FRENCH SWORDFISH LONGLINE FISHERY IN SOUTH WEST INDIAN OCEAN : PRELIMINARY RESULTS FROM THE PPR PROGRAM

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ABSTRACT

The Indian Ocean swordfish longline fishery based in Réunion Island started operating in 1991. Since July 1998, Ifremer has been compiling information on domestic longline fishery operating in the French EEZ. Data are collected from logbooks, from regular at-sea and landing samplings and from on-board scientists.

One of the aims of this programme (PPR), financed by the European Union and Reunion Local Councils, is to contribute to the management and conservation of the species taken in SWOI fisheries through a larger scale project monitored by IOTC. We here present the preliminary results obtained from this data collection system on the depredation of marine mammals and on the selectivity and efficiency of longline gear. We also describe the techniques used to study swordfish reproduction and growth. We are in the first phase of this three years program and are still collecting data. All data treatments are not yet completed.

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SOMMAIRE

1 Introduction

The domestic swordfish (*Xiphias gladius*) longline fishery started in 1991. Two main factors promoted the development of this fishery : (1) the success of the Asian fleet based on the island that inspired a local fisherman to begin longline trials on a 12-meter boat ; (2) a new tax regulation, offering exemption for certain investments in French overseas departments, which encouraged fishing companies to come to Reunion. Four 16-meter longliners based at the « Pointe des Galets » harbour started operating in 1992, initially targeting bigeye tuna, destined for the Japanese market. Information on the success of the fishery rapidly spread. Significant changes in various aspects of the fishery have since been recorded. Boat and gear characteristics, fishing techniques, fishing grounds and seasonal activity, target species, as well as markets have evolved.

Swordfish biology in the Indian Ocean is poorly known and no stock assessment has been performed for swordfish in this area. Since July 1998, Ifremer has been collecting scientific data from voluntary maintenance of logbooks, thanks to regular at-sea and landing samplings, as well as on-board observers. This data collection system is designed to provide information on the different methods of processing swordfish, catches and by-catch, size composition of catches, fishing effort, CPUE, depredation of marine mammals on catches and swordfish biology. All these actions will take part in the « Programme Palangre Réunion » (PPR), an Ifremer programme financed by the European Union and Reunion local Councils. We are in the first phase of this three year program and are still collecting data. All data treatments are not yet completed.

The aims of this paper are (1) to present the domestic longline fleet characteristics, (2) to describe the different data collection procedures on the domestic swordfish longline fishery, set up by DDAM[2] and Ifremer, (3) to present both data bases, their particularities and the different links established between these two different sources of data, and (4) to present the preliminary results after two years of data collection.

2 Data source

2.1 French fisheries Administration data base

Responsibility for collecting data on Reunion fisheries for the FAO data base lies with the local fisheries office (DDAM). Every fishing company is requested to provide landing per species at the end of a fishing trip. The number of fishing crafts involved in the different fisheries are recorded by category and gear used. Thus, accurate figures on annual nominal catch by species and gear, annual fishing craft statistics by gear, type and size class of boats are available. The data received are entered into the data base (Access software ®).

2.2 Logbook format and IFREMER data base

The Ifremer laboratory in Reunion Island is in charge of the scientific monitoring of the fisheries. A logbook monitoring system has been implemented in association with longlining fishermen. Logbooks provide information on fishing effort expended daily, resulting catches by species, discards and vessel operations. These logbooks are regularly collected from the skippers

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and company managers. The whole data, including biology, are computerised and stored in an integrated data base (Access software ®)

We use data from the two on-going data collection programs in our analyses. Logbook data are cross-checked against the landing receipts, and corrections are made when necessary. This system provides basic confirmation of the information received. Figure 1 sums up the functionality of the two data bases described above and the different links existing between them and other data bases.

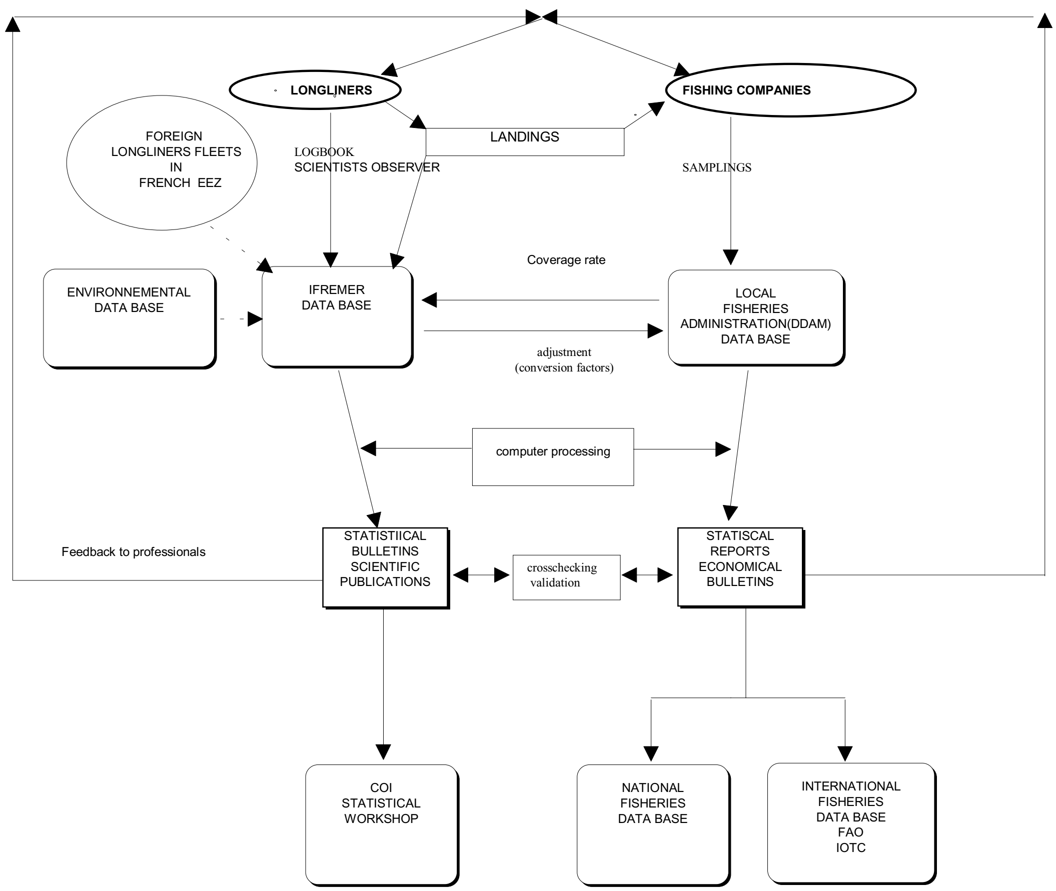


Figure 1 : Statistics flow chart (Poisson and Macé, 1997)

2.3 Logbook coverage rate

As logbooks record a fraction of the fishery, an estimated coverage must be applied. We use data from the two data bases presented above and estimate the rate for each vessel category with the following equation: It is defined by the ratio between the number of trips listed in the fishing logbooks and the total number of estimated trips by the entire fleet. These data are not definitive because the completed logbooks have not yet been received.
This first value give us a rough idea of logbook annual coverage rate.

$$\text{Coverage rate 1} = \frac{\text{Number of trips covered by logbooks (Ifremer data base)}}{\text{Total number of trips (Fisheries Administration Data base)}} \text{X } 100$$

To estimate by extrapolation effort, catch by statistical 5° square areas, another monthly coverage rate (2) is applied. In this case the fleet is separated into two segments of the fleet based on vessel length and fishing location.
This monthly coverage rate for each segment is calculated as follows:

$$\text{(2) Coverage rate 2} = \frac{\text{Number of sets covered by logbooks (Ifremer data base)}}{\text{Total number of sets (Fisheries Administration Data base)}} \text{ X } 100$$

2.4 Standard measurements

The most improved and reliable measure of length for swordfish is the lower jaw fork length (LJFL), the round weights have to be estimated thanks to international conversion conventions (Miyake, 1990). Research cruises provide the opportunity to take different types of measurements of individuals fish, thereby allowing the description of detailed length conversion.
As swordfish are dressed on board the fishing vessels, different lengths (to the nearest cm) are recorded during on board scientific sampling campaigns, during which every fish caught is available for measurement. Figure 2 shows the lengths applied in this study. The goal of this operation is to obtain length-length and length-weight relationships, as well as conversion factors for every kind of other processing methods (loins, extra loins...).

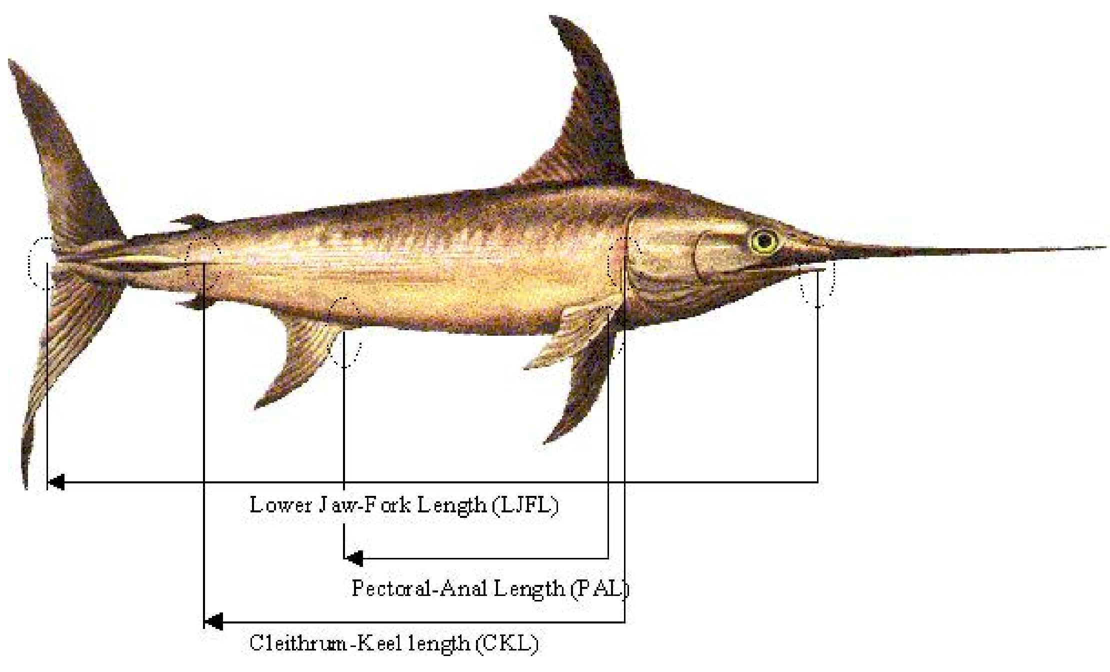


Figure 2: Alternative measurements of swordfish

2.5 Samplings

Landing Sampling

Most of the vessels unload their catch in the « Pointe des Galets » harbour. According to an interview with the captain, the small swordfish which are discarded and destined to « crew share», are measured in the ship's hold.

Thus, we collect length measurements (PAL or/and CKL) and dressed weights (VDK or VAT) from as many individuals as possible during the unloading process. There is no standardised procedure for selecting the number of swordfish to be measured, and it is usually a question of accessibility during processing. When the boats return to port, the fish have lost their identity in terms of time, date and location of catch.

Biological sampling at sea

During campaigns onboard commercial longliners, scientists record length measurements of all swordfish caught. They also determine the sex, collect gonads and the anal fin (figure 3).

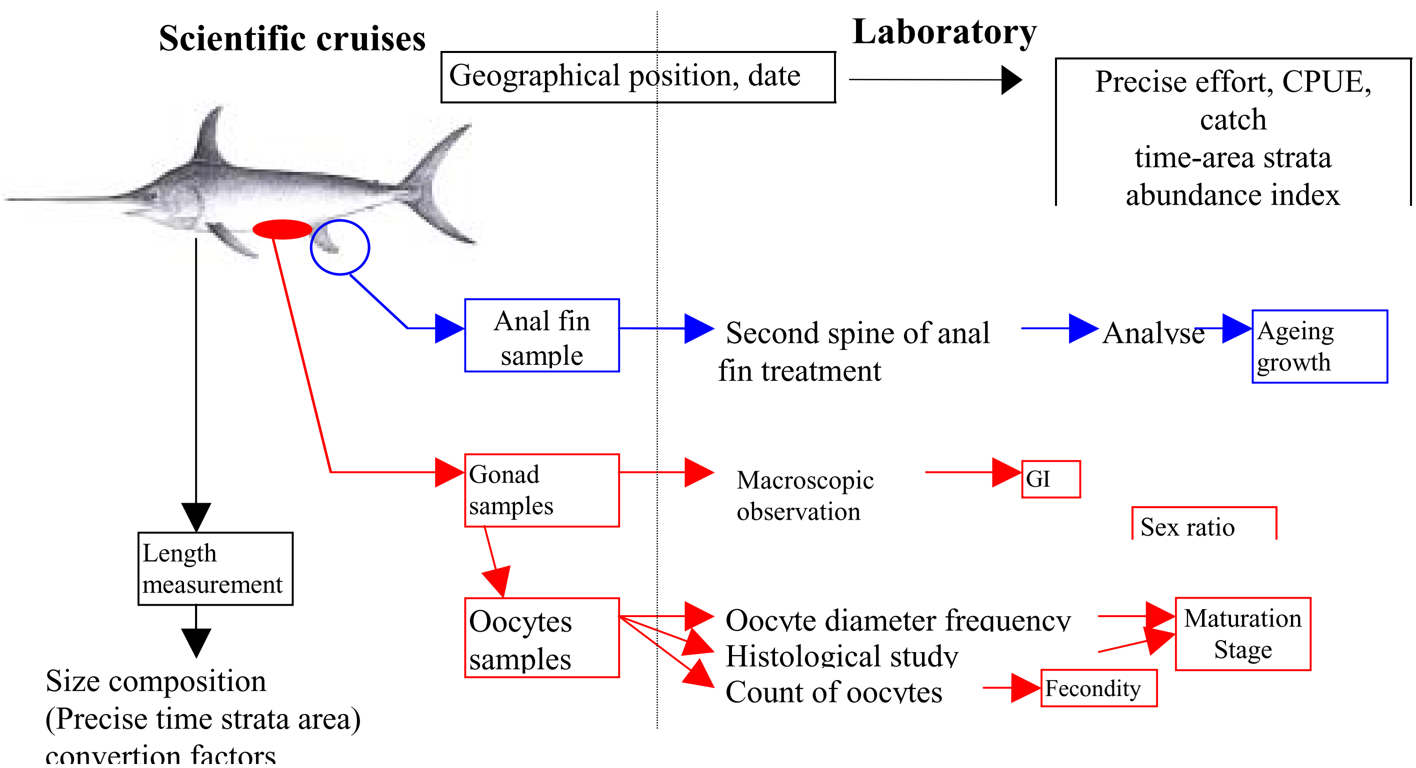


Figure 3: Sampling system scheme

As daily catch is rather small, and in order to implement our data set, some captains we are used to working with have been trained to measure and sex swordfish. Up to now, 3 captains have agreed to participate in this operation. This is done during the fishing operation, and if they do not have the possibility to measure every swordfish individual, fish are sampled randomly, regardless of size.

3 Swordfish longline fishery

3.1 Fishing gears and methods

All the Reunion vessels use a system of drifting longline utilising a main spool. The main line is a monofilament composed of nylon 3.5 or 4 mm in diameter. The monofilament main line is stored on a large Hydraulic-powered reel, each storing between 20 and 80 km of main line.

The lines with hooks (size 8/0 or 9/0) are 10 fathoms long and 2 mm in diameter. These are attached to the mainline with snaps. The depth of fishing is controlled by branch line and float line lengths, distance between buoys, number of hooks between two floats and speed of the boat during the setting.Weights can also be added to control the line depth in strong currents. In addition a larger float is used to separate the various sections composed of 60 to 100 hooks. Between 300 and 2500 hooks are utilised during each set. The buoys at the end of the longline are equipped with a strobe light and a radio assistance system in retrieval. So longlines can be rigged many ways.

Because swordfish is the target species, the longline is always set in the evening. Kume and Joseph (1969) have shown that lines set at night are more productive for capturing swordfish than lines sets during the day. Squid is used as bait in addition to a light stick placed one meter above the hook. Ligth sticks increase efficiency in catching swordfish either by attracting swordfish prey or swordfish itself (Berkeley *et al*, 1981). The longliners set about 6-10 hooks between floats and attach generally one light stick for every 3 branch lines. This whole operation requires three crewmen on deck for baiting the hooks and clipping buoys and branch lines on the mainline and one at the helm. The longline is set in 3 to 6 hours cruising down wind. The line is hauled after sunrise. The duration of the haul depends on the catch and sea conditions.

Between 1993 and 1999 sea surface temperature (SST) satellite images were used by the swordfish longline fishery to find probable fishing grounds. Images were prepared by IRD. Satellite information was available once a week. The largest vessels use temperature probes, global positioning system (GPS) navigation, automated track plotting system, satellite weather imaging and communications systems.

3.2 The processing of the catch

The processing of the catch is principally dependent on the market demand and duration of the fishing trip. Figure 4 sums up the different handling and processing methods and coefficients for each stage of the swordfish handling. The extremities of the caudal fin are removed, around 8 –10 cm of the caudal rays is left. Dorsal, anal and pectoral fins are cut at their bases. The internal abdominal walls are scraped to remove the mesenteries and kidneys beneath the vertebrae.

Consequently, two different types of on board processing methods are distinguished.

- Either the fish is conserved « H&G » (that is to say headed, gutted, fins and gills discarded; French designation « VDK »), chilled under ice, in insulated or refrigerated holds at 0°C
- Or the fish is conserved «dressed» (gutted with head gills discarded ; French designation « VAT »), which is the case for the swordfish weighing less than 20 kg.

« H&G » fish can also be frozen at -20°C (for the European market), or at -50°C for the tuna destined for the Japanese sashimi market and the loins for the European market. This loin processing necessitates an on-board factory and concerns mainly vessels over 20 m, which stay at sea for a period exceeding 20 days. Some fishermen wrap fish into plastic bags to ensure the skin is not damaged by ice.

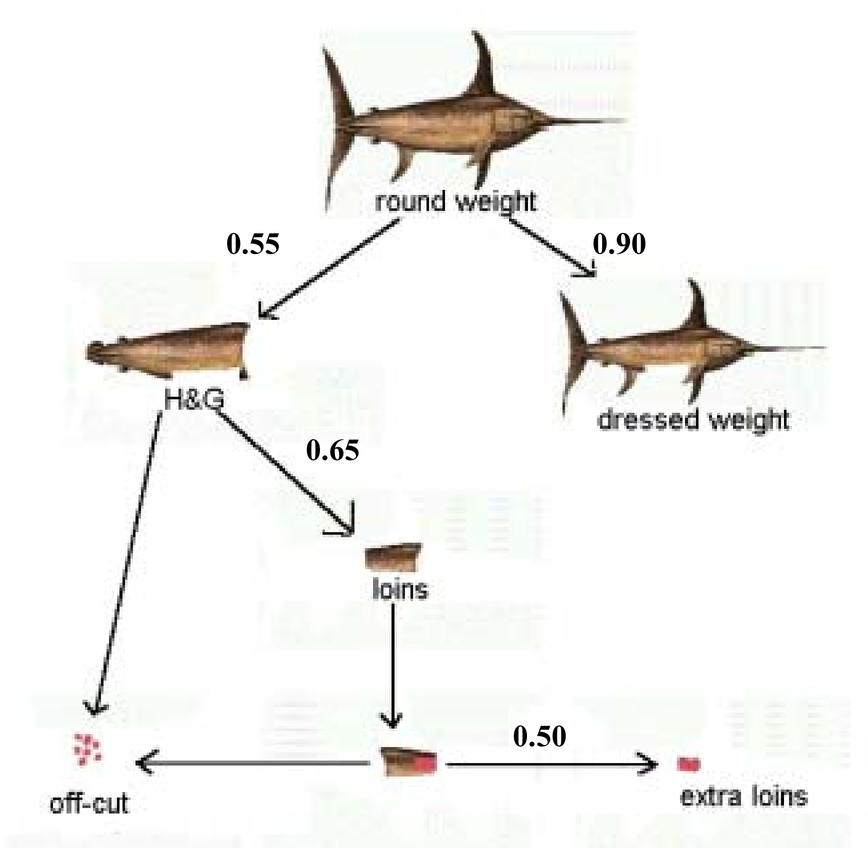


Figure 4 : Principal handling and processing techniques of the swordfish landed at Reunion Island, and corresponding processing coefficients (Poisson and Macé, 1997).

Different coefficients have been established for each species to convert product types into round weights (table I).

Species names	Ctoi code	Product	Coefficient (round weight)
Tetrapturus angustirostris	SSP	VAT	1.14
Tetrapturus angustirostris	SSP	VDK	1.2
Tetrapturus angustirostris	SSP	Loins	2
Euthynnus affinis	KAW	VDK	1.13
Thunnus albacares	YFT	VAT	1.13
Thunnus albacares	YFT	VDK	1.3
Thunnus albacares	YFT	Loins	1.82
Thunnus alalunga	ALB	VAT	1.13
Thunnus alalunga	ALB	VDK	1.3
Thunnus alalunga	ALB	Loins	2
Thunnus obesus	BET	VAT	1.13
Thunnus obesus	BET	VDK	1.3
Thunnus obesus	BET	Loins	2
Istiophorus platypterus	SFA	VAT	1.14
Istiophorus platypterus	SFA	VDK	1.2
Istiophorus platypterus	SFA	Loins	2
Tetrapturus audax	MLS	VAT	1.14
Tetrapturus audax	MLS	VDK	1.2
Xiphias gladius	SWO	VAT	1.18
Xiphias gladius	SWO	VDK	1.33
Xiphias gladius	SWO	Loins	2.05
Xiphias gladius	SWO	Flanks	0
Xiphias gladius	SWO	Extra-loins	4.84
Acanthocybium solandri	WHA	VAT	1.13
Gymnosarda unicolor	DOT	VAT	1.13

Table I: Round weight coefficients for the different sub-products.(VDK; or trunk weight is the weight after the head, gills, viscera and tail have been removed. VAT fish is just eviscerated).

3.3 Domestic fleet

The rapid development of the domestic swordfish longline fishery has been widely described (Poisson *et al*, 1998; Poisson et René, 1999). We have categorised vessels into three classes of overall length (1) less than 10 meters (small boat class) (2) between 10 and 16 meters (medium boat class) (3) and over 16 meters (large boat class). The number of days at sea varies according to vessel size and capacity and weather conditions. The smallest boats stay at sea 2 or 3 days, whilst vessels from the medium class stay 6 to 8 days and the greater up to 30 days. Based in the Pointe-des-Galets harbour, the fleet has increased over the last 9 years, reaching 31 active units in 1999 (Figure 5). The bigger units reach up to 33 m long, and the smallest ones 8 m.

The major issues concerning this fleet since the end of 1996 are (1) the settlement of a new company running three 25 m aluminiun catamaran (2) the progressive departure of three large vessels to Pacific Ocean fishing areas in 1998 and 1999 (3) the arrival of four small boats (4) the new entrants investors come from the local artisanal sector (Tessier et Poisson, in press).

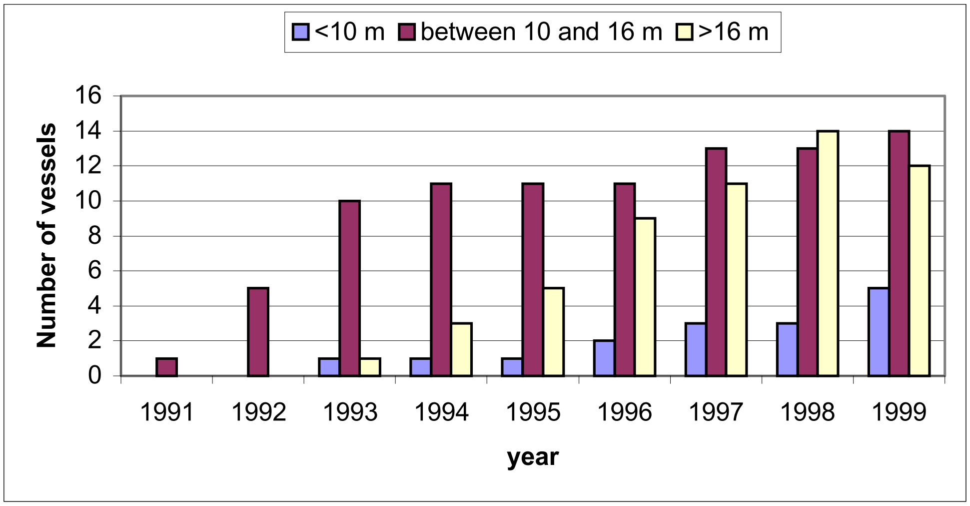


Figure 5 : Evolution of the Reunion Island longlining fleet from 1991 to 1999, sorted by size (in meters).

3.4 Coverage rates

The fishing logbook collection system, set up since 1993, has widely been accepted by the large majority of fishing companies and captains, as they benefit in return from the constant data and information, enabling them to observe the evolution of their global fishing characteristics (Table II).

	1993	1994	1995	1996	1997	1998	1999
Number of trips covered by logbooks	55	171	204	182	196	182	280
Coverage rate (1)	37%	87%	99%	58%	47%	37%	46%

Table II: Evolution of the Coverage rates from 1993 to 1999.

To obtain more accurate data, a second monthly coverage rate (2) is estimated for each segment of the fleet. The first segment (Segment 1) groups vessels between 8 and 16 m in overall length that generally fish within 200 nm, the second segment groups larger vessels, which can operate beyond 200 nm (Tables III, IV).

month	1994	1995	1996	1997	1998	1999
1	91	52	100	21	54	28
2	42	65	62	28	51	33
3	100	72	70	26	54	44
4	85	54	56	73	31	33
5	44	85	44	56	27	31
6	62	91	67	100	49	32
7	77	78	56	73	66	33
8	63	91	49	69	68	33
9	76	76	36	50	33	35
10	93	46	18	54	42	23
11	45	100	18	44	64	28
12	42	60	17	59	48	34

Table III: Monthly Coverage rates (2) from 1994 to 1999 for the first segment.

month	1994	1995	1996	1997	1998	1999
1	0	100	82	100	100	55
2	0	88	77	44	40	100
3	0	64	78	100	78	100
4	26	78	81	48	20	52
5	76	100	75	93	27	39
6	100	78	84	55	40	36
7	55	70	56	54	20	62
8	100	100	91	38	64	52
9	80	89	37	100	34	57
10	100	96	66	43	100	61
11	38	62	55	60	34	70
12	100	100	55	38	26	37

Table IV: Monthly Coverage rates (2) from 1994 to 1999 for the second segment.

3.5 Effort

The effort of the fleet is represented by the yearly estimated number of hooks set by the two segments of the fleet (figure 6). Since 1991 effort has been steadily increasing except in 1997. The contribution of the largest vessels to the fishing effort decreased slowly especially in 1999. Thus for the first time, in 1999, the number of hooks set by the first segment overtook the number of hooks set by the largest vessels.

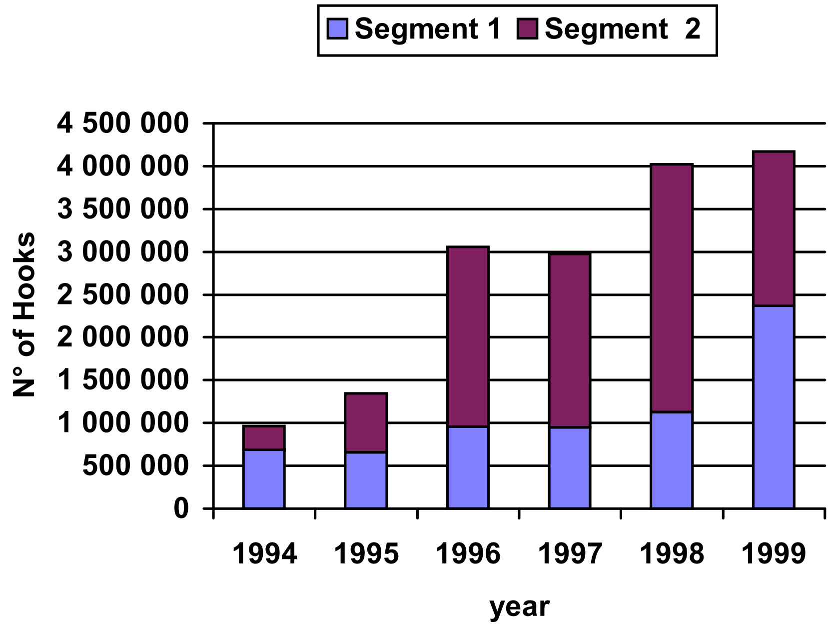


Figure 6 : Estimated number of hooks set by the two segments of the fleet

The increase of the average number of hooks set per fishing operation during 1994-1997 could be explained by a progressive mastering of the fishing techniques by the crews (figure 7).

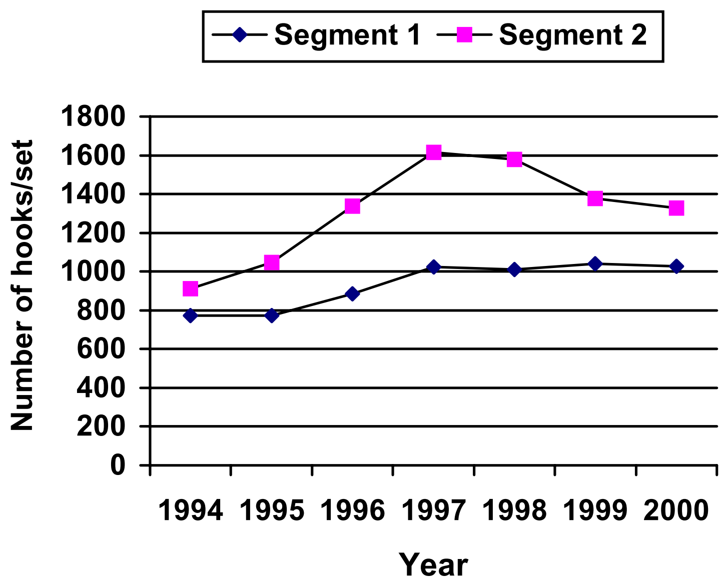


Figure 7: Evolution of the average hooks set per fishing operation for the 2 segments of the fleet.

3.6 Catches

The longline catch of swordfish was 278 mt in 1991, increased to a high of 2076 mt in 1998 and decreased to an estimated 1926 t in 1999 (table V). The swordfish component of total longline landings (by weight) ranged from 54% in 1993 to 71 % in 1994, and averaged 66 % over the 7 year-period. Albacore tuna (12 %), yellowfin tuna (11 %) and bigeye tuna (3 %) contributed about 26% of the total catch of the pelagic fish during the same period. The percentage contribution by billfish and sharks were respectively 4 and 2 %. The NCAD category is mostly composed of dolphin fish (*Coryphaena hippurus)*.

year	SWO	ALB	YFT	BET	MAR	NCAD	SFA	SHK
1993	278	94	86	3	31	8	2	12
1994	729	132	93	4	34	10	2	10
1995	767	115	118	9	50	11	2	12
1996	1331	294	212	93	77	20	3	24
1997	1557	244	240	87	65	78	4	64
1998	2076	271	360	108	104	54	11	89
1999	1926	304	236	210	79	100	12	66

Table V: Estimates of the global nominal catch by species are calculated from the DDAM data base.

The first segment has steadily increased and reaches the same level in 1999 (Figure 7).

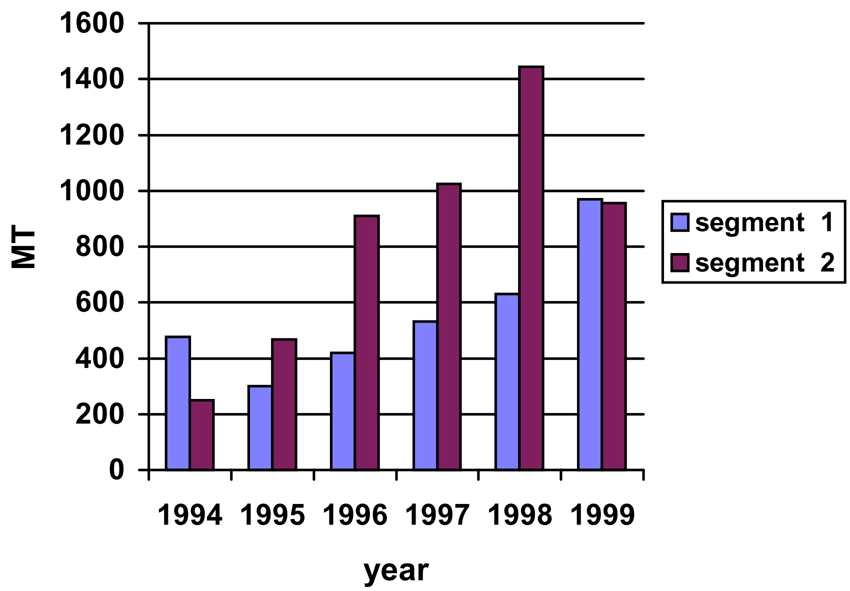


Figure 8 : Swordfish landings by the two segments of the domestic fleet .

Precise data on the effort and catches are not available for the entire domestic fleet, so the effort and catch data were adjusted upward with a monthly segment coverage rate (§ 3.4). The following maps show the estimated yearly swordfish catch by five-degree square from 1994 to 1999. The size of the circle is proportional to the catch in that square (root scale).

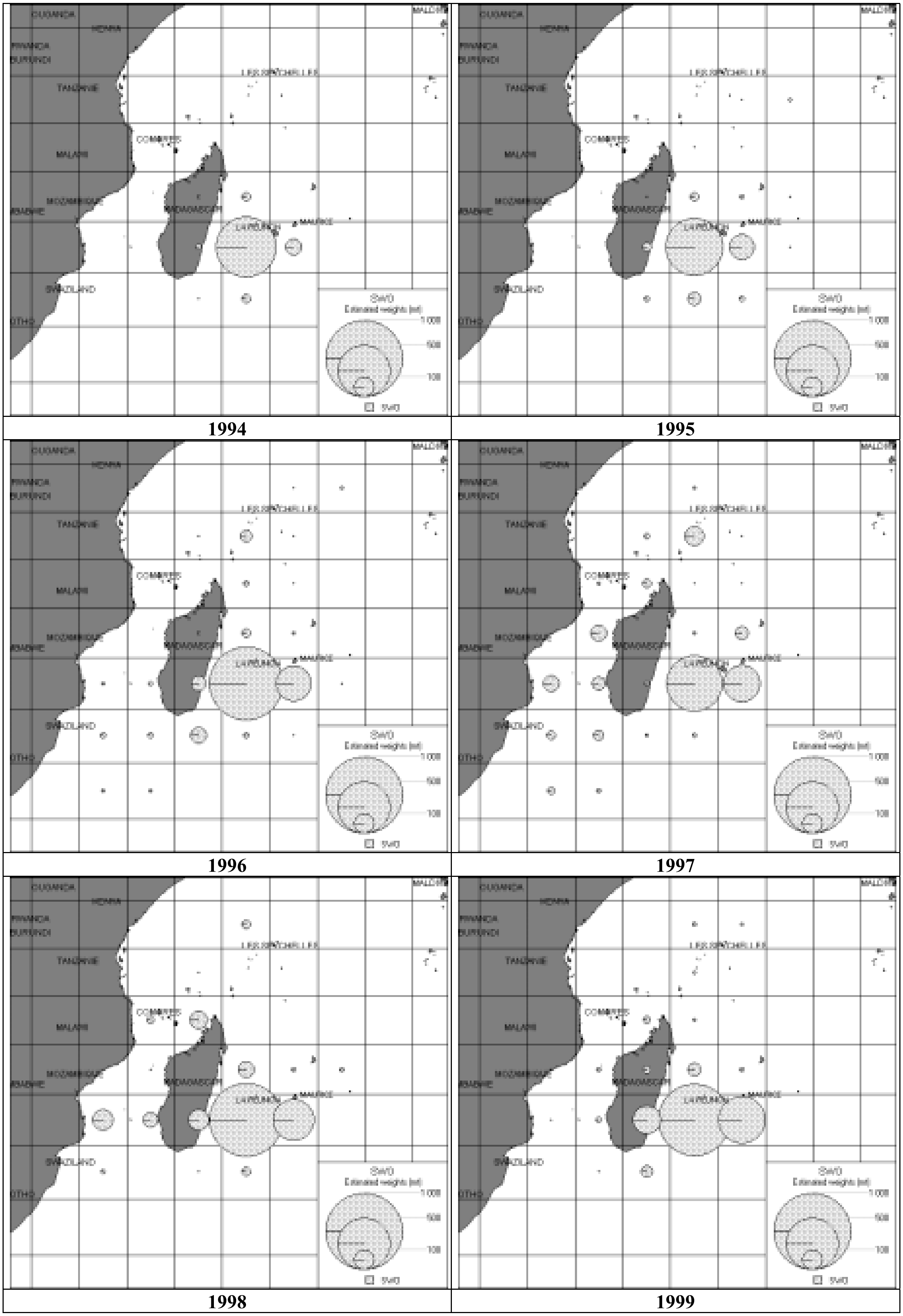


Figure 9: Evolution of yearly estimated catches of swordfish by 5° square between 1994 to 1999.

No longliners are authorised to fish within a zone of 12 nautical miles from Reunion in order to avoid conflicts with the artisanal tuna fishery (Tessier et Poisson, in press).

The fishing grounds of the Reunion longliners are located to the West and South of Reunion in the French EEZ and in international waters. The arrival of more powerful vessels, a mastership and an improvement of techniques as well as the discovery of new zones of exploitation, have brought notable changes to fishing strategies after 1994. This is illustrated by figure 9 that shows the progressive spatial extension of the activity. A catch zone westward of the island in 1993, evolves to a SW zone in 1994. This trend continued with an extension to the Southwest in the 200 nautical mile zone, in the Mozambique channel and Seychelles waters. But the maximum catches are made every year in a zone close to the island (between 30 and 60 nautical miles in the West and the Southwest). Thanks to the shift of the fleet's configuration, catches in 1999 are therefore made mainly around Reunion island between 50 E and 60 E and 20 S and 25 S. Only a few vessels can ventur as far as these zones.

The transition to an all year round operation is now established, but the climatic hazards must be taken into consideration, as they can stop the vessels putting to sea and modify the catch possibilities. Thus, the very active cyclone season of 1995, with its 14 cyclones and associated storms, limited the Reunion fleet expeditions and explains the stagnation of the catches in 1995 over three to four months. The period of the most intensive activity corresponds to the Southern Hemisphere summer (figure 10).

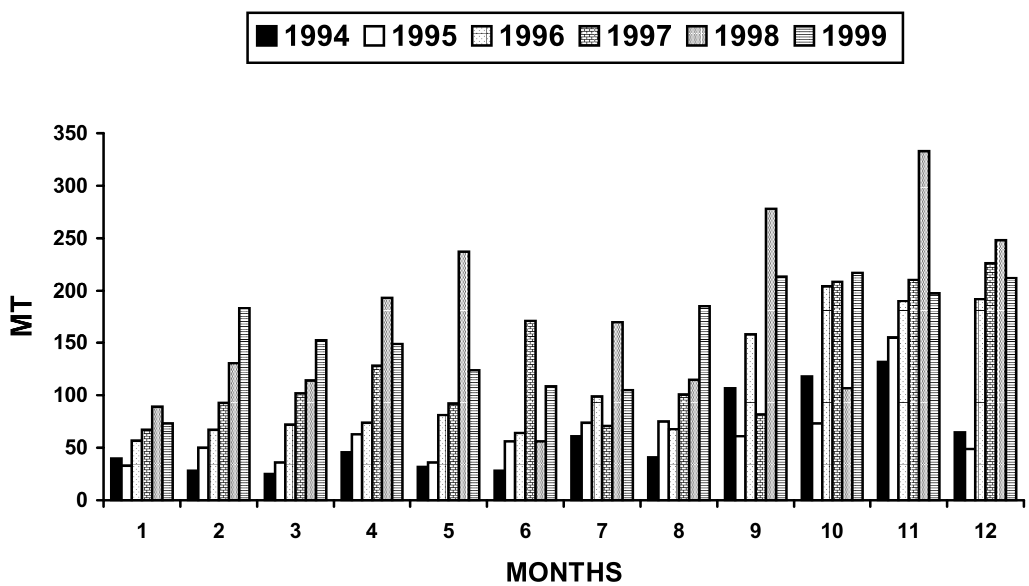


Figure 10: Monthly swordfish catch between 1994 and 1999.

Catch occurs mainly at the end of the year. The violent trade winds that characterise the southern winter (June to August) could limit the activity of the smallest boats of the domestic fleet which prefer to careen during this period.

Other billfish

Swordfish is by far the most dominant component of billfish catch. Marlins (*Makaira mazara* and *Makaira indica*) catch peaked at 104 mt in 1998 and dropped to 79 mt in 1999 (figure 11). Catch of sailfish (*Istiophorus platypterus)* and short-billed-spearfish (*Tetrapterus angustirostris*) is very low compared to that of marlins.

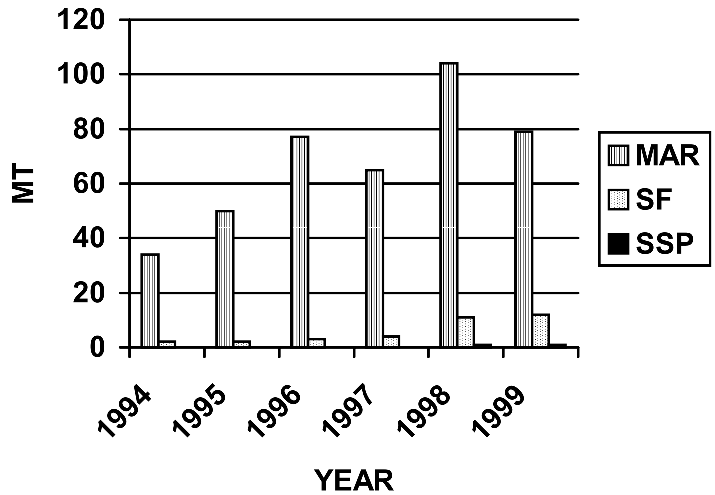


Figure 11: Production of Marlins (*Makaira mazara* and *Makaira indica*), sailfish (*Istiophorus platypterus)* and short-billed-spearfish (*Tetrapterus angustirostris*) between 1994 and 1999.

3.7 Catch-per-Unit of effort

Figure 12 shows the evolution of the monthly swordfish CPUE for the total fleet between 1994 and 1999. The most prominent change in CPUE (number of fish caught per 1 000 hooks) is a significant decrease (down to 8-9 individuals) after 1994.

Clearly, the definition of a better abundance index (including kilometers of line, number of hours per number of hooks set...) seems crucial to understand the evolution of the CPUE.

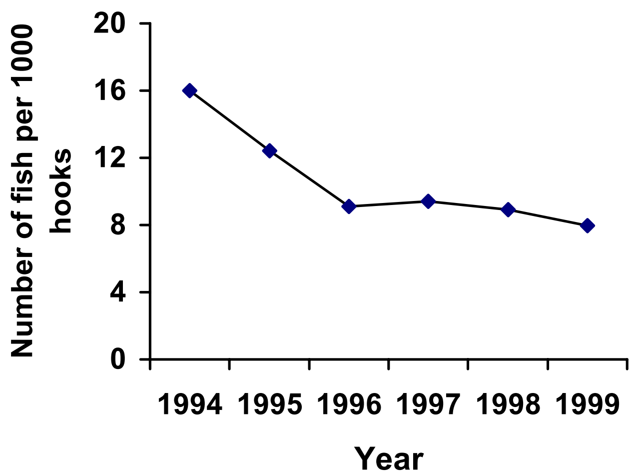


Figure 12: Evolution of nominal swordfish CPUE from 1994 to 1999

Other billfish

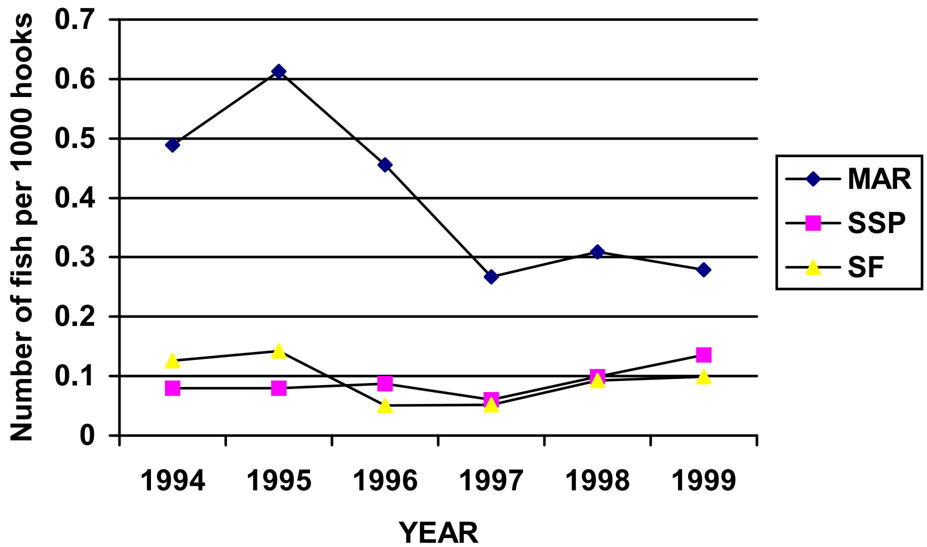


Figure 13: Evolution of marlins, Short-billed spearfish and sailfish CPUE from 1994 to 1999.

After a sharp decrease from 1995 to 1996, the nominal yearly marlins CPUE appears to be quite stable around 0.3 fish per 1000 hooks. Short-billed spearfish and sailfish CPUE remain, for the most part, around 0.1 fish per 1000 hooks.

3.8 Conversions between measurements

Length-length relationships

For fish measured only by PAL and CKL, Lower Jaw-Fork Length (LJFL) can be estimated using the appropriated linear regression (Table VI).

x (cm)	y (cm)	a	b	Range x mini (cm)	x maxi (cm)	sample size	R^2
PAL	LJFL	2.6098	18.8818	21	90	990	0.926
CKL	LJFL	1.5312	20.0175	37	135	271	0.973

Table VI: Linear regression parameters for the two different lengths of swordfish caught by the Reunion longline fleet (Poisson and Macé, 1997)

Length-weight conversions

Lengths can be converted into dressed weights, using the allometric length-weight conversion formula ($y = a * x^b$) developed from swordfish sampling in Reunion (table VII).

x (cm)	y (Kg)	a	b	Range x mini (cm)	Range x maxi (cm)	n	R^2
PAL	vdk	9.9518×10^{-4}	2.6586	22	109	2395	0.878
LJLF	vdk	5.8641×10^{-6}	3.0849	90	250	334	0.926
LJFL	vat	1.753×10^{-6}	3.3433	51	215	430	0.959
CKL	vdk	1.5762×10^{-4}	2.7297	50	158	773	0.924

Table VII: Length-weight conversion formula ($y = a * x^b$) developed from swordfish sampling in Reunion (Poisson and Macé, 1997)

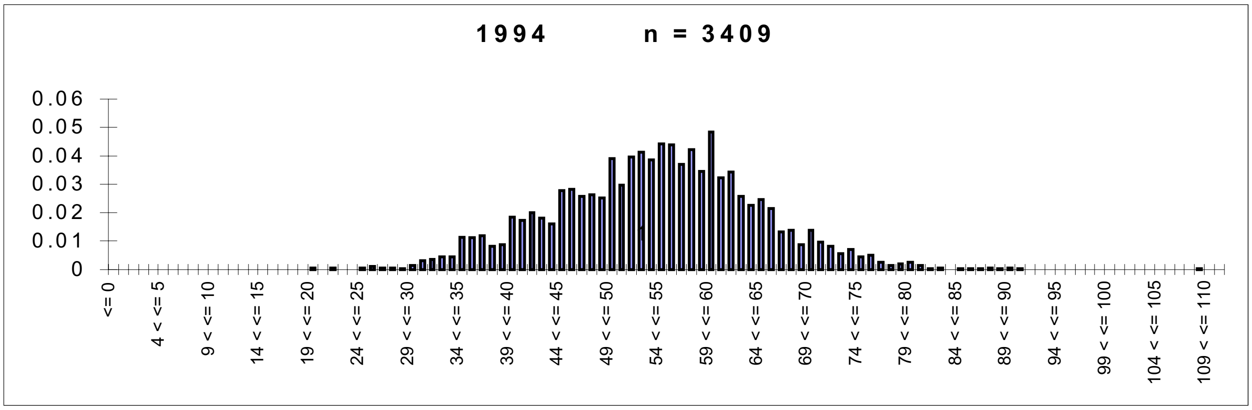
4 Size of fish

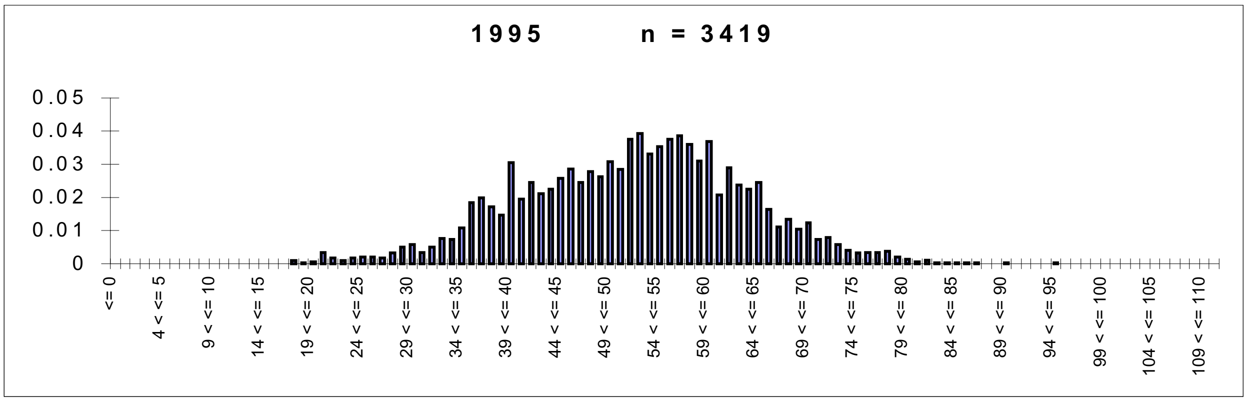
The monthly number of fish sampled from 1994 to 1999 is given in table VIII. At least 2600 fish are measured a year. Swordfish caught by the longline fishery are within a range of 17-116 cm PAL (LJFL: 63-321 cm).

months	1994	1995	1996	1997	1998	1999
January	102	339	478	330	315	442
February	46	334	407	307	140	209
March	262	199	462	425	145	329
April	300	211	309	393	175	198
May	140	127	374	219	300	136
June	398	206	512	188	319	184
July	155	553	464	213	350	153
August	412	301	358	270	256	89
September	402	385	454	226	93	276
October	482	195	400	422	138	190
November	260	273	342	341	297	244
December	450	296	235	316	103	184
	3409	**3419**	**4795**	**3650**	**2631**	**2634**

Table VIII: Number of swordfish sampled per month and per year between 1994 and 1999.

Figure 15 shows the yearly swordfish length frequency (PAL) distribution from 1994 to 1999. These charts are based on the three sampling sets of data presented above (§ 2.5). The size class is generally expressed in 1 cm intervals of pectoral-anal length.


1994 n = 3409
0.06
0.05
0.04
0.03
0.02
0.01
0
<= 0
4 < <= 5
9 < <= 10
14 < <= 15
19 < <= 20
24 < <= 25
29 < <= 30
34 < <= 35
39 < <= 40
44 < <= 45
49 < <= 50
54 < <= 55
59 < <= 60
64 < <= 65
69 < <= 70
74 < <= 75
79 < <= 80
84 < <= 85
89 < <= 90
94 < <= 95
99 < <= 100
104 < <= 105
109 < <= 110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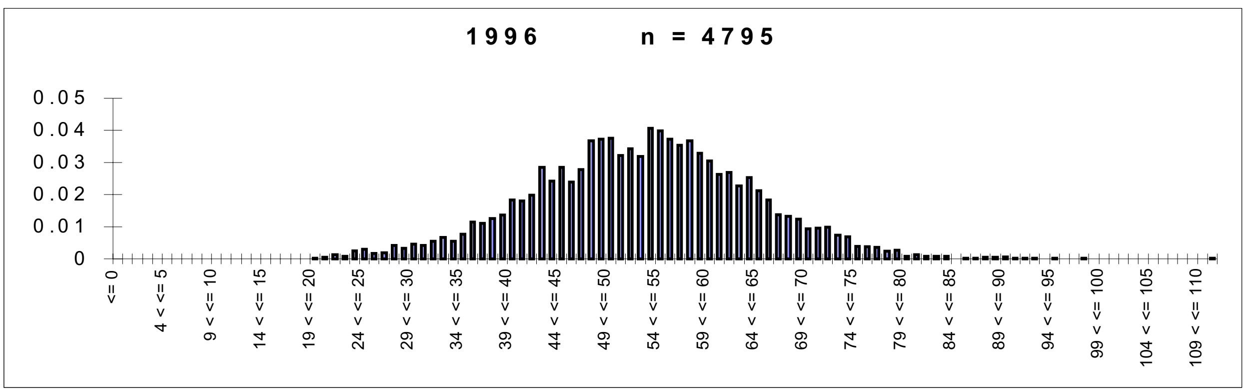
0.04
0.03
0.02
0.01
0
<= 0
4 < <= 5
9 < <= 10
14 < <= 15
19 < <= 20
24 < <= 25
29 < <= 30
34 < <= 35
39 < <= 40
44 < <= 45
49 < <= 50
54 < <= 55
59 < <= 60
64 < <= 65
69 < <= 70
74 < <= 75
79 < <= 80
84 < <= 85
89 < <= 90
94 < <= 95
99 < <= 100
104 < <= 105
109 < <= 110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0.03
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0.01
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24 < <= 25
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54 < <= 55
59 < <= 60
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94 < <= 95
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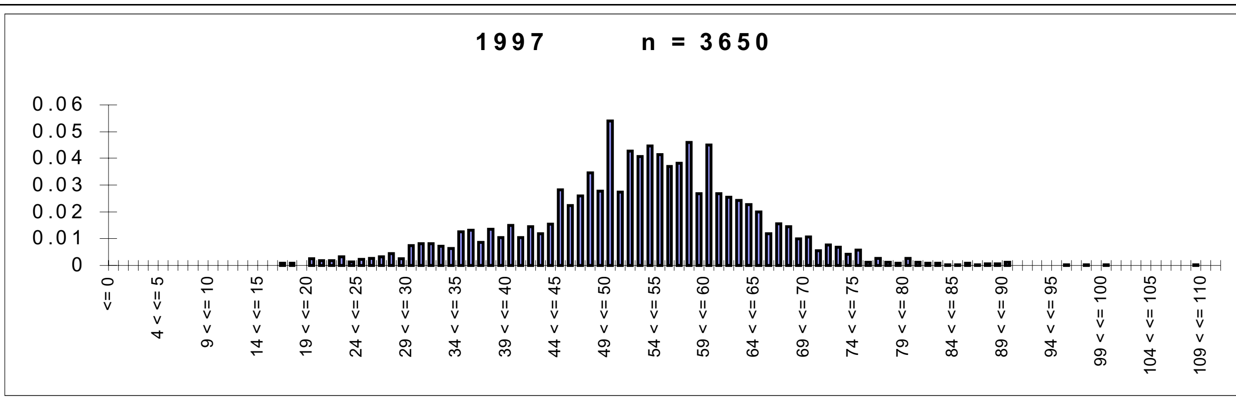
104 < <= 105
109 < <= 110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0.04
0.03
0.02
0.01
0
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104 < <= 105
109 < <= 110

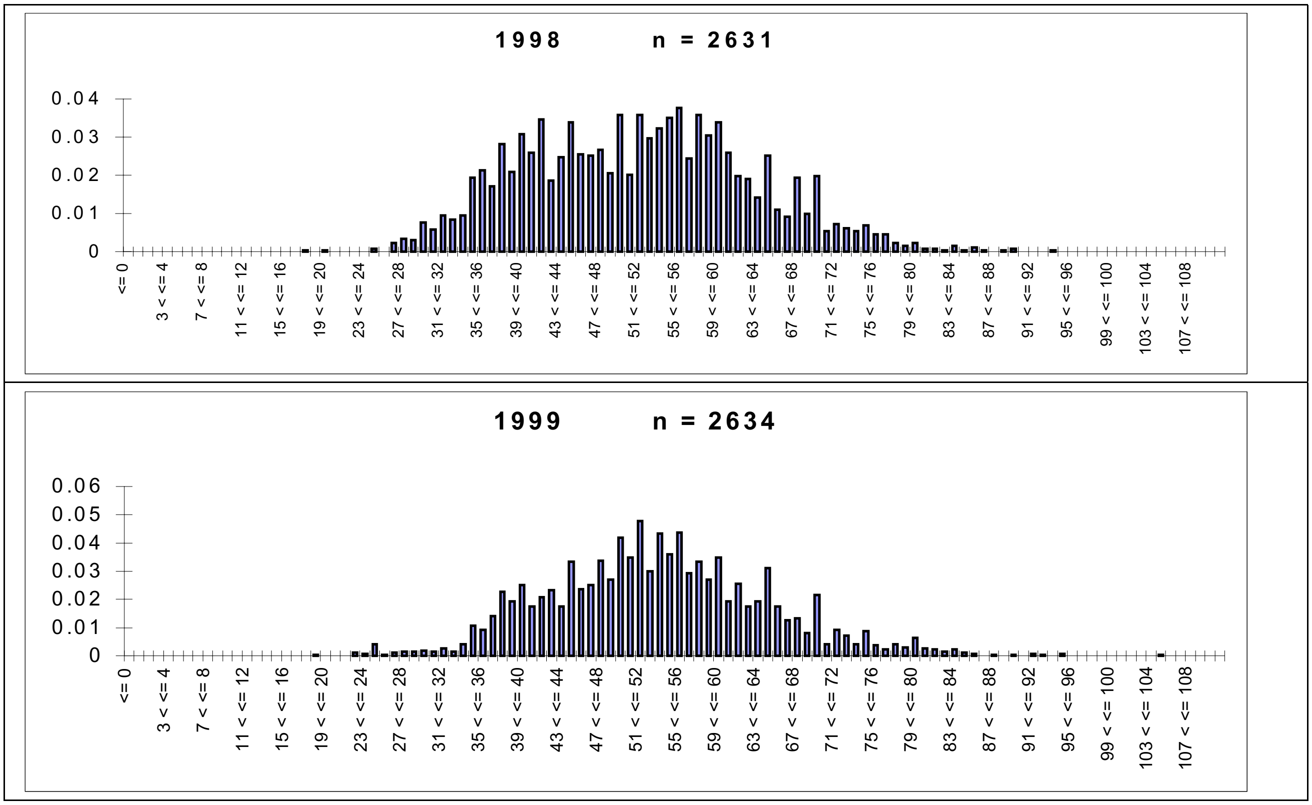

Figure 6 : Length frequency distribution of swordfish landed from 1994 to 1999.

The yearly average PAL has been calculated from the set of data. By converting these values round weights and LJFL have been estimated (table IX).

Year	Number of observations	PAL (cm) mean	Standard deviation cm	LJFL (cm) (mean estimated)	RW kg (mean estimated)
1994	3409	54.42	10.10	160.91	50.14
1995	3419	52.31	11.26	155.40	45.03
1996	4795	53.28	10.48	158.19	47.34
1997	3650	52.97	11.25	157.12	46.6
1998	2631	51.9	11.56	154.3	44.08
1999	2634	53.81	11.15	159.31	48.6

Table IX: Yearly evolution of measured PAL, mean estimated LJFL round weights

There is no real trend of the annual mean LPA length from 1994 to 1999. It dropped rapidly in 1995 before increasing and remaining quite stable in 1996 and 1997. An upward trend is observed after 1998.

It is also important to point out that the largest fish are caught between September and November (figure 14).

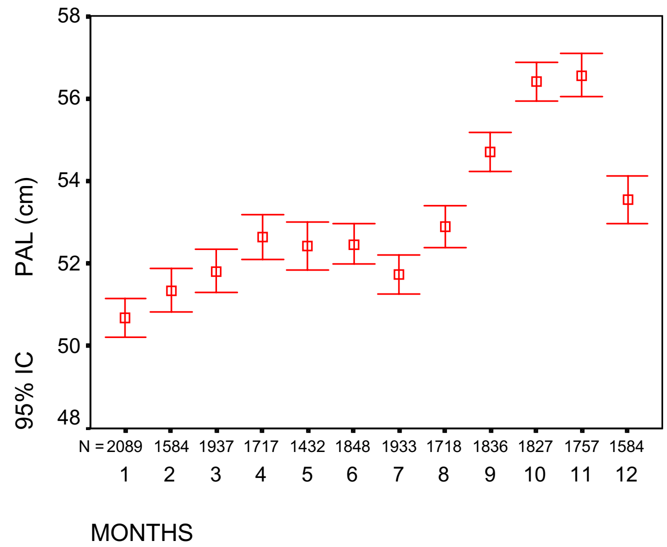

Figure 14: Monthly average length frequency (PAL) of swordfish caught (combined between 1994 to 1999).

5 Swordfish biology

Table X sums up the number of fishing operations followed by scientists since the beginning of the program. The number of fish per species sampled during the campaigns is given in table XI. The location of the different fishing operations followed by scientists is illustrated in figure 15.

Year	N°of day at sea	N° of fishing operations
1998	45	37
1999	125	98
2000 (mai)	36	28
TOTAL	**206**	**163**

Table X : Number of fishing operations followed by scientist.

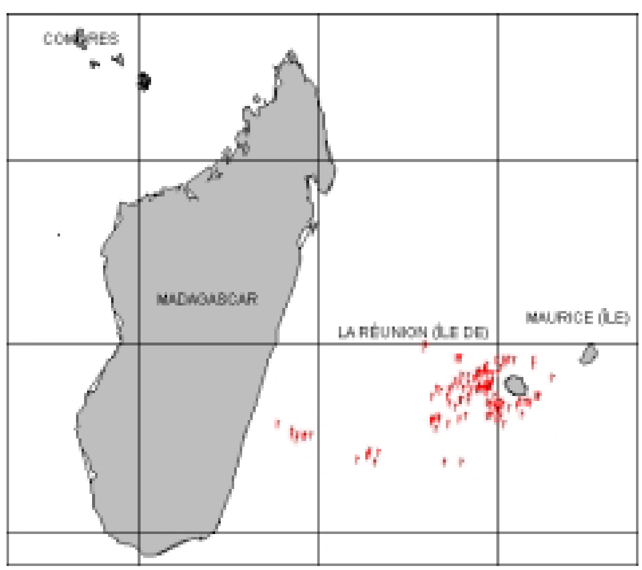

Figure 15 : Locations of different at-sea samples since the beginning of the program.

5.1 Maturation and spawning

Data on sex composition of swordfish caught by domestic longliners are presently limited to fish sampled at sea during campaigns by observers or fishermen. The raw size (LJFL) data obtained since 1998 has been combined for both sexes (figures 17 and 18).

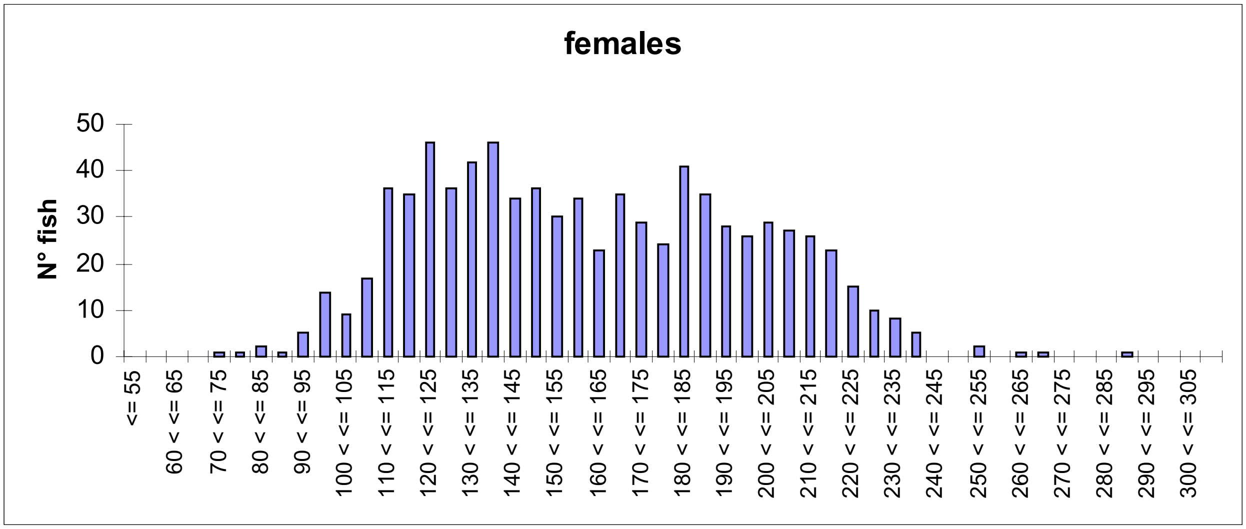

Figure 16: Length frequency distribution of female swordfish sampled in the vicinity of Réunion Island (n= 814)

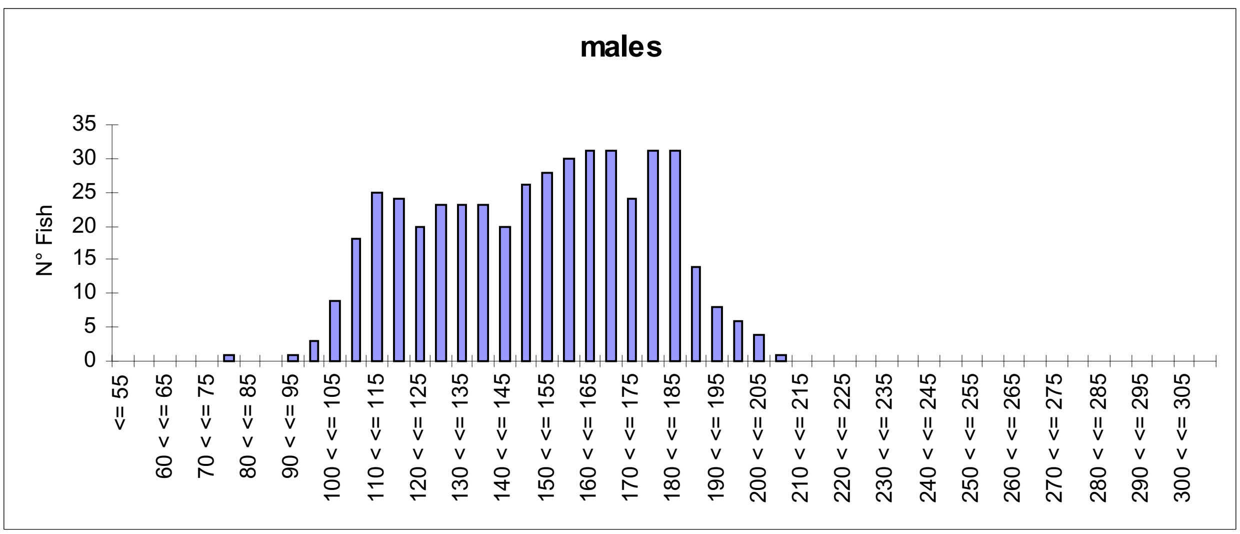

Figure 17: Length frequency distribution of male swordfish sampled in the vicinity of Réunion Island (n= 455)

As for the other billfish, swordfish males are smaller than the females. The size sampled fall within a range of 79-208 cm for males and 75-289 cm for females.

Gonad index

The gonad index GI, the ratio of the weight of the ovaries to a theoritical weight of the fish , was used to indicate the maturity of both sex and to determine the spawning season. The gonad index is estimated as:

GI=(W/(LJFL) ^{3} X 10^4 ;

Where W=gonad weight in grams and LJFL = Lower Jaw-Fork Length in centimeters (Kume et Joseph, 1969).

In the vicinity of Reunion Island, all maturation stages can be observed throughout the year. Figure 18 represents the mean GI evolution by quarter for the total sample. This index has been calculated from 1996 to 2000 (July), for 908 females ranging from 67-289 cm LJFL and for 485 males ranging 67-213 cm. Swordfish with the greatest gonad index are caught from October to March, so the spawning season occurs in the summertime. Ripe females can be caugth up to April. Swordfish larvae have been observed in the Mozambique Channel during the months of January (Kondritskaya, 1970) as well as off the East Coast of Madagascar (Gorbunova, 1969) and are abundant between lat.12° and 17°S, approximately in the eastern of the South Equatorial Current.

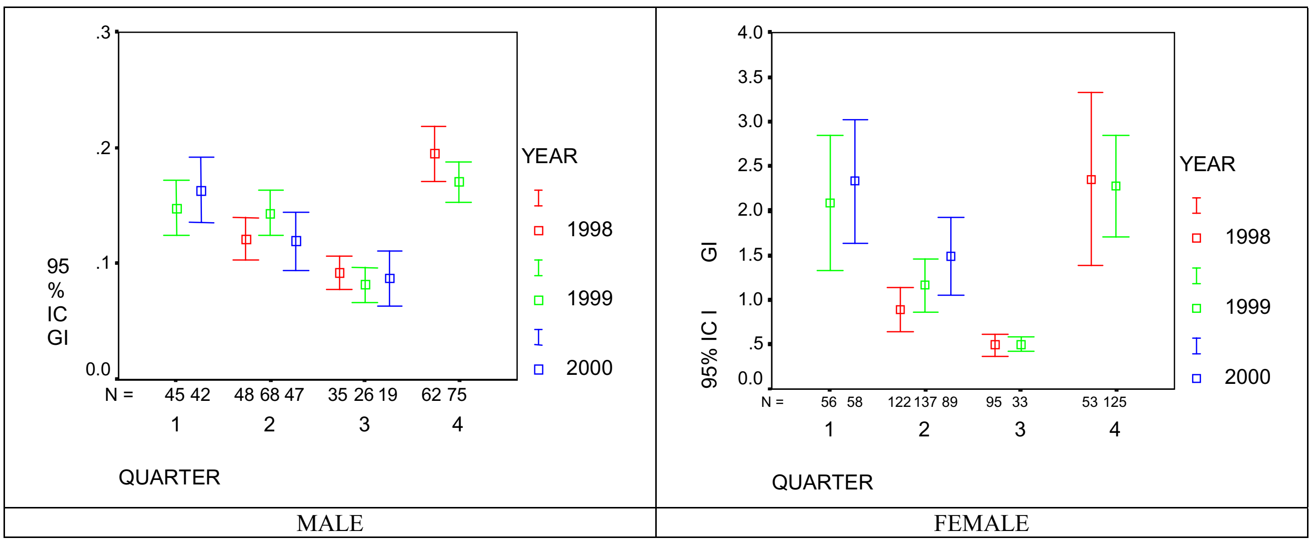

Figure 18: Evolution per quarter of both sex swordfish average gonad index around Réunion Island (between 17°S and 23°S and 49 E and 57 E).

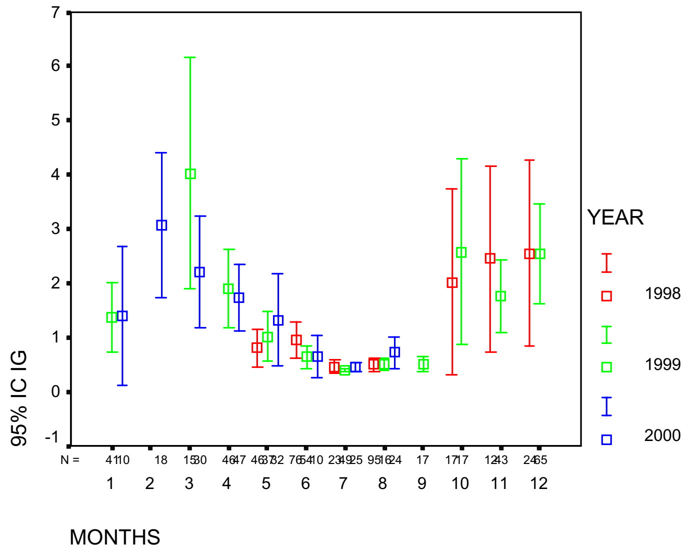

Figure 19: Monthly evolution of female swordfish average gonad index around Réunion Island. (Between 17°S and 23°S and 49 E and 57 E).

The relationships between the gonad index and LJFL are shown in figure 20. Kume and Joseph (1969) and shingu *et al* (1974) considered females with gonad indices of 3.0 or greater to be mature. Thus, the smallest mature female was 152 cm in length.

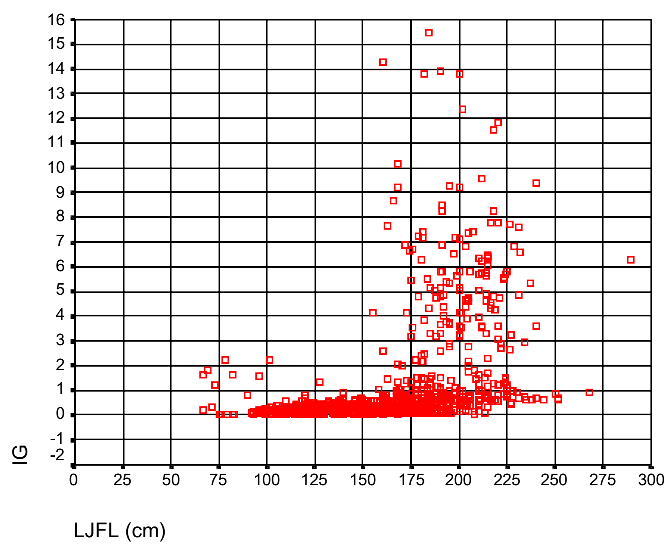

Figure 20: Relationship between gonad index and LJFL for female Swordfish.

. The greatest gonad index encountered was 15.47, for a 184-cm fish caught in December with gonads weighing 9640 g.

Histological analysis

Different maturation states have been assessed histologically using standard tissue staining, sectionning, slide preparation and analysis. The description of all stages of maturity and cells at different stage of ovogenesis has been achieved (figure 20). Thus, a paper describing histological features of maturation of swordfish in the SWIO is in preparation.

Echelle : 8 µm

Figure 21 : Early stage of the vitellogenesis.

Size composition of oocytes

To determine the characteristic oocyte diameter pattern for each stage, we have been using Visilog (Noesis ®) software. Data processing using software functions has been developped in order to obtain oocyte diameter histogrammes from one picture of each sample (figure 19).

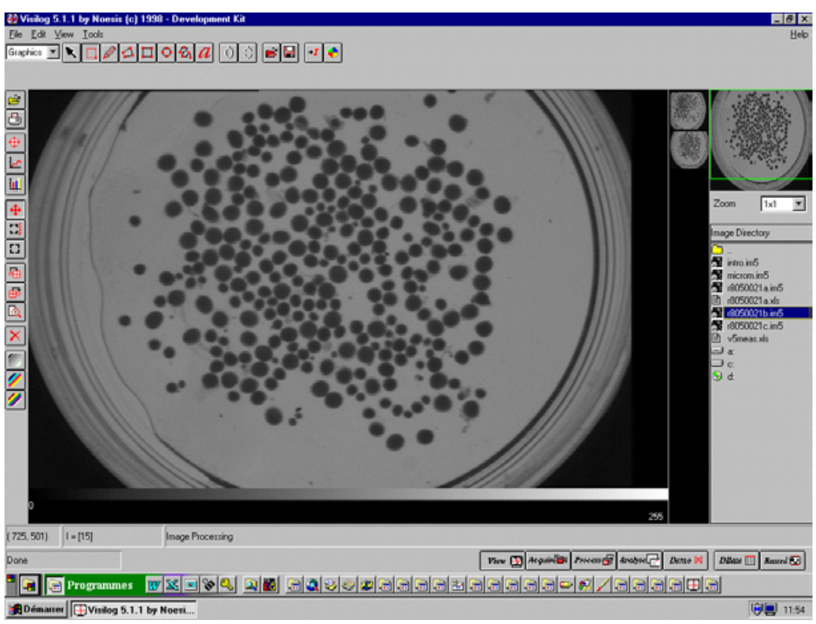

Figure 22: Main window of “Visilog” software. Oocytes sample.

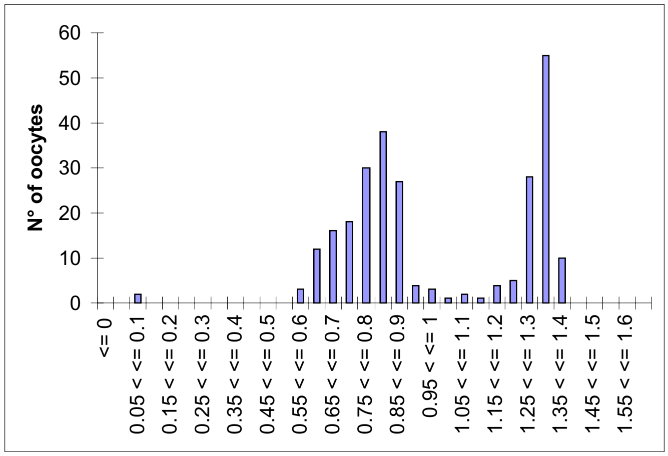

Figure 23: oocyte diameter histogramme of an early ripe female

Sex ratio

During the 2 year period, 1269 individuals swordfish have been sexed. Figure 24 shows the monthly sex ratio.

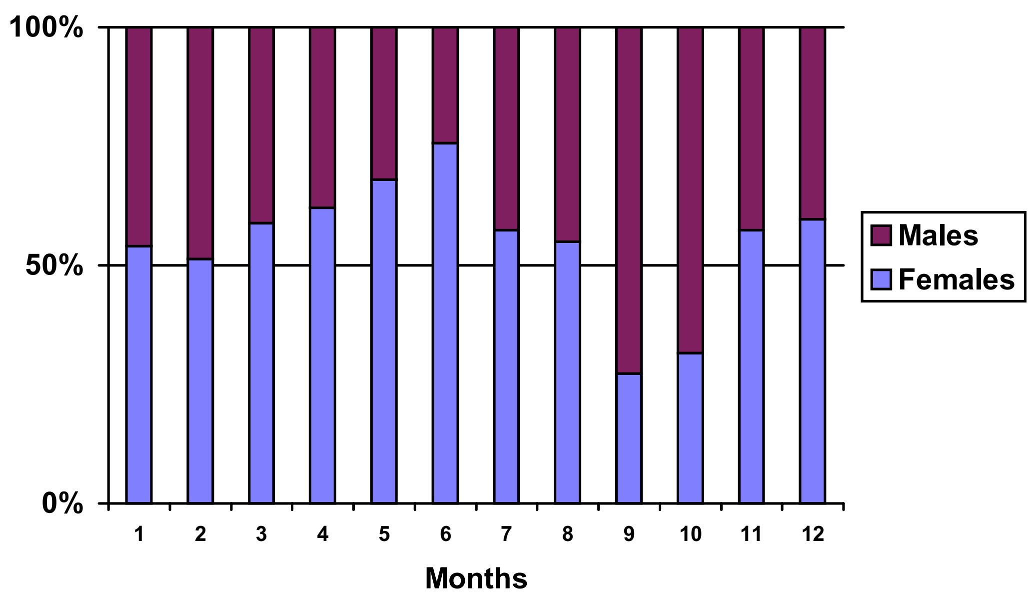

Figure 24 : Overall sex ratio

Figure 24 suggests that individuals from both sexes are present throughout the year and that female are predominant except in September and October.

5.2 Ageing

According to Berkeley and (1983), we have been using the second anal fin spine, which has the smallest matrix and the largest diameter as the source of information to estimate growth. Anal fins are collected aboard fishing vessels with lower jaw for length (LJLF), sex, sex maturation and geographical location. The total fin is cut, stored in a plastic bag, labelled and kept refrigerated or frozen. At the laboratory, each fin is boiled in order to separate the spines (annexe 1). The second spine is sectionned with a diamond saw (Isomet). Two successive sections are embedded in polyester resin (Eukitt). On 15 juveniles, otholiths have also been extracted. This study has been undertaken in partnership with the Ifremer team of LASAA (Laboratoire de Sclérochronologie des Animaux Aquatiques). A total of 902 swordfish fins have been collected throughout the year, since the beginning of the program (figure 25).

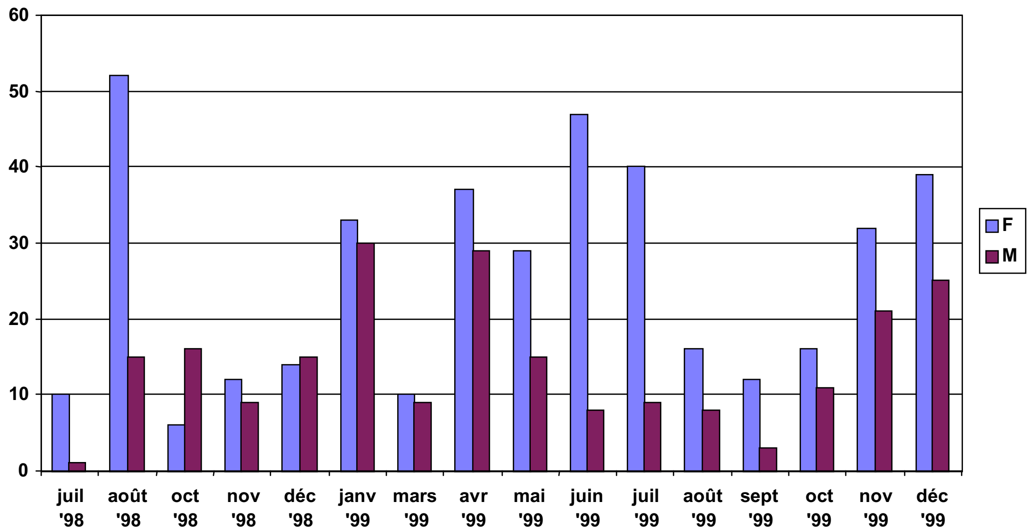

Figure 25: Number of anal fins sampled since July 1998.

Every spine section picture has been stored with TNPC (Traitement Numérique de Pièces Calcifiées) which is software developed by LASAA/Ifremer for digital image processing of calcified structures (figure 23).

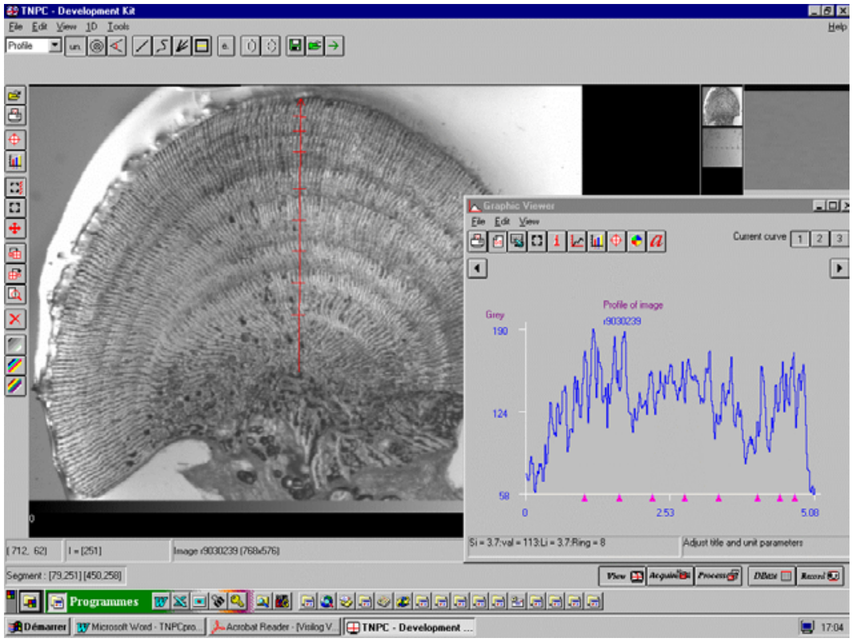

Figure 26: Main window where image of the spine section is managed with the graphic viewer.

This software is based on the dual principle of radial profile image processing and of inserting biological knowledge into the process, and is composed of two sets :

- ❖ Automatic radial processing tools (smoothing, detrend, ring detection, demodulation)
- ❖ A full on-line interactive module made up for automatic detection correction.

Data are stored in ASCII files (CSV format) and can be loaded onto any spreadsheet.

TNPC proposes on the one hand, the possibility of integrating the signal between several profiles in order to build a synthetic profile over an area of interest and on the other hand, the possibility of taking into account an *a priori* growth pattern (Von Bertalanffy, Gompertz, exponential) in the profile processing by signal demodulation.

In addition TNPC proposes real time distance measurements and a configurable fish length back-calculation based on different models. It can be used interactively with a keyboard or a mouse and also automatically or semi-automatically using a series of processes. Sample data can be associated with the images in a single database. The treatment of all the data compiled is in process (Table XI).

YEAR	Sex	N°samples	N° spines cut	N°sections analysed
1998	M	69	56	24
1998	F	112	94	14
1999	M	182	168	33
1999	F	326	311	37
2000	M	75	52	0
2000	F	138	71	0
total		**902**	**752**	**108**

Table XI: Summary of sampling operations.

6 Capture time of longline caught pelagic fish

The present study has been designed to describe the captures time of tunas, billfishes, sharks and other pelagic fish using electronic timing devices and estimate the relative fishing efficiency of the gear.

Hook timers are battery-powered microchip clocks controlled by a magnet embeded in a plastic resin. A fish biting the hook pulls out the magnet and triggers the clock. Hook timers are attached to the branch line near the snap. Each hook timer position is controlled by timing the attachement of branch lines as the mainline is set. So hook timers which only indicated elapsed time were read as the branch line was recovered. If the hook timer triggered 2 mn after the launching or 2 mm before the retrieval cases were not taking into account in the results.

Longline fishing are conducted on domestic longliners. Gear is usually deployed around the sunset and retrieved early in the morning. One lightstick is attached 1 meter above the hook on every branch line.

Species	N° caught
Swordfish (*Xiphias gladius*)	227
Albacore (*Thunnus alalunga*)	72
Blue shark (*Prionace glauca*)	67
Yellowfin tuna (*Thunnus albacares*)	44
Bigeye tuna (*Thunnus obesus*)	25
Dolfin fish (*Coryphaena hippurus*)	19
Stingray (*Dasyatis sp.*)	15
Oceanic whitetip shark (*Carcharinus longimanus)*)	10
hammerhead shark (*Sphyrna sp)*	4
Sailfish (*Istiophorus platypterus)*	4
Snoek (*Thyrsitoides sp*)	3
Blue marlin (*Makaira mazara*)	2
Wahoo (*Acanthocybium solandri*)	2
Barracuda (*Sphyraena barracuda*)	1
Shortfin mako (*Isurus oxyrinchus*)	1
Other sharks	10
Other species	11
TOTAL	**517**

Table XII: Catch data during experimental fishing operations.

Between 60 and 400 hook timers have been set per fishing operation and 16296 hook timers have been deployed since July 1998. Among the 517 fish caught, 227 swordfish have been retained (44%)(table XII). The preliminary results show that 48% are caught during the 3 hours following the hook deployement and the high level of lossed fish. Others treatments are in process.

7 Interaction with endangered species

7.1 Depredation

None of the skippers interviewed mentionned marine mammals as part of the by-catch but they have been reporting that marine mammals feed on the longline catch before it can be harvested. From fishermen's and scientists observers' pictures, short finned pilot whale (*Globicephala macrorhynchus*) and false killer whale (*Pseudorca crassidens*) have been identify as the involved species. Those cetaceans seem especially interested in the swordfish. They usually eat the body of the fish leaving a part of the head. According to logbook data, fishermen have recorded 3 or 4 consecutively day's catch completely destroyed by marine mammals. In this case, the attitude of the skipper is to move to another area. Loss due to marine mammals is under estimated we do take into account only the cases where at least, 80% of the hooked fish are consumed.

Fishermen are convinced that those animals learned to follow the longline vessels, this question of apprendiceship is poorly understood and researchers worldwide are just beginning to address this topic.

Pseudorca crassidens *Globicephala macrorhynchus*

Figure 27 : Main species involved in depredation, source : Media Design Interactive

The global percentage loss due to marine mammals has been established from the data collected in the logbook. To determine this percentage, the mean monthly CPUE (per segment), the number of attacks recorded and the monthly coverage rate are used.

To calculate depredation by sharks, the number of fish damage is taken into account (table 7). The depredation done by marine mammals is always higher. The phenomenon increased over the year with a peak in 1998 (5.5% of the swordfish annual catch) whereas discards due to sharks are quite stable (around 3%). Discards of swordfish is really significant, Sivasubramanian (1965) reported in his paper that killer whales (*Orcina orca*) and sharks damaged up only 4% of the annual catch of the tuna longline boats in the Indian Ocean.

We have been investigating on effective methods to deal with this problem and during the next summer, we are going to equip one of our domestic longline with 50 acoustic deterrents to test according to our protocoles if those devices could be a possible remedy for this problem.

Around seven shark's species are caught (table 4). A significant by-catch of blue shark (*Prionace glauca)* has been observed by analyses of the logbooks (92%) Most of them are released alive often due to the fish cutting nylon before they reach the vessel. If they are dead, only fins are kept and the carcasses are discarded. The remaining 8% of landed shark is composed of 5.4% of Oceanic whitetip shark (*Carcharinus longimanus*), 2% of Shortfin mako (*Isurus oxyrinchus*) and 0.6% of hammerhead shark (*Sphyrna sp.*) Other species are rarely caught.

year	Loss due to marine mammals (mt)	Loss due to sharks (mt)	Total swordfish loss (mt)	% of the total catch
1997	64 (4.1%)	43 (2.7%)	107	6.8
1998	114 (5.5%)	68 (3.3%)	182	8.8
1999	72 (3.7%)	52 (2.7%)	124	6.4

Table 7: Estimation in weights and percentage of depredation on swordfish longline catches caused by marine life from 1997 to 1999.

7.2 Sea Turtles

Table 4 shows a summary of the interactions with sea turles recorded in the logbooks. The condition of animals upon release is categorized as either alive or dead.

	Total	*Dermochelys coriacea*		*Chelonia mydas*		*Eretmochelys imbricata*		Non identified	
		Released/ Alive	dead	Released/ Alive	Dead	Realeased /Alive	Dead	Realeased /Alive	Dead
1997	**39**	**21**	**0**	**2**	**0**	**13**	**12**	**4**	**0**
1998	**20**	**8**	**0**	**2**	**1**	**3**	**0**	**3**	**3**
1999	**32**	**11**	**0**	**4**	**4**	**7**	**2**	**2**	**2**

Table 13 : Domestic longline logbook summary for sea turtles interactions

Almost all of the turtles are released alive (74%), some of them with the hook in their mouths when fishermen can not take them off. Dead ones are generally entangled in the line.
Turtle bycatch rates are very low, between 0.01 et 0.019 per 1000 hooks compared to 3.2 turtles per 1000 hooks mentionned by uruguayan researchers (Achaval *et al*, 1998)

8 Conclusion

As the swordfish longline fishery increases in Reunion the Ifremer laboratory has decided to make an effort to monitor the new fishery and collect relevant data for stock assessment. All the data on longline catch effort and swordfish biology used in this on-going study were obtained from records of scientific campaigns onboard domestic longliners. At this stage we are still compiling additional data and results are considered preliminary. Treatments and analysis will be completed throughout the third year of this program. It is clear that cooperation among interested nations is required. Seychelles Fishing Authority, Ifremer and IRD have been collaborating in the preparation of a common “Scientific accompaniment program on the longline fishery targeting swordfish in Southwestern Indian Ocean”.

Acknowledgements

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