growth between males and females, with sex-specific biomass that accumulates at different sizes.

- *Tuna diet*

Our results suggest that forage resources available to surface dwelling tunas exhibit geographic characteristics (Fig. 10). North of Seychelles, the pelagic crab (*Charybdis smithii*) makes up the bulk of prey for tuna. Recent studies on lancetfish diet [1] confirm this fact in the same region. Indeed, this crustacean is known to make huge swarms (Losse 1969) at the end of the summer monsoon. *C. smithii* is at the same time an active predator for micronekton and a forage resource for top predators. However, the source of the recruitment is still unknown. East of Seychelles, *Cubiceps pauciradiatus* has already been identified as a key prey species at the turn of the year (e.g. trip of the purse seiner Avel Vor in January 2001). The Equatorial Counter Current is likely to play an important role in the distribution and concentration of Cubiceps schools in the epipelagic ecosystem, although adults are known to be mesopelagic. South of Seychelles is a less productive area for forage resources and is composed of mixed prey fish species (nomeids and Engraulids/Carangids).

Another crustacean, the stomatopod *Natosquilla investigatoris*, can represent almost 100% of the tuna diet, but this is not reported in our observations because the dense swarms of Natosquilla occur essentially from April to October, that is out of the sampled period.

Ménard et al (in press) and Potier et al[2] have shown a good coherence between the size spectrum of the epipelagic micronekton community and that found in the tuna stomachs. This result, combined with the opportunistic feeding strategy of tuna allows considering the surface dwelling tunas, such as yellowfin, as reliable samplers of the prey species swarming in the epipelagic realm. Therefore, monitoring the relative proportion of the prey groups in the tuna diet can provide valuable descriptors of the status of the pelagic ecosystem.

Conclusion

Monitoring biological parameters of tuna populations on the long term is necessary to assess changes in the pelagic ecosystem. Apart from observer programmes, it is still possible to maintain a routine collection at the canneries, such as IRD and SFA carry out at the cannery in Seychelles. The sampling procedure must meet minimal requirements but the cost is marginal compared to the great interest of building ecological time series.

We therefore strongly support the continuation of the sampling carried out at the Victoria’s cannery and Seychelles and recommend that similar surveys be conducted in other places where the access to various sizes of tuna is possible at landing sites. The collection of stomachs can be made even if the country does not have the capacity to determine the species. In this respect, IRD (Thetis group) can play a role of regional coordinator and organise training to build capacity in this field of research.

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[1] Two papers submitted :
- Feeding habits of the longnose lancetfish (*Alepisaurus ferox*, Lowe 1833) in the Western Indian Ocean. By E. Romanov and V. Zamorov. Submitted to Western Indian Ocean Journal of Marine Science by
- Pelagic crustaceans as major prey of the longnose lancetfish (Alepisaurus ferox) in the Seychelles waters. By M. Potier, F. ménard, Y. Cherel, A. Lorrain, R. Sabatié and F. Marsac.

[2] Forage fauna in the diet of three large pelagic fishes (lancetfish, swordfish and yellowfin tuna) in the western equatorial Indian Ocean. M. Potier, F. Marsac, Y. Cherel, V. Lucas, R. Sabatie, O. Maury and F. Ménard. Submitted to Fisheries research.

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Table 1: number of FL, FDL, body weight, gonad weight and sex determinations by year/month in the merged data set

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	total
No of FL	1984			116	3									119
	1986				94	53			29					176
	1987			62	10	129		163	46	354	447	32	74	1317
	1988	125	287	38	21		124	162	171	122	23	20	42	1135
	1989	86	129	63	48	35	81	24	41	27				534
	1990		5	130	97	36	185	166	109		144			872
	1991	32												32
	2003										173	78	60	311
	2004	218	141	378	215			100						1052
	2005							309			114	426	133	982
	2006		318			210	280	207						1015
	total	461	880	787	488	463	670	1131	396	503	901	556	309	**7545**
No of FDL	1984			116	3									119
	1986				80	37			41	5				163
	1987		2	68	42	173	5	77	21	344	469	17	74	1292
	1988	125	257	30	6		106	160	58	66	23	41	42	914
	1989	69	129	60	25	35	81	24	41	27				491
	1990		5	130	97	36	185	166	109		144			872
	1991	32												32
	2003										173	78	59	310
	2004	217	141	378	215			99						1050
	2005							309			114	425	131	979
	2006		318			210	280	207						1015
	total	443	852	782	468	491	657	1042	270	442	923	561	306	**7237**
No of body weight	1984			101	3									104
	1986				76	16			12	5				109
	1987		2	10	52	104	5	117	45	356	193	32	74	990
	1988	107	125	38	15		123	162	171	122	23	41	42	969
	1989	86	129	53	48	35	81	24	41	27				524
	1990		5	130	97	36	185	166	109		144			872
	1991	32												32
	2003										168	78	59	305
	2004	218	140	378	215			100						1051
	2005							310			114	425	133	982
	2006		318			210	280	207						1015
	total	443	719	710	506	401	674	1086	378	510	642	576	308	**6953**
No of gonad weight	2003										80	78	57	215
	2004	116	70	152	80			38						456
	2005							247			65	355	129	796
	2006		248			206	280	206						940
	total	116	318	152	80	206	280	491			145	433	186	**2407**
No of sex det.	2003										84	78	60	222
	2004	218	141	378	168			100						1005
	2005							296			65	345	119	825
	2006		247			204	280	204						935
	total	218	388	378	168	204	280	600			149	423	179	**2987**

Table 2 : FL-FDL relationship for Indian Ocean yellowfin
(Values are estimated within the range of observations)

FDL	FL	FDL	FL	FDL	FL
9.0	26	**21.5**	71	**34.0**	120
9.5	28	**22.0**	73	**34.5**	122
10.0	29	**22.5**	75	**35.0**	124
10.5	31	**23.0**	77	**35.5**	126
11.0	33	**23.5**	79	**36.0**	129
11.5	35	**24.0**	81	**36.5**	131
12.0	36	**24.5**	83	**37.0**	133
12.5	38	**25.0**	84	**37.5**	135
13.0	40	**25.5**	86	**38.0**	137
13.5	42	**26.0**	88	**38.5**	139
14.0	43	**26.5**	90	**39.0**	141
14.5	45	**27.0**	92	**39.5**	143
15.0	47	**27.5**	94	**40.0**	145
15.5	49	**28.0**	96	**40.5**	147
16.0	51	**28.5**	98	**41.0**	149
16.5	52	**29.0**	100	**41.5**	151
17.0	54	**29.5**	102	**42.0**	153
17.5	56	**30.0**	104	**42.5**	156
18.0	58	**30.5**	106	**43.0**	158
18.5	60	**31.0**	108	**43.5**	160
19.0	62	**31.5**	110	**44.0**	162
19.5	63	**32.0**	112	**44.5**	164
20.0	65	**32.5**	114	**45.0**	166
20.5	67	**33.0**	116	**45.5**	168
21.0	69	**33.5**	118	**46.0**	170

Table 3 : LF-Weight keys for Indian Ocean yellowfin tuna

(Values are estimated within the range of observations)

FL	Weight	FL	Weight	FL	Weight	FL	Weight
30	0.5	**64**	5.4	**98**	19.4	**132**	47.7
31	0.6	**65**	5.6	**99**	20.0	**133**	48.8
32	0.7	**66**	5.9	**100**	20.6	**134**	49.9
33	0.7	**67**	6.2	**101**	21.3	**135**	51.1
34	0.8	**68**	6.4	**102**	21.9	**136**	52.2
35	0.9	**69**	6.7	**103**	22.6	**137**	53.4
36	0.9	**70**	7.0	**104**	23.2	**138**	54.6
37	1.0	**71**	7.3	**105**	23.9	**139**	55.8
38	1.1	**72**	7.7	**106**	24.6	**140**	57.0
39	1.2	**73**	8.0	**107**	25.3	**141**	58.2
40	1.3	**74**	8.3	**108**	26.0	**142**	59.5
41	1.4	**75**	8.7	**109**	26.8	**143**	60.8
42	1.5	**76**	9.0	**110**	27.5	**144**	62.0
43	1.6	**77**	9.4	**111**	28.3	**145**	63.4
44	1.7	**78**	9.7	**112**	29.1	**146**	64.7
45	1.9	**79**	10.1	**113**	29.8	**147**	66.0
46	2.0	**80**	10.5	**114**	30.6	**148**	67.4
47	2.1	**81**	10.9	**115**	31.5	**149**	68.8
48	2.2	**82**	11.3	**116**	32.3	**150**	70.2
49	2.4	**83**	11.8	**117**	33.1	**151**	71.6
50	2.5	**84**	12.2	**118**	34.0	**152**	73.0
51	2.7	**85**	12.6	**119**	34.9	**153**	74.5
52	2.9	**86**	13.1	**120**	35.8	**154**	76.0
53	3.0	**87**	13.5	**121**	36.7	**155**	77.5
54	3.2	**88**	14.0	**122**	37.6	**156**	79.0
55	3.4	**89**	14.5	**123**	38.5	**157**	80.5
56	3.6	**90**	15.0	**124**	39.5	**158**	82.1
57	3.8	**91**	15.5	**125**	40.5	**159**	83.7
58	4.0	**92**	16.0	**126**	41.5	**160**	85.3
59	4.2	**93**	16.6	**127**	42.5	**161**	86.9
60	4.4	**94**	17.1	**128**	43.5	**162**	88.5
61	4.6	**95**	17.7	**129**	44.5	**163**	90.2
62	4.9	**96**	18.2	**130**	45.6	**164**	91.9
63	5.1	**97**	18.8	**131**	46.6	**165**	93.6

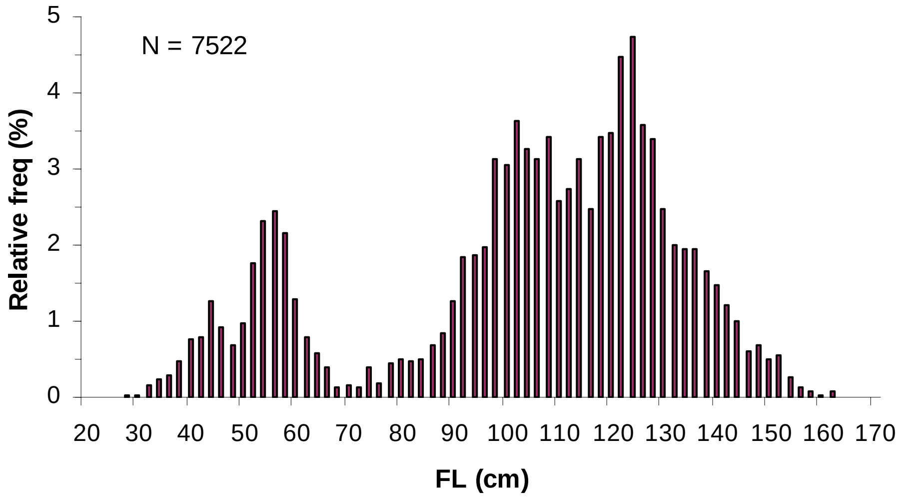


Figure 1 - Size distribution of yellowfin considered in this study

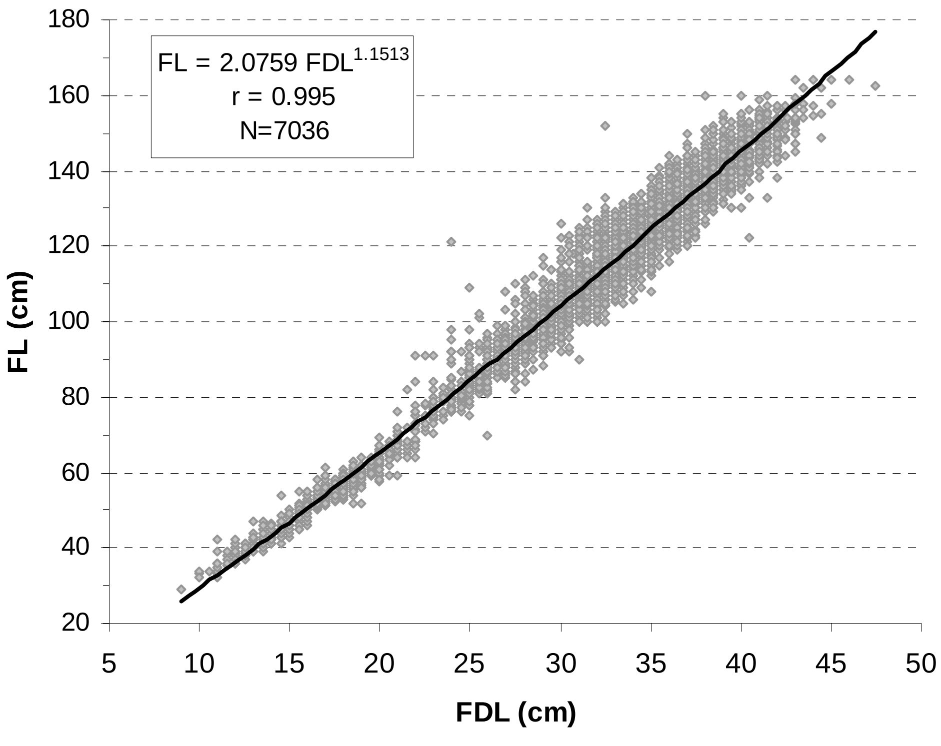


Figure 2 - Scatterplot and power fit of the FL-FDL relationship
for yellowfin tuna taken with the purse seine

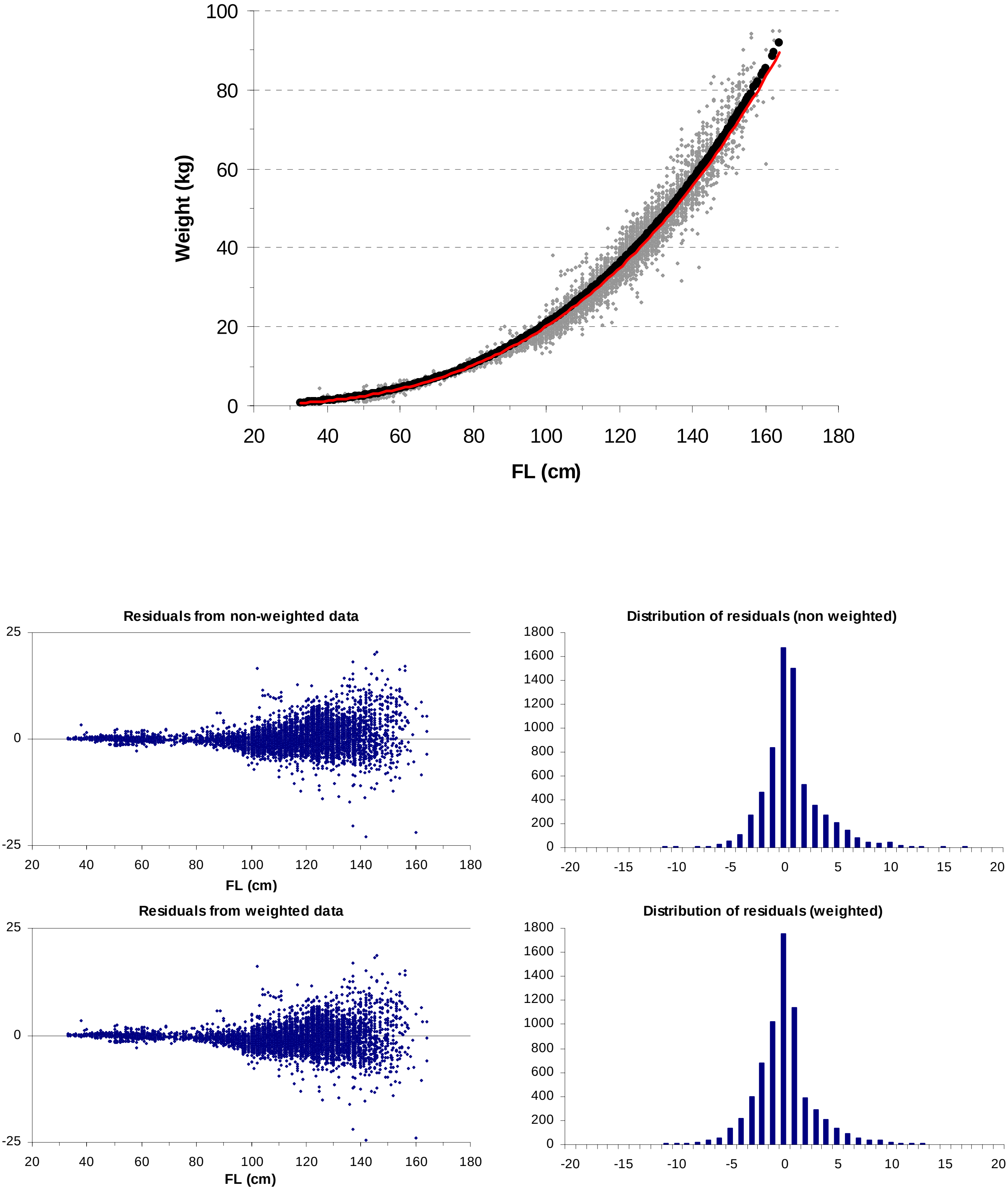


Figure 3 – FL-Weight relationship: scatterplot and power regressions (top)
and distribution of residuals (bottom) for the two fits (see text)

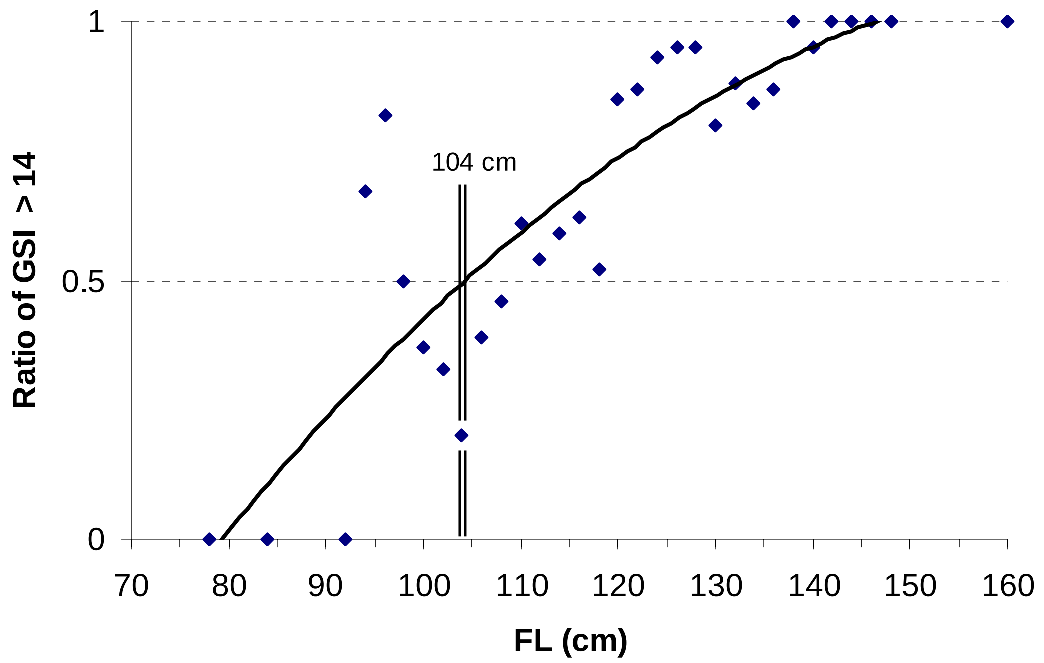


Figure 4 – Variation of the ratio of females with GSI > 14 (e.g. about to spawn) by size intervals of 2 cm. The baseline 0.5 represents the threshold defining the size at first maturity.

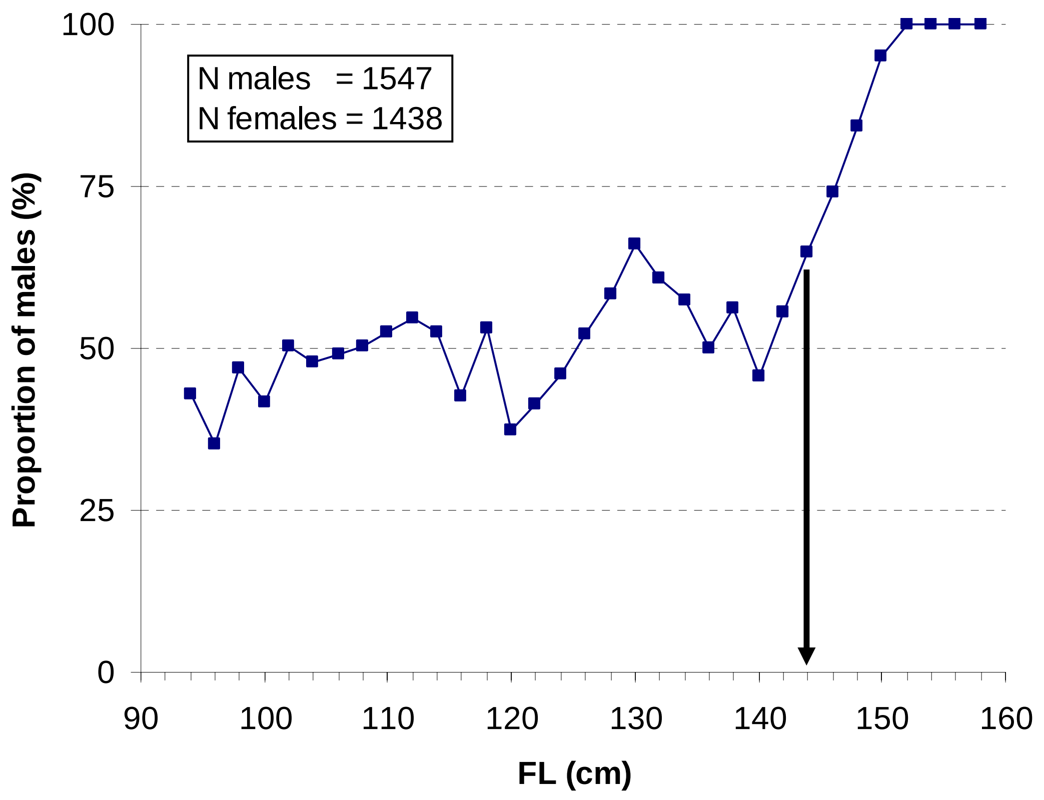


Figure 5 – Variation of the sex ratio of yellowfin (proportion of males) by size.

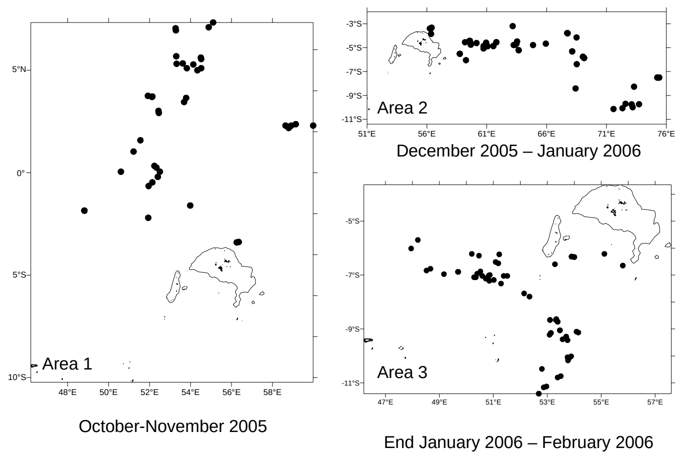
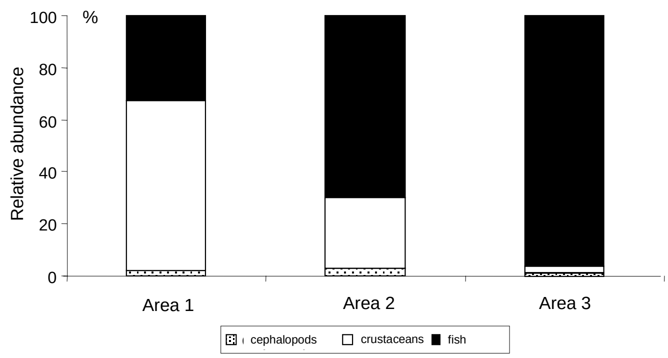


Figure 6 – Geographic distribution of stomachs collected from yellowfin caught by purse seiners from October 2005 to February 2006

Figure 7 – Relative abundance of prey by major taxonomic group (cephalopods: grey; crustaceans: white; fish: black) and by area in the yellowfin stomachs



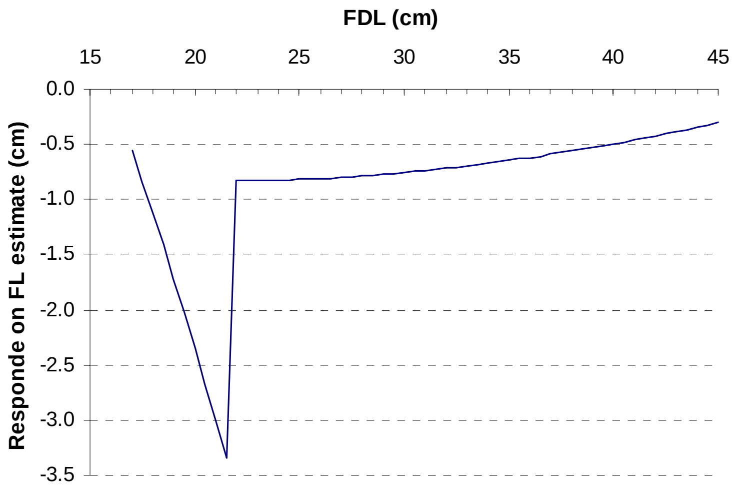


Figure 8 – Response on FL estimate from two different FL-FDL relationships used. The values represented are the difference : De Montaudoin *minus* present study. Negative values mean that the Montaudoin equation gives smaller FL estimates than the present study does. The jump in the curve is due to the two equations used in De Montaudoin relationship.

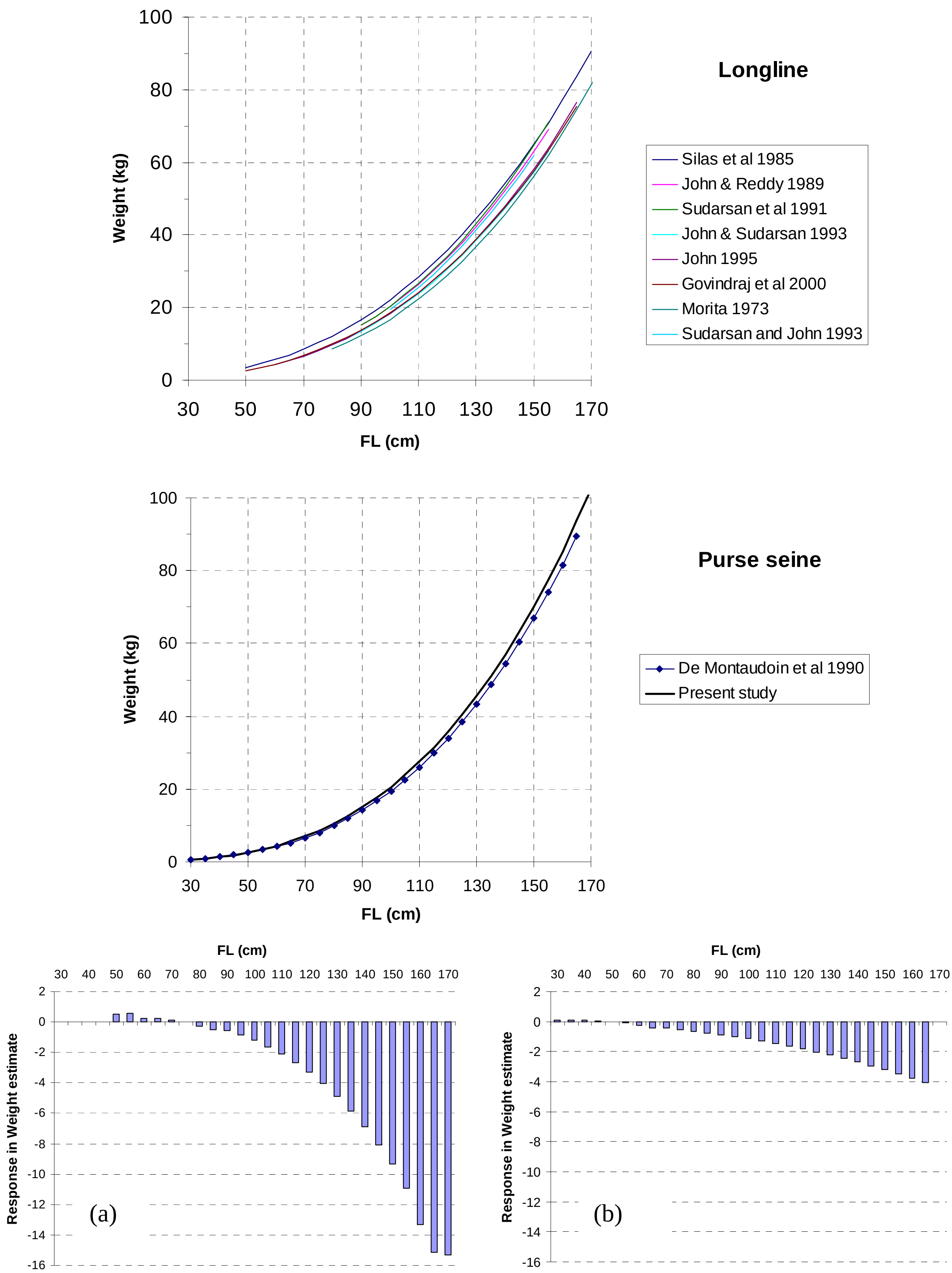


Figure 9 – Comparison of size-weight relations for yellowfin in longline (LL) and purse seine (PS) fisheries from past studies for the Indian Ocean. The difference in weight is given across the size range: (a) between a composite LL curve and a PS curve (present study); (b) within PS, between the IOTC curve and the curve proposed by the present study.

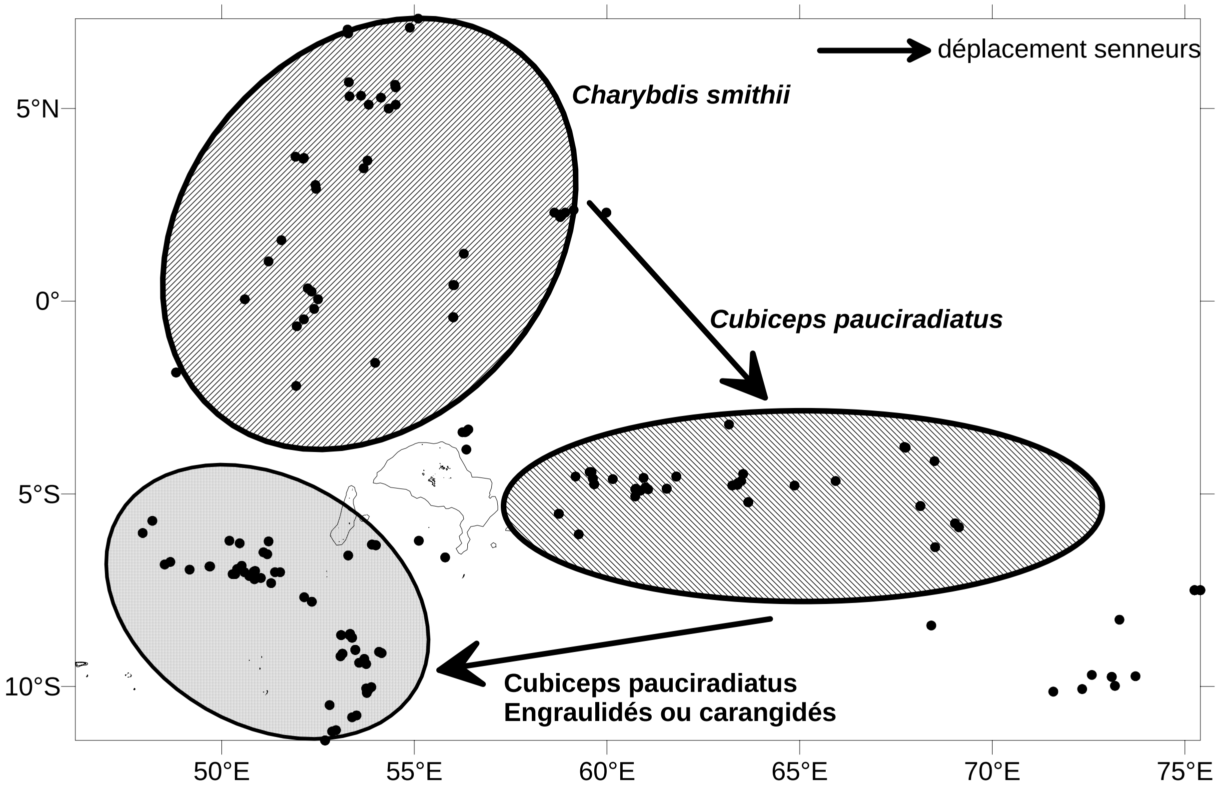


Figure 10 - Geographic characteristics of dominant prey found in the stomachs of yellowfin caught by the purse seine from October 2005 to February 2006