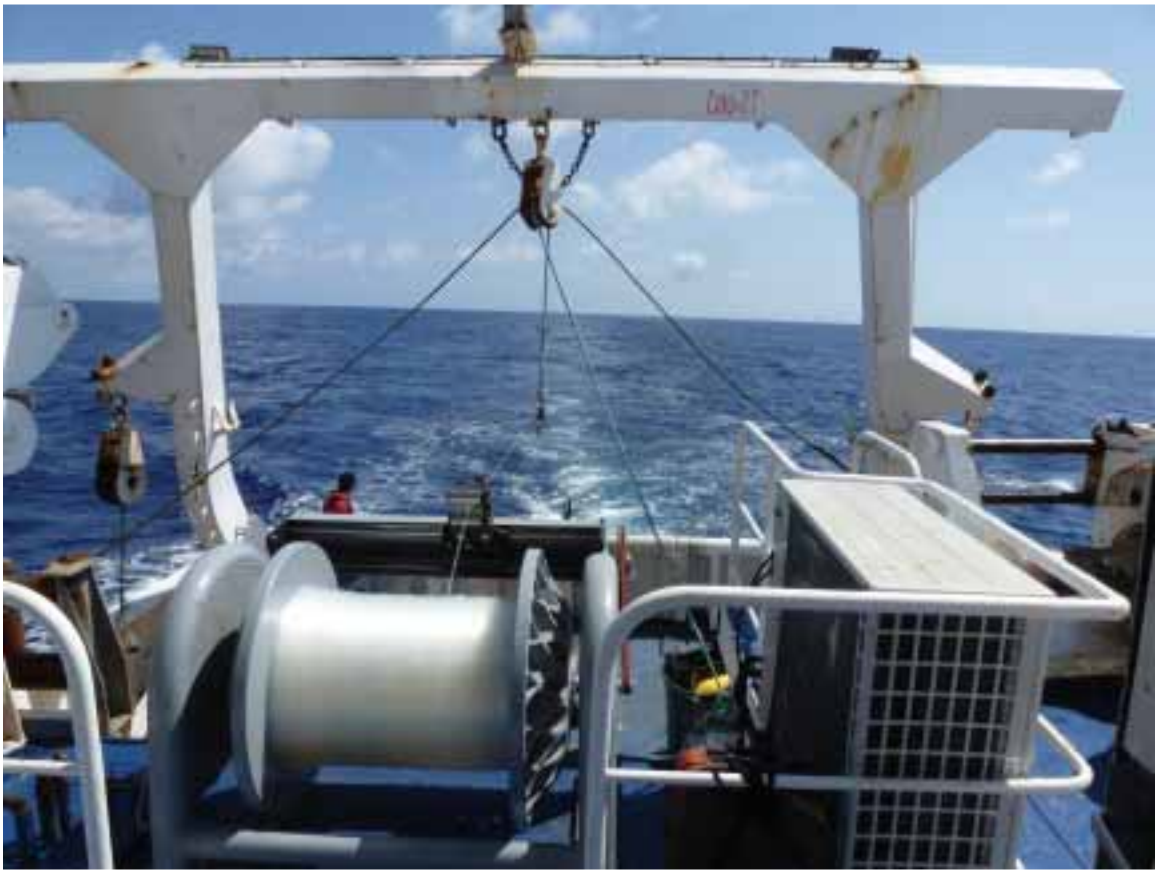
SWIOFP – ASCLME Project

Cruise report of swordfish tagging with miniPATs carried out on board the R/V "La Curieuse" from 9th to 22sd November 2012

Rapport de la campagne de pose de marques électroniques « miniPAT » sur des espadons réalisée à bord du N/O « La Curieuse » du 9 au 22 Novembre 2012



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IRD
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SWIOFP

CONTENTS

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1 Context : SWIOFP/ASCLME project

Up to now, only tuna and some large pelagic fishes associated with tuna fisheries in the South Western Indian Ocean are under monitoring and management by the regional fisheries management organization (RFMO): Indian Ocean Tuna Commission (IOTC). However numbers of other marine living resources in the region are exploited by commercial fisheries and need a regional approach in order to improve their respective management in the framework of the "ecosystem approach to fisheries". These resources are mostly spread across Exclusive Economic Zones (EEZs) of coastal countries representing shared stocks of crustaceans, demersal fishes and small pelagic fishes. Because of weaknesses in the financial support to marine fisheries research in the region compared to the diversity of stocks to manage, both scientists and managers have to share information and knowledge to improve marine resource management at local, regional and basin-wide scales. Moreover, the south-western part of the Indian Ocean is known to be frequently visited by endangered species of the marine megafauna (sea turtles, marine mammals) and the improvement of biological knowledge regarding these species is essential in order to reduce their interactions with fishing activities. The South West Indian Ocean Fishery Commission became operational relatively recently. The aim of this commission is to promote a regional management of local fisheries complementary to marine fisheries management activities of the Indian Ocean Tuna Commission. This management will be structured around the three classical operating functions which are essentials for fisheries management: the survey/monitoring, the control (decisions on the appropriate exploitation levels) and the strict monitoring of compliance. Activities regarding the survey/monitoring are classically carried out by the Scientific and Technical Committee (SCT). The major objectives for the first 5-year phase of the SWIOF Project (completed in June 2013) are to develop operational framework allowing the establishment of this SCT, whose principal components are:

☞ Integration of local fishery database at a regional level,

☞ Audit of knowledge in general (scientific, technical) of major exploited stocks (crustaceans, demersal stocks and small and large pelagic fishes) with the aim of respective estimations of exploitation levels,

☞ The collect of data for non-commercial species due to theirs interactions with commercial fisheries (for instance some marine mammals interacted with gillnet fisheries, sea turtles interacted with longline fishery and purse seine fishery on FAD).

Countries involved in the project are countries of the South West Indian Ocean having coast along the ocean: Kenya, Tanzania, Mozambique, Republic of South Africa, Seychelles, Comoros, Madagascar, Mauritius and France (Eparses Islands, Mayotte, Tromelin, Reunion). Somalia could be soon integrated in the project as observer country.

The global cost of these five years project is 28.3 $ US (18.9 millions €).

The French Fund for the Environment (FFEM = Fonds Français pour l'Environnement Mondial) participates in this project as co-financial support at a level of 800 K€ (1 millions of US $). Essentially, these funds are mobilized to support 3 components of the project :

- ❖ <u>Component 1 "Data and Information"</u>: Gap analysis and supply of an integrator database software named « StatBase »,

- Component 4 "Pelagic Fishes": Electronic tagging programme for swordfish and bigeye tuna, deployment of anchored Fish Aggregating Devices (FADs) allowing managing actions to increase the number of fishing activities for a given fishing pressure, improvement of fishing gear (develop methods to mitigate adverse impact of some fishing practices, application of the ecosystem based approach to fisheries),
- Component 5 "Non-commercial species": research studies of some marine mammals populations interacting with longline fisheries in the region, research programme of sea turtles movement behaviour to identify area and period for which the risk of accidental mortality due to fishing activities is high.

This project is carried out at a regional scale simultaneously with the ASCLME project (Agulhas Somalia Current Large Marine Ecosystem). One of the objectives of the ASCLME project is to develop indicators (simple or composite) to characterize ecosystems. As corollary of this objective, ASCLME investigates physical and biological characteristics of the ocean in this region and then the habitat of marine living resources studied in the SWIOF project. These two regional projects ASCLME and SWIOFP are parts of a Large Marine Ecosystem programme supported by the GEF. These two projects share some tools or operational framework such as oceanographic cruises.

2 Introduction: SWIOFP swordfish tagging cruise

Large pelagic fisheries are an important component of the development of local both small and medium scales fisheries for riparian countries of the South West Indian Ocean region. In this context these countries are developing or plan to develop large pelagic fisheries to harvest swordfish and tunas in their own EEZ. Fishing gear involved are longline for targeting swordfish and tunas, trolling line and handline to target tunas around anchored FADs.

For some countries and islands regions of the SW Indian Ocean, the swordfish represents an important fishing resource exploited by rather recent longline fisheries (La Reunion, Mauritius, Seychelles, Mayotte, South Africa). In the Indian Ocean, swordfish is caught mainly using drifting longlines (95%) and gillnets (5%) (Figure 1). Swordfish was mainly a bycatch of industrial longline fisheries before the early 1990's. Initially, swordfish catches increased gradually from 1950 to 1990 as bycatch while catches of targeted species (such as tropical and temperate tunas) were increasing. After 1990, swordfish catches increased rapidly to peaks of around 35,000 t in 1998 and 36,000 t in 2003 and 2004 and they drop to around 25,000 t. The catch increase since the early 1990's is attributed to a change in targeting from tunas to swordfish by part of the Taiwanese fleet, the development of longline fisheries in Australia, La Reunion, Seychelles and Mauritius targeting swordfish, and the arrival of longline fleets from the Atlantic Ocean (Portugal, Spain and other fleets operating under various flags) also targeting swordfish (IOTC, 2010 [1]).

1 - IOTC 2010 - Report of the Eighth Session of the IOTC Working Party on Billfish. IOTC-2010-WPB8, 57 pp. + App.

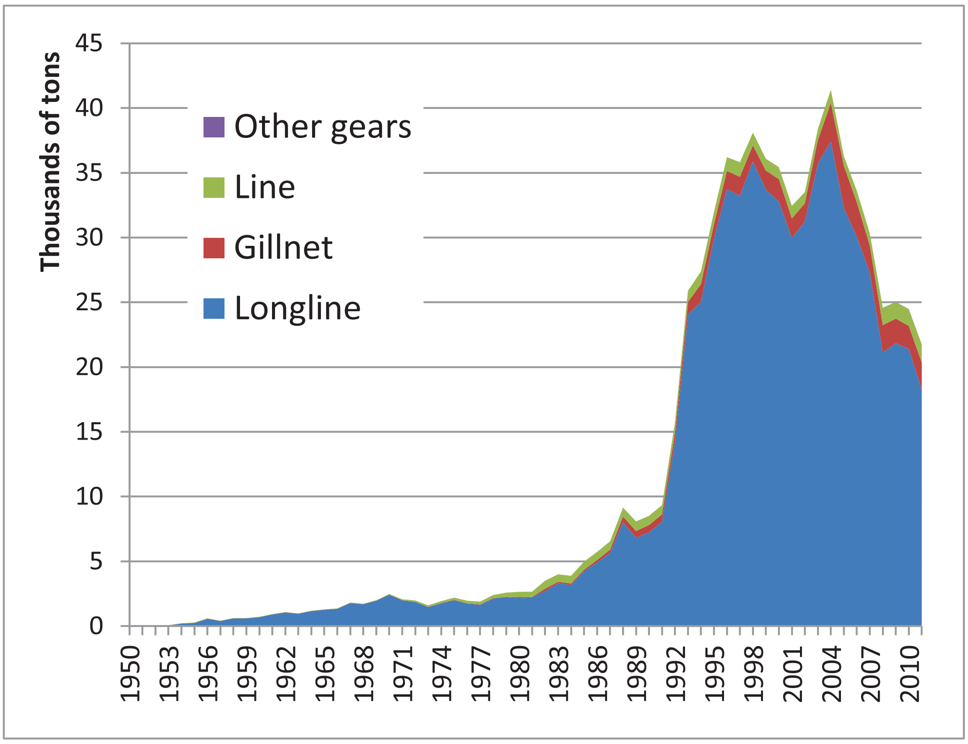


Figure 1 - Catches of swordfish in the Indian Ocean by gear type (1950-2011). (Source : IOTC database).

Swordfish catches are spatially heterogeneous at the Indian Ocean basin scale and the south west part is mainly exploited by longline fleets from Japan, China Taipei, Spain and South Africa which highly contribute to the total catches (Figure 2 [2]). Recent results of a genetic study undertaken at the basin scale tend to confirm that the IO swordfish belong to a single unique panmictic population or at least, to several breeding grounds with significant exchange of genetic material (Muths et al., 2012 [3]). Such spatial and temporal homogeneity on genetic structure of the large pelagic swordfish supports the hypothesis of a unique stock for stock management purposes. However, scientific experts of the IOTC consider the southwest region as a management unit of particular concern, because it seems to be more depleted than other regions in the Indian Ocean, and may have limited mixing with other regions.

One of the primary focus of Component 4 is to understand the distribution and movement of swordfish, and secondly, of bigeye and yellowfin tuna within the SWIO region. In 2011, SWIOFP provided 12 pop-up satellite archival tags (PSATs) for deployment on these species as well as hook monitors and time- depth recorders for deployment of an instrumented longline.

2 - IOTC, 2012. Report of the Tenth Session of the IOTC Working Party on Billfish. IOTC–2012–WPB10, 65 pp.

3 - D. Muths, S. Le Couls, H. Evano, P. Grewe and J. Bourjea, 2012 - Microsatellite and mtDNA markers were unable to reveal genetic population structure of swordfish (Xiphias gladius) in the Indian Ocean. IOTC–2012–WPB10–15.

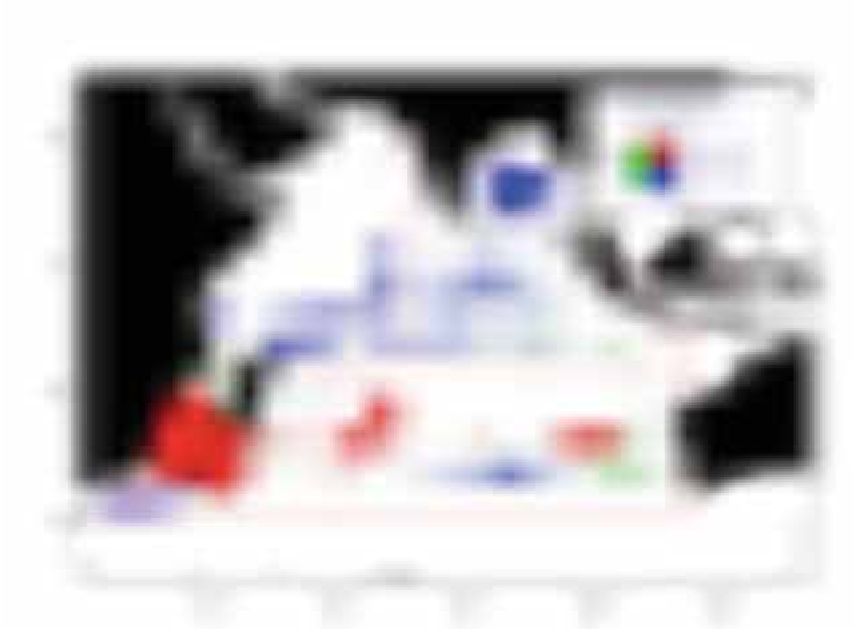


Figure 2 - Geographical distribution of swordfish catches (tonnes) as reported for majopr longline fleets tarteging swordfish (Japan:JPN), China Taipei:TWN and Spain:ESP). Red lines represent the boundaries of the areas used for the assessments of swordfish. (Source : IOTC, 2012).

In 2011, during a cruise on board the South Africa R/V "Ellen Khuzwayo", eleven longline-caught swordfishes were tagged with pop-up satellite (PSAT) tags off the coast of South Africa. Although post-release mortality rates were high, four fishes (36%) yielded datasets longer than two months. Fish condition on visual assessment or duration hooked on the longline was a poor indicator of release success. All four swordfish undertook periodical diel diving behaviour, but one fish dived mainly at night. Basking behaviour was not observed as all fishes stayed below 8 m of water depth. Bathymetry and moon phase did not seem to influence diving depth, but dives seemed to be restricted by a temperature ceiling of ca. 8°C. Maximum and minimum water temperature encountered by the fish generally matched those found in other studies around the world. Diving patterns did not change with average swimming speed, but longer presence in shallow waters during faster swimming was observed in one fish. All swordfishes remained within the region but one fish crossed the 20 deg longitude boundary twice indicating that there might be a link to the Southern Atlantic stock. Swordfish horizontal movement showed no clear link with bathymetry or chlorophyll-a, but two fishes seemed to trace the edge of meso-scale eddies (West et al., 2012 [4])

Based on positive results obtained in 2011, SWIOFP decided to purchase 10 additional miniPATS to be deployed on swordfish between La Réunion and the south east coast of Madagascar. The French R/V " La Curieuse" based in La Reunion and recently equipped with a monofilament longline was wet-leased under the FFEM funding, to undertake the tagging cruise (SWOPAT 2). For tagging purposes, our regional research team benefited from the participation in the cruise of Karen Evans, a renowned swordfish expert from CSIRO Hobart (Tasmania, Australia).

In addition to tagging activities, biological sampling was conducted. Indeed, large pelagic fish predators exhibit a wide range of foraging strategies. Understanding the mechanisms that drive prey selection is a challenge in foraging ecology. Here we hypothesized that metabolic costs should

4 - West W., S. Kerwath, C. da Silva, C.G. Wilke and F. Marsac, 2012 - Horizontal and vertical movements of swordfish tagged with pop-up satellite transmitters in the south-west Indian Ocean, off South Africa IOTC–2012–WPB10–16.

determine the prey composition (and quality) of the diet of fish predators. To test this hypothesis, we selected two predatory fish, albacore tuna (*Thunnus alalunga*) and swordfish (*Xiphias gladius*), and we collected 12 muscle samples (white and red) in three individuals of both species. We aimed at measuring a structural indicator of muscle performance by providing the mitochondrial density of muscle in each samples. Laboratory analyses (extraction, amplification and PCR) will allow us to estimate and compare ratios between mitochondrial DNA and total DNA quantities. This study is a first step towards a larger project that will allow the sampling of the main species of the top predator community in order to compare their foraging strategy.

A team member (physical oceanographer) took advantage of this cruise to increase the number of hydrological stations in the region and to collect samples dedicated to the measure of the chlorophyll along vertical profiles.

Then, the objectives of the SWOPAT2 cruise were of different nature:

- to address interactions between the pelagic longline and the marine megafauna by collecting capture data observed on a instrumented longline equipped with both temperature depth recorders and hook timers ,
- **to deploy miniPATs on swordfish**
- to collect 12 muscle samples (white and red) by individuals for three individuals of *Thunnus alalunga* and *Xiphias gladius*. for analyzing,
- to provide a description of the environment at the location of the LL operations complementary to the monitoring of SST (eg TMI microwave product, to avoid cloud coverage, Remote Sensing System/ NASA) and sea surface topography (altimetry, AVISO / CNES) by satellite observations.
- to improve the calibration of the CTD fluorometer against chlorophyll_a measurements on water samples collected at four different depth levels (chosen according to the CTD fluorometer profiles).

3 Time schedule of operations

This sixth cruise (including the Instrumented Longline Training Course, Bach et al., 2012) of the SWIOFP Component 4 dedicated to Large Pelagic Fishes started on Friday 9th of November from Le Port (La Reunion) at 5:00 pm.
The route of the cruise (date, time, latitude, longitude every 5 minutes) was obtained from the vessel monitoring system (VMS) and data stored in the SEALOR [5] database.

The initial route to rejoin the first LL fishing station was decided from the last SLA map available on the departure day. We headed for an important anticyclonic structure detected around 26°S and 51°E on the altimetry (SLA) map.

3.1 SWOPAT2 cruise journal

9th of November
5:30 p.m : Departure of the SWOPAT2 cruise. Bearing 220°

10th of November
Shipping route all the day. Rough sea. Wind 25 knots with peaks at 30 knots

11th of November
Shipping route until 4:30 p.m. We decided to cancel the hydrological station (CTD and vertical sea water sampling) due to rough sea conditions.
Longline set 1 started at 9:15 p.m. Due to branchline entanglements in hook boxes only 109 hooks equipped with hook timers could be deployed at irregular intervals along the mainline. End of the setting at 11:45 p.m. Return to the location of the first GPS buoy set.

12th of November
Hauling started at 3:00 a.m. Due to strong currents, 90% of branchlines were entangled with the mainline. This contributes to increase the hauling time which ended at 9:30 a.m. As decided the day before the hydrological station was canceled due to rough sea conditions.
After the set we took the decision to ship out the depression area by going northern to the current position to rejoin 24°S – 50°E.
Route all the day and the night.

13th of November

Arrival at the longline n°2 position at 14:00.

16:30 – 18:15 / Hydrological station n°1 (CTD profile & chlorophyll profile – filtration of sea water samples)

21:10 – 23:00 / Setting Longline n°2 (55 baskets; 5 HPB (Hook per basket) ; 212 hooks; 8 TDRs (Temperature Depth Recorder), mainline length = 20.46 km)

14th of November

2:55 – 7:52 / Hauling longline n°2 (10 hooking contacts, 8 captures).
8:30 – Launching XBTn°1

5 - Bach P., N. Rabearisoa, T. Filippi & S. Hubas, 2008 - The first year of **SEALOR** : Database of **SEA**-going observer surveys monitoring the local pelagic **LO**ngline fishery based in La **R**eunion. IOTC/WPEB/WP13, 26 p

9:30 - Route in a west direction to reach a fishing ground less windy. Arrival at the longline n° 3 position at 15:30.

16:15 – 18:15 / Hydrological station n° 2 (CTD profile & chlorophyll profile – filtration of sea water samples)

21:15 – 23:10 / Setting Longline n° 3 (48 baskets; 6 HPB; 278 hooks; 8 TDRs, mainline length ~18 km)

15th of November

2:30 – 6:15 / Hauling longline n°3 (15 hooking contacts, 3 captures).
MiniPATs n° 11P0500 deployed on a swordfish caught at 3:40.

6:45 – Launching XBTn°2

7:30 – Route on the west along the sea surface temperature front close to the border north of a anticyclonic eddy.

17:00 – 18:30 / Hydrological station n°3 (CTD profile & chlorophyll profile – filtration of sea water samples)

21:30 – 23:10 / Setting Longline n°4 (54 baskets; 5 HPB; 264 hooks; 8 TDRs, mainline length ~18 km)

16th of November

3:10 – 7:45 / Hauling longline n°4 (15 hooking contacts, 3 captures).

8:30 – 10:30 / Route towards the northeast along the sea surface temperature gradient along the northern edge of an anticyclonic eddy.

17:00 – 18:30 / Hydrological station n°4 (CTD profile & chlorophyll profile – filtration of sea water samples)

21:05 – 22:45 / Setting Longline n°5 (50 baskets; 5 HPB; 249 hooks; 7 TDRs, mainline length ~ 19 km)

17th of November

3:15 – 7:44 / Hauling longline n°5 (16 hooking contacts, 8 captures).

8:30 – XBT profile n°3

9:00 – 15:30 / Route towards the east along the sea surface temperature gradient (same as in previous day) along the latitude 24°S.

17:00 – 18:30 / Hydrological station n°5 (CTD profile & chlorophyll profile – filtration of sea water samples)

20:28 – 22:10 / Setting Longline n°6 (50 baskets; 5 HPB; 250 hooks; 8 TDRs, mainline length ~ 19 km)

<u>18th of November</u>

1:37 – 5:39 / Hauling longline n°6 (7 hooking contacts, 1 capture).

6:00 – XBT profile n°4

6:30 – 15:30 / Route towards the east along the sea surface temperature front close to the border north of a anticyclonic eddy along the latitude 24°S.

16:30 – 17:45 / Hydrological station n°6 (CTD profile & chlorophyll profile – filtration of sea water samples)

20:07 – 21:52 / Setting Longline n°7 (47 baskets; 6 HPB; 274 hooks; 8 TDRs, mainline length ~ 18 km)

<u>19th of November</u>

1:38 – 6:00 / Hauling longline n°7 (13 hooking contacts, 6 captures).
<u>MiniPATs n° 11P0492 deployed on a swordfish caught at 2:29 a.m.</u>

6:30 – XBT profile n°5

7:00 – 15:30 / Route towards the east along the sea surface temperature front close to the border north of an anticyclonic eddy along the latitude 24°S.

16:45 – 17:45 / Hydrological station n°7 (CTD profile & chlorophyll profile – filtration of sea water samples)
20:07 – 21:53 / Setting Longline n°8 (47 baskets; 6 HPB; 280 hooks; 8 TDRs, mainline length ~ 17 km)

<u>20th of November</u>

1:33 – 5:20 / Hauling longline n°8 (8 hooking contacts, 5 captures).
<u>MiniPATs n° 11P0498 deployed on a swordfish caught at 3:49 a.m.</u>

6:00 – XBT profile n°7

6:30 – 14:00 / Route towards on the north east for the last set of the cruise.

16:15 – 17:45 / Hydrological station n°8 (CTD profile & chlorophyll profile – filtration of sea water samples)
20:06 – 21:53 / Setting Longline n°9 (47 baskets; 6 HPB; 288 hooks; 8 TDRs, mainline length ~ 17 km)

<u>21st of November</u>

1:37 – 4:51 / Hauling longline n°8 (8 hooking contacts, 5 captures).

13:20 – 13:55 / Hydrological station n°9 (CTD profile)

20:00 – Arrival at le Port – End of the cruise

3.2 Synthetic representation of operations

A summarized chronology of operations at sea (hydrology, instrumented longline fishing=ILL) carried out during this cruise is displayed on Table 1 and Figure 3.

Day	F	S	S	M	T	W	T	F	S	S	M	T	W
Hour	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*
0													
1													
2										LL6	LL7	LL8	LL9
3													
4							***LL3***						
5				***LL1***		***LL2***		LL4	LL5				
6													
7													
8													
9													
10													
11													
12													
13													***HS 9***
14													
15													
16					***HS 1***	***HS 2***	***HS 3***					***HS 8***	
17								***HS 4***	***HS 5***	***HS 6***	***HS 7***		
18													
19													
20									***LL6***	***LL7***	***LL8***	***LL9***	
21					***LL2***	***LL3***	***LL4***	***LL5***					
22			**LL1**										
23													

Shipping or drifting period	Longline setting
Hydrological station (HS)	Soak time - Fishing time
	Longline hauling

Table 1 – Sequence of operations undertaken during the cruise SWOPAT2.

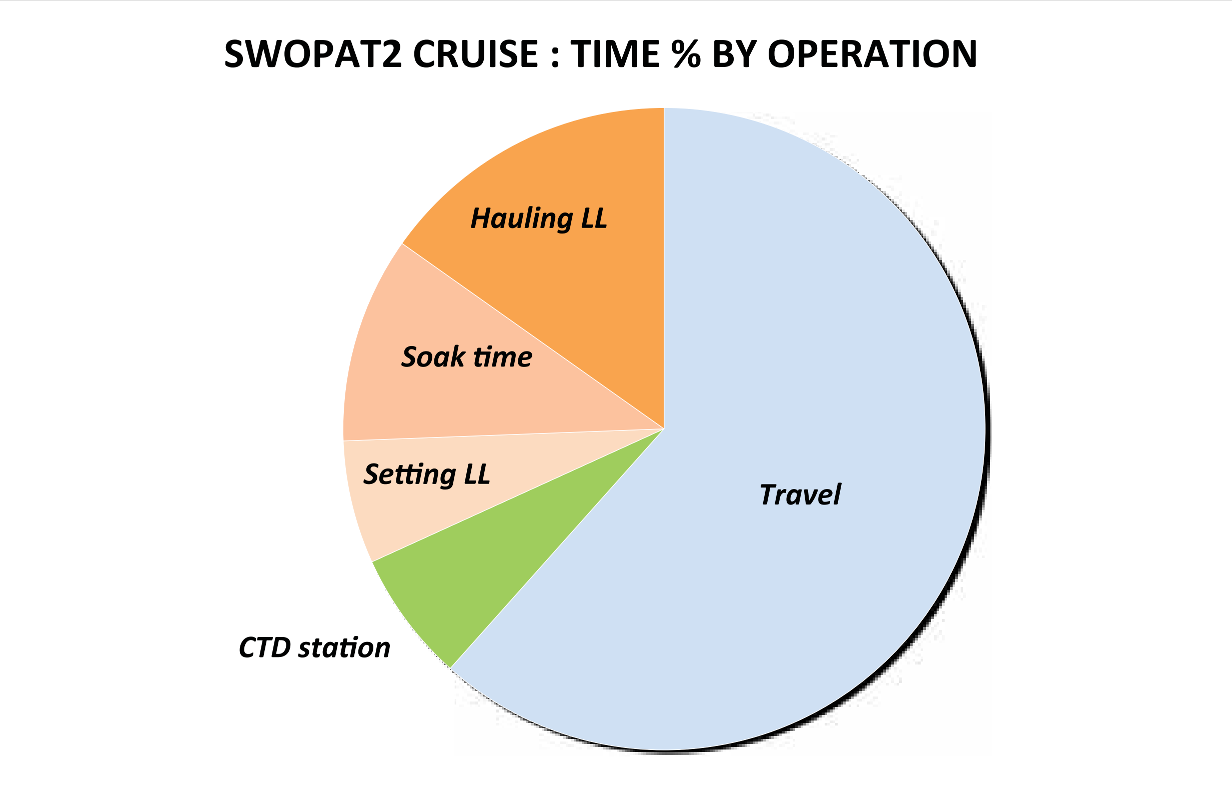


Figure 3 : Percentage of time dedicated for each operation during the cruise SWOPAT2.

4 Material & Methods

4.1 Oceanographic observations

In-situ measurements (CTD, XBT) were performed at least at each LL sites to describe the habitat sampled by the gear. The design of the Sippican's system is displayed on the Figure 4. XBT probes were launched while the ship was cruising. The probes used were the T-6 model from SIPPICAN; with a nominal depth range of 0-460 m. Profiles were recorded and displayed on board by the WinMK21 software.

For profiles at stations, we used a CTD probe (Sea Bird SBE 19, Figure 5) equipped with an oxygen sensor (SBE 43), a fluorometer (WetStar/WetLab), a PAR sensor (Biospherical, LiCor) and a backscatter (OBS) sensor (D&A). This CTD probe has been used by IRD Réunion for multi-purpose environmental cruises, in particular a SWIOFP LL cruise in the Mozambique Channel in 2010. CTD casts were down to 350m (maximum length of the wire available). Information of CTD and XBT profiles done during the cruise are presented in Tables 2 and 3.

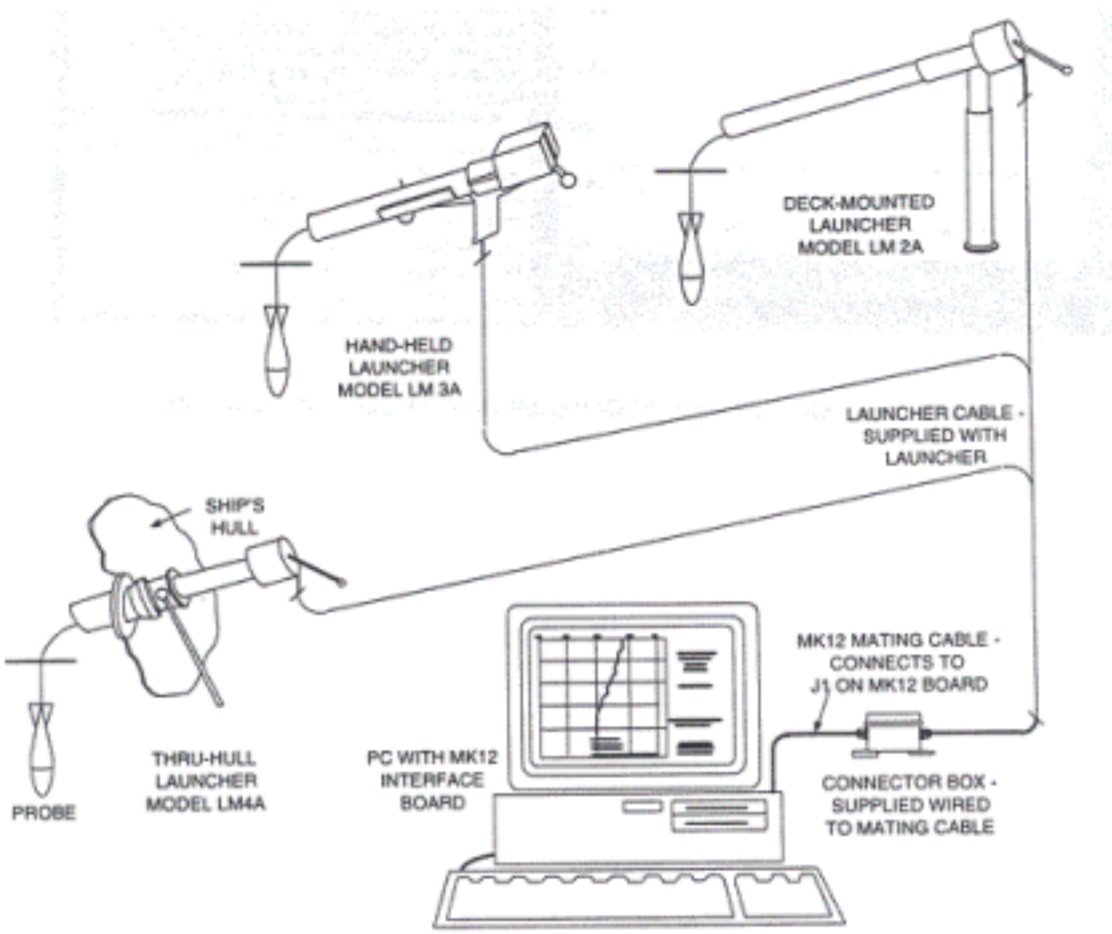


Figure 4 – Design of the Sippican's XBT system used to carry out temperature – depth profiles (Source : http://www.sippican.com).

The CTD probe (Sea Bird SBE 19) was equipped with an oxygen sensor (SBE 43), a fluorometer (WetStar/WetLab), a PAR sensor (Biospherical, LiCor) and a backscatterance (OBS) sensor (D&A), (Figure 5). This CTD probe has been used by IRD Réunion for multi-purpose environmental cruises, in particular a SWIOFP LL cruise in the Mozambique Channel in 2008[6] and 2010[7]. CTD casts were down to 350m (maximum length of the wire available).

Finally, satellite SST (TMI microwave, not affected by could cover) and alitimetry products (AVISO/CNES) were downloaded every day on board to describe the sea surface environment at the location of the LL sets. Information of CTD and XBT profiles realized during the cruise are presented in Tables 2 and 3.

6 - Bach P., E. Romanov, T. Filippi, 2009. SWIOFP/ASCLME Project : Mesoscale eddies and large pelagic fish in the Mozambic Channel – Report of monitored longline fishing experiments carried out on board the fishing vessel "Manohal" from 27th of November to 18th of December 2008. IRD/SWIOFP/FFEM Report, 74 p.

7 - Bach P., T. Fillipi, G. Berke & A. Sharp, 2013. SWIOFP/ASCLME Project: Mesoscale eddies and large pelagic fish in the Mozambique Channel – Report of monitored longline fishing experiments carried out on board the fishing vessel "Brahma" from 1st to 20 of April 2010. IRD/SWIOFP/FFEM Report, 32 p.

Figure 5 - CTD launching during the SWOPAT2 cruise.

Table 2 – Information on the CTD casts carried out during the SWOPAT2 cruise.

LL n°	station	CTD cast	Date	Time	Lat (° S)	Long (°E)	Depth max (m)	Cable set (m)
LL2	SWOPAT2_station 1	CTD1	13/11/12	16:20	24	50	340	340
		CTD2	13/11/12	17:09			231	220
LL3	SWOPAT2_station 2	CTD3	14/11/12	17:15	24.117	50.383	301	355
		CTD4	14/11/12	18:03			227	236
LL4	SWOPAT2_station 3	CTD5	15/11/12	16:51	24	50	326	351
		CTD6	15/11/12	17:58			145	161
LL5	SWOPAT2_station 4	CTD7	16/11/12	16:57	23.983	50.983	294	345
		CTD8	16/11/12	17:36			205	235
LL6	SWOPAT2_station 5	CTD9	17/11/12	16:40	23.967	51.7	170	276
		CTD10	17/11/12	17:40			169	292
LL7	SWOPAT2_station 6	CTD11	18/11/12	16:19	24	53.017	360	360
		CTD12	18/11/12	16:52			214	200
LL8	SWOPAT2_station 7	CTD13	19/11/12	16:33	23.783	54.033	352	355
		CTD14	19/11/12	17:19			227	222
LL9	SWOPAT2_station 8	CTD15	20/11/12	16:49	23.017	54.517	331	350
		CTD16	20/11/12	17:33			241	232
No	SWOPAT2_station 9	CTD17	21/11/12	13:20	21.4	55	316	351
		CTD18	21/11/12	13:55			191	222

(grey shading) Bad functioning of the pulley counter

Table 3 – Information on the XBT carried out during the SWOPAT2 cruise.

File	Date	Time	Lat (° S)
SWOPAT2_XBT1	14/11/12	08:15	23.971
SWOPAT2_XBT2	15/11/12	06:45	23.955
No			
SWOPAT2_XBT3	17/11/12	08:15	23.801
SWOPAT2_XBT4	18/11/12	05:45	23.907
SWOPAT2_XBT5	19/11/12	06:15	23.828
SWOPAT2_XBT6	20/11/12	05:35	23.521
No			
No			

4.2 Fishing experiments using instrumented longline

The R/V "La Curieuse" was equipped with a nylon monofilament mainline stored on a spool manufactured by Lindgren Pitman™. The line capacity of the spool is ~ 20 miles for a line diameter of ~ 3.4 mm (Figure 6). This spool is also used for the hauling of the mainline. The longline is a string of hooks attached with a snap to the mainline, which is maintained at the surface of the ocean by buoys also attached to the mainline at regular intervals. A transmitter buoy is fastened at each end of the mainline (Figure 7). During our fishing experiments, the mainline was attached to about 5.4 m polypropylene float lines with floats regularly deployed at the surface. Monofilament branch lines were 12-m long and snapped on at a constant time interval for a given set. Each branchline is equipped with circle hook. Circle hooks were used because their lower impact on potential capture of non-target species (mainly sea turtles) and their facilitation to hook the fish on the jaw hooking allowing a better post release survival. Squid (*Ilex* spp) was used as bait.

For each set, all baskets (the part of the longline between two successive floats) were equipped with time depth recorders. TDRs were programmed to record fishing depth once per minute. The TDRs were placed at the mid-point on the basket mainline which corresponds to its maximum depth (Figure 7). For one experiment the longline behaviour was studied with several TDRs close to each hook of a given basket and with GPS buoys to measure simultaneously the variation of the sag ratio.

Each branch line was equipped with a hook timer. Hook timers indicate elapsed time in minutes between the hooking contact (triggered hook timer with or without capture) of fish on the line and landing on deck, from which the time of the hooking contact is calculated. Hooking depths can be inferred from hook depths at hooking times estimated by a longline shape model.

Figure 6 – Position of the spool of the nylon mainline on the R/V "La Curieuse".

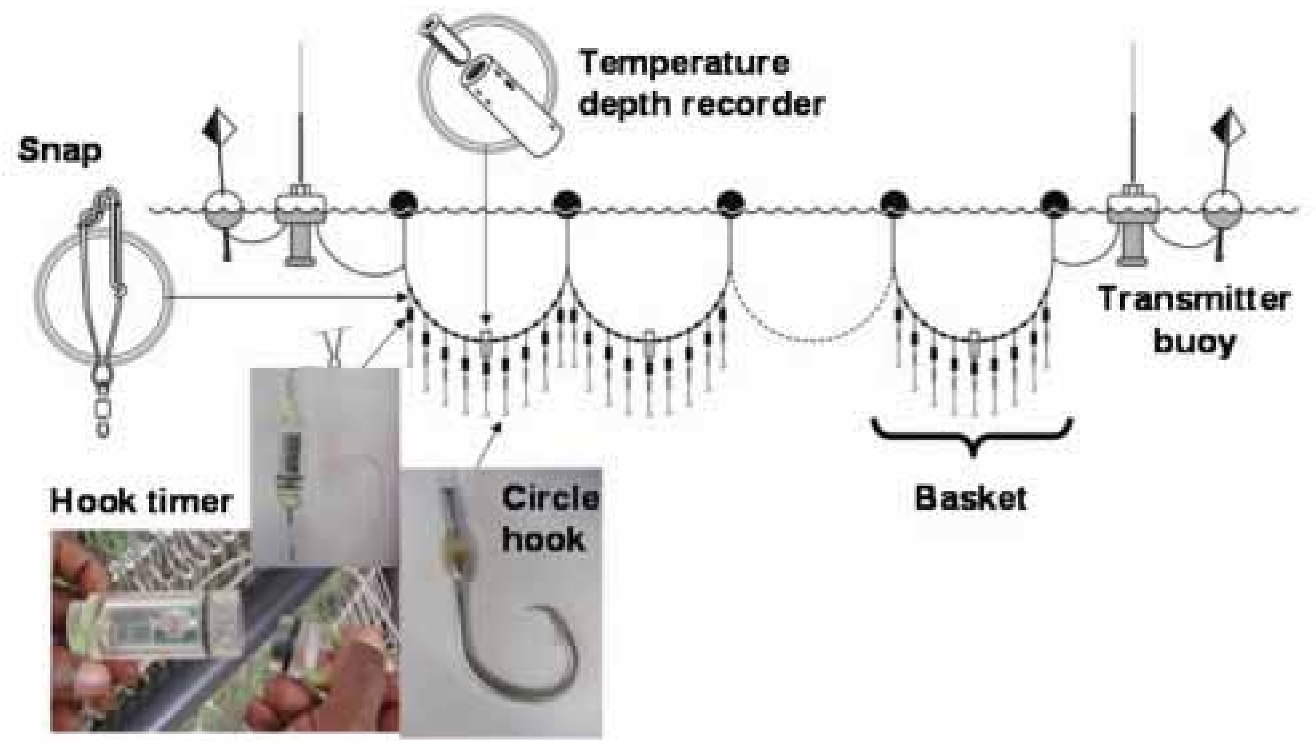
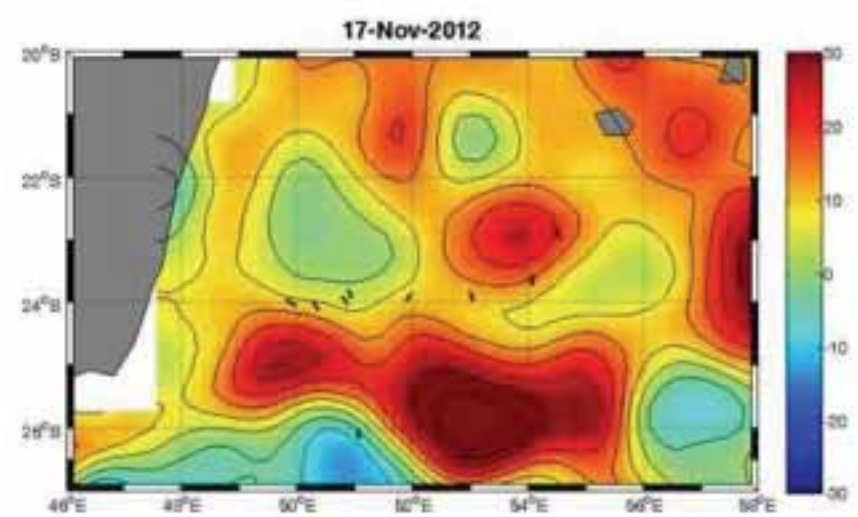


Figure 7 - The instrumented longline deployed during the SWOPAT2 cruise.



Nine fishing experiments were carried out during the cruise. Time and geographical coordinates of both setting and hauling operations are presented on Figure 8 and Table 4.

Figure 8 – Locations of the fishing experiments carried out during the SWOPAT2 cruise.

Table 4 – Date, time and geographical positions of the setting and the hauling of instrumented longline (ILL) sets for the SWIOFP Longline Survey and Tagging cruise SWOPAT2.

			START			END		
Date	Set n°	Operation	Local time	Lat (°S)	Long (°E)	Local Time	Lat (°S)	Long (°E)
11/11/12	1	Setting	21:08	-26.012	51.07	23:49	-26.18	51.067
12/11/12	1	Hauling	02:30	-26.167	51.2	09:30	-26.367	51.2
13/11/12	2	Setting	21:08	-26.05	49.97	23:00	-23.95	49.8
14/11/12	2	Hauling	02:51	-24.07	49.9	07:52	-24.03	49.92
14/11/12	3	Setting	21:17	-24.12	50.37	23:05	-23.97	50.27
15/11/12	3	Hauling	02:32	-24.05	50.33	06:15	-23.95	50.23
15/11/12	4	Setting	21:12	-24.03	50.88	22:57	-23.9	50.78
16/11/12	4	Hauling	03:08	-24.05	50.85	07:45	-23.92	50.78
16/11/12	5	Setting	21:06	-23.93	50.95	22:41	-23.78	50.88
17/11/12	5	Hauling	03:13	-23.93	50.93	07:41	-23.8	50.88
17/11/12	6	Setting	20:28	-23.98	51.87	22:10	-23.86	51.99
18/11/12	6	Hauling	01:50	-24	51.87	05:39	-23.9	51.98
18/11/12	7	Setting	20:07	-23.98	53.05	21:52	-23.82	53
19/11/12	7	Hauling	01:32	-23.96	53.13	06:00	-23.82	53.14
19/11/12	8	Setting	20:07	-23.73	54.07	21:53	-23.55	54.1
20/11/12	8	Hauling	01:34	-23.68	54.15	05:19	-23.52	54.22
20/11/12	9	Setting	20:06	-22.97	54.55	21:53	-22.8	54.5
21/12/12	9	Hauling	01:37	-22.91	54.55	04:51	-22.77	54.52

Information on the setting strategy used for the deployment of the pelagic longline for the different setting operations are detailed in the Table 5. Five to six hooks per baskets were attached with a time between hooks (TBHs) of 20 s. The nine fishing operations operated totalized 461 baskets. 63 TDR were deployed to characterize the depth of the pelagic habitat sampled by the gear. A total of 2192 circle hooks were deployed and 2189 of them were equipped with hook timers.

Table 5 – Details on the setting strategy undertaken for the pelagic longline deployment

Set n°	Setting date	Time start setting	Boat speed (knts)	HPB	TBH (s)	DBF (m)	N. sections	N. Baskets	LFL (m)	N. TDRs	N. Circle	N. HTs
1 (*)	11/11/12	21:15	5.3	5	20	327	2	60	5.4	0	109	109
2 (*)	13/11/12	21:10	5.3	5	20	327	2	55	5.4	8	212	212
3	14/11/12	21:18	5.3	6	20	382	2	48	5.4	8	264	264
4	15/11/12	21:12	5.5	5	20	340	2	54	5.4	8	272	272
5	16/11/12	21:05	5.5	5	20	340	2	50	5.4	7	249	249
6	17/11/12	20:28	5.5	5	20	340	2	52	5.4	8	244	244
7	18/11/12	20:09	5.5	5	20	340	2	47	5.4	8	274	274
8	19/11/12	20:06	5.1	6	20	367	2	47	5.4	8	280	280
9	20/11/12	20:06	5.1	6	20	367	2	48	5.4	8	288	285
										63	2192	2189

(*) Due to branchline entanglements in hook boxes the number of HPB was ranged between 1 and 5

TDR = Temperature Depth Recorder HT = Hook Timer

4.3 Deployment of electronic tags on swordfish

We performed short fishing operations (maximum of 5 hours) in order to optimize the chance of catching swordfish alive. Hauling started early in the night between 1 :30 a.m. and 3 :13 a.m. Two criteria were used to decide whether a live swordfish could be tagged: i) the time elapsed between the time of capture and the hauling time (given by the hook timer); ii) the way the fish was hooked (only fish hooked on the jaw can be tagged). The swordfish was led alongside the vessel and the MK 10 PSAT (Wildlife Computers) tag was placed on the fish by means of a pole (Evans et al., 2012 [8]) to which the tag was temporarily affixed with elastic bands (Figure 9). The relative high freeboard of the vessel (~ 3 m) necessitated the use of an extended (~ 5 m) carbon-fibre jab-pole (Figure 10). The tag was fitted with a custom made stainless steel Floy-type anchor (Evans et al. 2012) attached by a stainless steel leader with a swivel midway between tag and anchor. The anchor was inserted into the dorsal musculature of the fish in a position just below the dorsal fin. Time of release and tagging positions were recorded using the vessel's onboard GPS system and the immediate post-release behaviour of the swordfish after tagging was noted. All released fishes were monitored as long as they remained visible from the vessel. Tags were set to pop up to the surface and transmit summarized depth, temperature and light sensor data after 90 to 360 days (depending on tags) and to summarize depth and temperature data at intervals ranging from 25m to >900m and 2.5°C to >32.5°C, respectively. Tags were also programmed to corrode the pin when a tag would record a constant depth for more than 24 hours (for instance, for a fish dead on a shelf). A mechanical release device (RD1800, Wildlife Computers) was used to cut the tether when animal reached a depth exceeding 1800 m, which occurs when the fish is dying. Such systems generate what is called a "premature release" as it takes place before the planned pop-off date.

Figure 9 – Design of the attachment of the tag on the pole.

Figure 10 – Pole used to deploy the tag from the vessel deck.

8 - Evans, K., Kolody, D., Abascal, F., Holdsworth, J., Maru, P. and Sippel, T. (2012) Spatial Dynamics of swordfish in the South Pacific Ocean Inferred from Tagging Data. Eighth regular session of the WCPFC. Busan, Republic of Korea, 7-15 December 2011. WCPFC-SC8-2012/ SA-IP-05.

Time intervals were set at 4 measurements (180 day tags) recording data at 1:00, 7:00, 13:00 and 19:00 or 6 measurements (90 day tags) recording data at 2:00, 6:00, 10:00, 14:00, 18:00 and 22:00. The tags recorded the depth (m) and temperature (°C) in bins. After pop-off, data recorded in the tag's chip were transmitted through the Argos satellite link and processed using the Wildlife Computer software (Wildlife Computers, Redmond, WA, USA). Transmitted data were archived in the Argos centre server, and was then emailed to us.

4.4 Biological observations

All biological sampling were performed during hauling of the longline. All fish caught were identified and measured with a calliper (for straight length measurements) to the lowest cm. For species on interest such as tunas, billfishes and sharks, the sex and the sexual maturity stage were identified Samples of muscle were collected for genetic and isotopes purposes for tunas and billfishes as well as otoliths for ageing studies. In order to test if the metabolic costs of living should determine the prey composition (and quality) of the diet of fish predators, several samples of dorsal and ventral white muscles and of the red muscle (Figure 11) were taken and stored in the alcohol 70°.

Figure 11 – Sampling of dorsal and ventral white muscles and of the red muscle on a albacore tuna.

5 Preliminary results

5.1 Hydrological context

Sea Surface Height and Sea Surface Temperature : The distribution of the Sea Surface Height (SSH) anomaly at the time of the cruise showed the presence of a well-developed anticyclonic structure (AC) centred around 26°S / 53°E (Fig 12 a). North of this structure, the eddy field is moderately developed. Most of the fishing operations and CTD stations have been achieved at the northern boundary of the AC (Fig 12 b). Relatively strong currents have been experienced there. SST distribution (Fig 13) shows slight gradient in the area prospected.

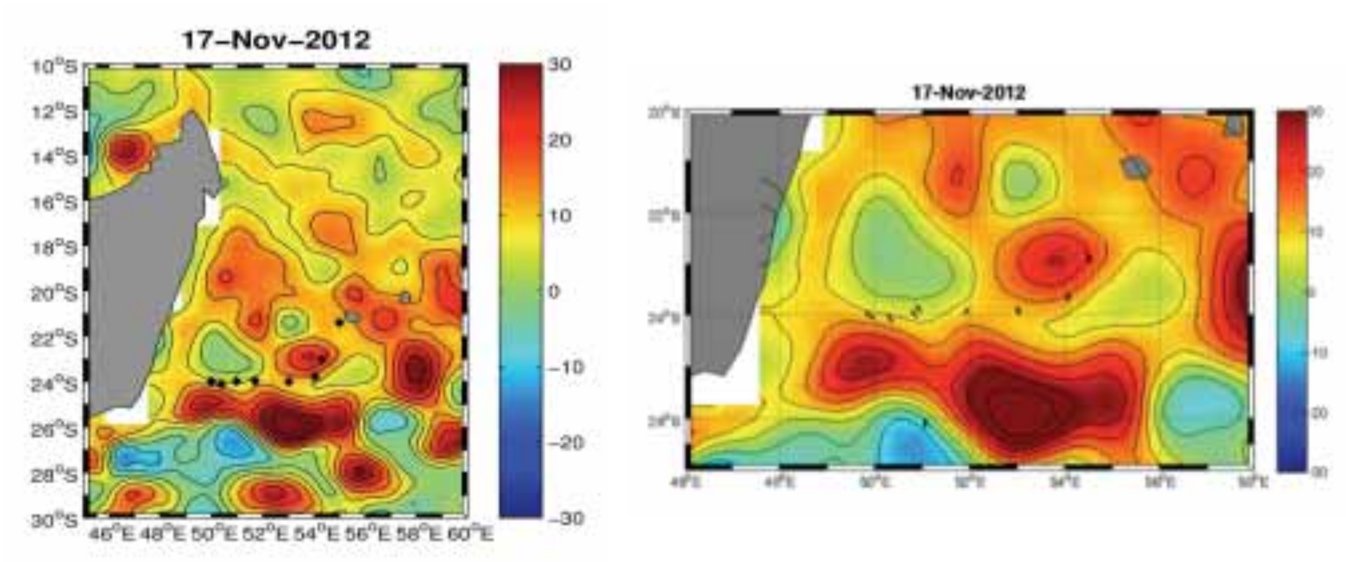


Figure 12 - (a - left) The eddy field east of Madagascar at the time of the cruise. Dots represent the location of the CTD stations; (b - right) positions of the LL sets relative to the eddy field.

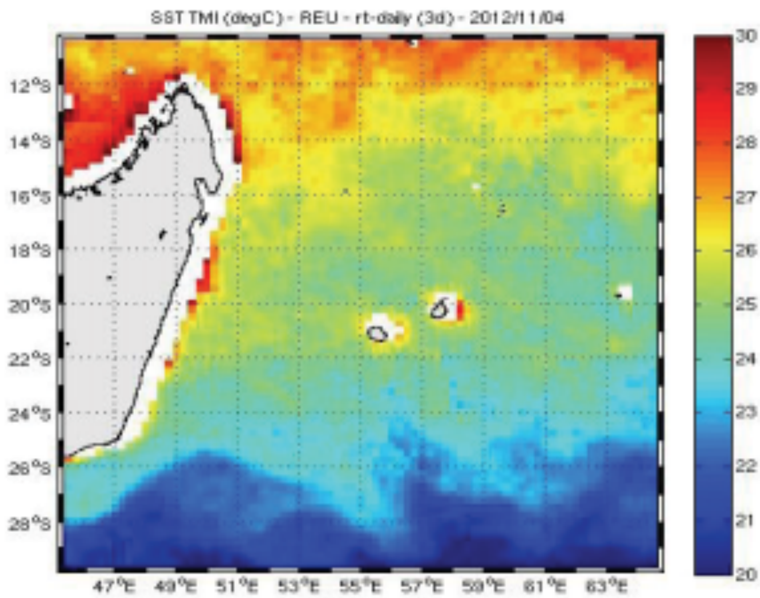


Figure 13 – SST distribution at the east of Madagascar at the time of the cruise.

Vertical structure of the environment : Nine CTD stations were performed and 6 XBT were launched (Tables 2 & 3) during the cruise, at the location of the LL operations. Vertical profiles of temperature (°C), salinity, dissolved oxygen (mg l^{-1}) and fluorescence (uncalibrated units) at the third station are shown (Figure 14) as an example. Temperature decrease was smooth all over the area, with a mean gradient of about 10°C over 300m (see temperature vertical section along the full transect on Figure 15 a). Most of the stations were characterised by a sharp Deep Chlorophyll Maximum (DCM) around 100m (Figures 14 & 15 b). In order to calibrate the CTD fluorescence sensor, this DCM was focussed for the collection of seawater samples.

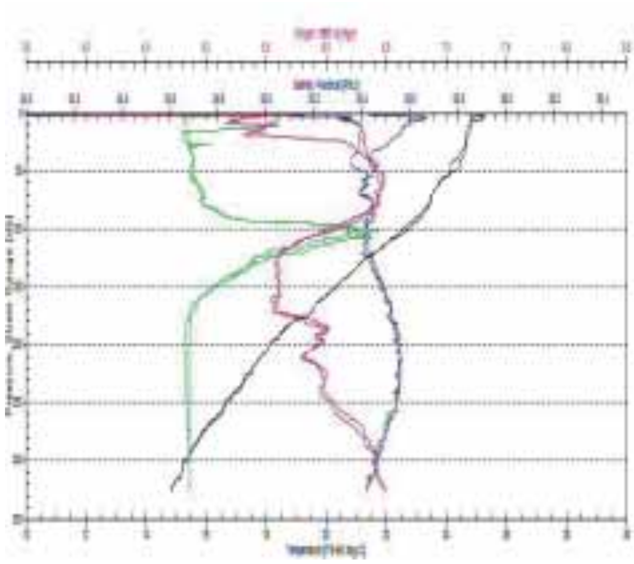


Figure 14 - Vertical profiles of temperature (°C), salinity, oxygen (mg l^{-1}) and fluorescence (uncalibrated) at the 3rd longline fishing operation..

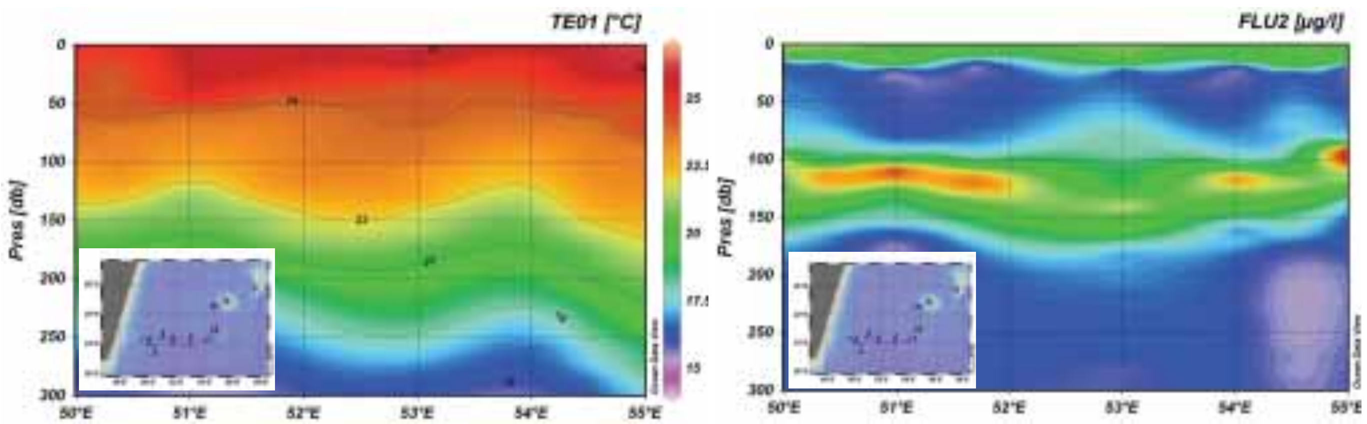


Figure 15 – (a) : Vertical distribution of temperature (°C, on the left). (b) Fluorescence (uncalibreted unit, on the right) along the full transect. The section is plotted against the longitude.

Fluorometer calibration : Due to the water sampling protocol (a first CTD cast to draw the fluorescence profile and a second one to take the samples) and to the narrow layer containing the DCM, it was not always possible to sample at the exact depth of the DCM. However, the full data set collected along the cruise allowed us to get an acceptable range of fluorescence (and chlorophyll_a) values to determine a calibration equation of the CTD sensor. The precise determination of the sampling depth was not always simple (due to the sampling protocol). However, the use of TDR (Temperature Depth Recorder) probes attached to the sampling bottles greatly improved this determination.

The relationship between CTD fluorescence and the chlorophyll_a concentration measured by fluorimetry is presented on the Figure 16. From this first analysis, a preliminary calibration equation is estimated :

$$[chlorophyll\_a\ (\mu g\ l^{-1})] = 0.095 * CTD\_fluoresence + 0.0.27$$

This equation needs to be confirmed and adjusted by a closest analysis of the *in-situ* data (due to the uncertainties mentioned above).

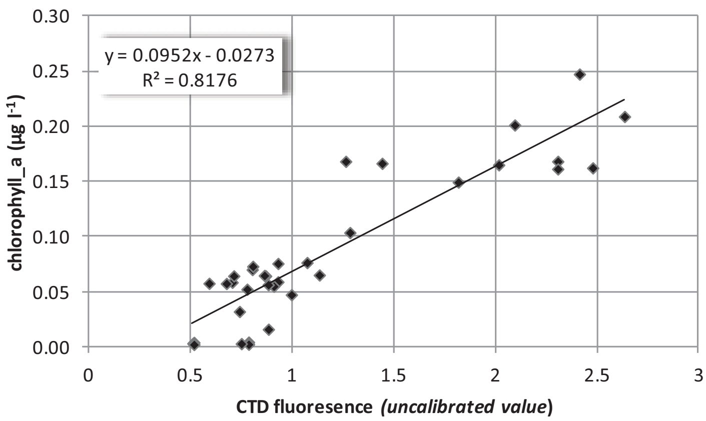


Figure 16 - Relationship between the fluorescence measured by the CTD probe and chlorophyll_a (µg l^{-1}) determined by fluorometry on seawater samples caught at different depths (raw data analysis).

5.2 Longline fishing experiments

Eight TDRs were deployed out of the 9 longline fishing operations carried out. The TDRs were attached at the deepest point of the mainline for the instrumented basket. TDRs were distributed randomly along the longline.

Depth data recorded by TDR for each basket by longline are displayed on the Figure 17. The maximum fishing value observed was 130 m but in general these values for each basket were about 80 m. On average the mean value of depth series by longline ranged from 30 m to 70 m.

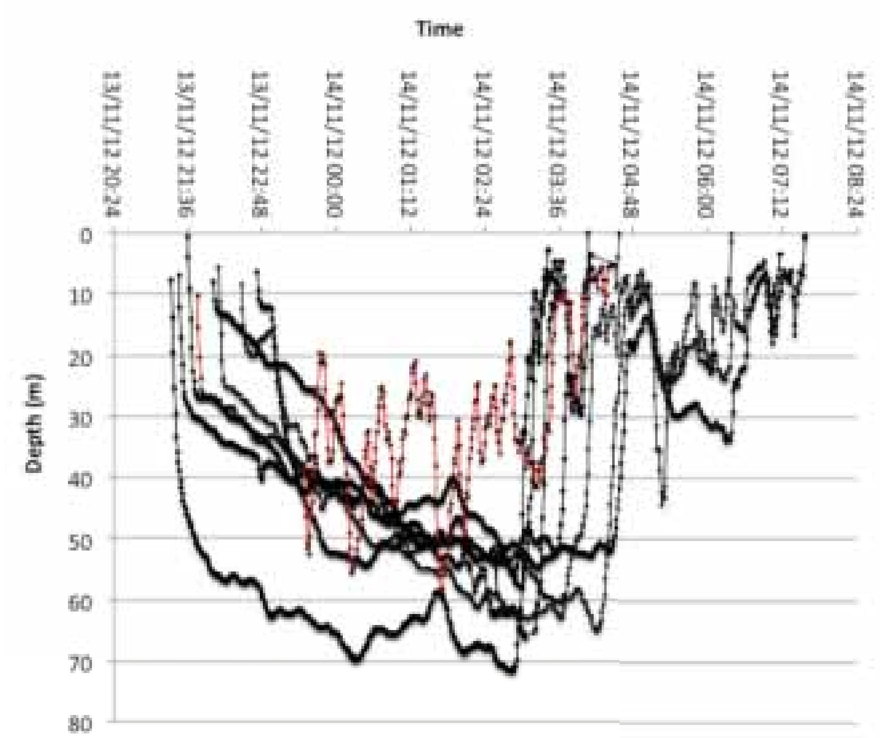
For the 2195 hooks deployed, 87 hooking contacts (HC = triggered hook timer with or without capture) were observed representing a total hooking contact rate (number of HC for 100 hooks) of 4%. Among these hooking contacts, 44 led to a capture (hooking success) resulting in a 2% hooking success rate and a 50% hooking efficiency (ratio between hooking success and hooking contact) (Table 6). At the scale of the longline fishing operation, hooking contact and hooking success were linearly related (R^2 = 33%, $P<0.01$) and the value of the slope of the linear regression line that corresponds to the average efficiency at the longline scale is 33% (Figure 18).

Eleven species were caught during the 9 fishing experiments. The two dominant species in the catch were the blue shark and the swordfish with 11 and 10 individuals, respectively (Table 7).

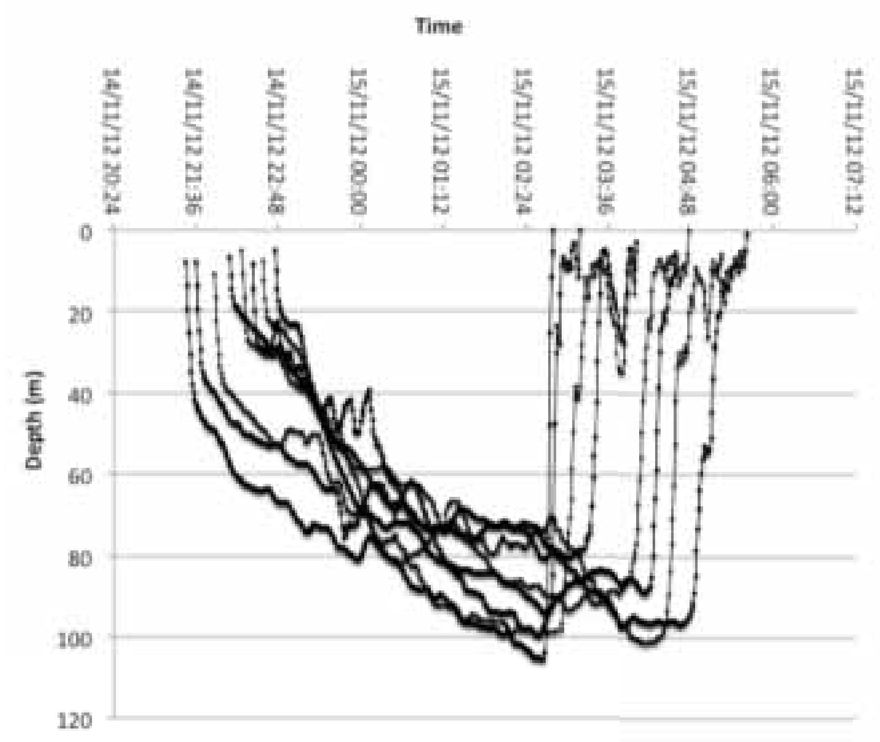
The capture time of individuals during the fishing time did not show any particular trend. The percentage of catch for period of two hours was around 20% (Figure 19).

Table 6 – Results of hooking contact (HC) et hooking success (HS) registered by longline fishing experiments.

	N. hooks	HC	HC (%)	HS	HS (%)
LL1	109	3	2.8	3	2.8
LL2	212	10	4.7	8	3.8
LL3	278	15	5.4	3	1.1
LL4	264	11	4.2	7	2.7
LL5	249	15	6	8	3.2
LL6	244	6	2.5	1	0.4
LL7	274	13	4.7	6	2.2
LL8	280	8	2.9	5	1.8
LL9	285	6	2.1	3	1.1
Total	2195	87	4	44	2

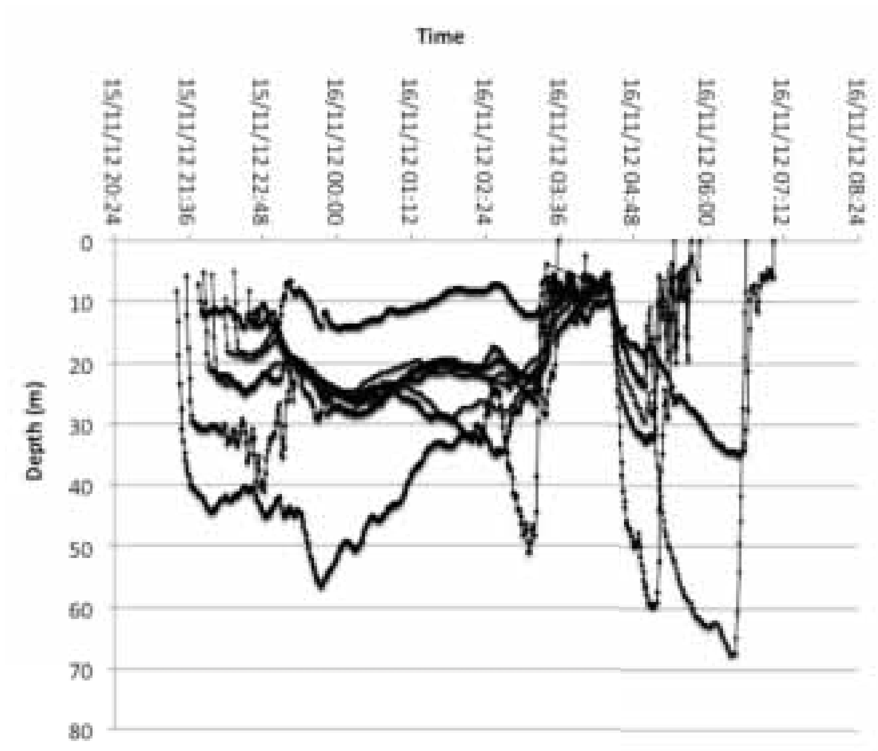


Longline n° 2

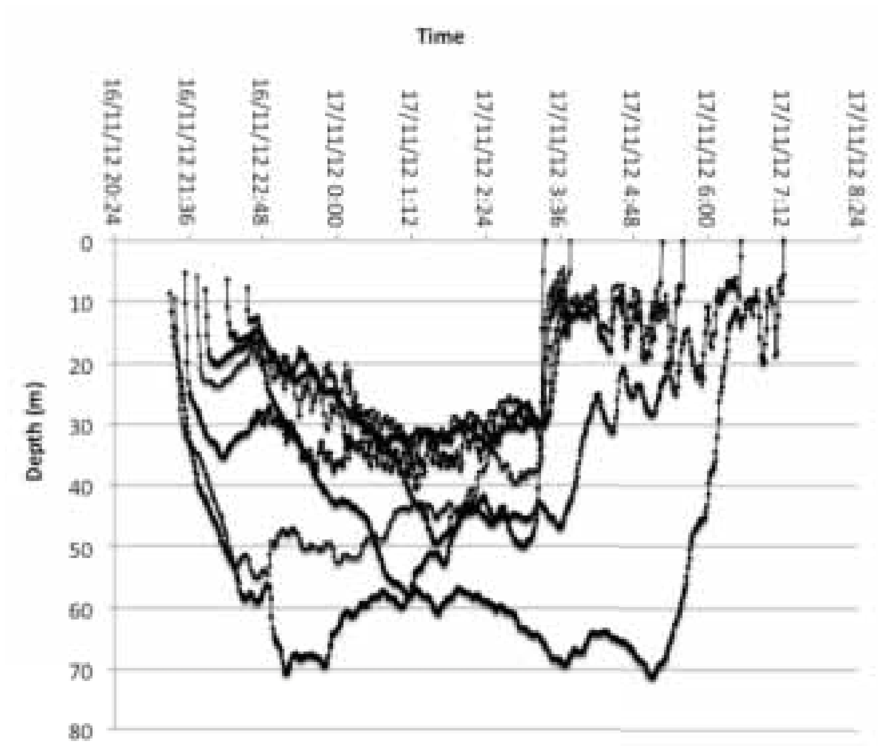


Longline n° 3

Figure 17 – Depth profiles recorded by TDRs at the deepest fishing point of the mainline for several baskets.

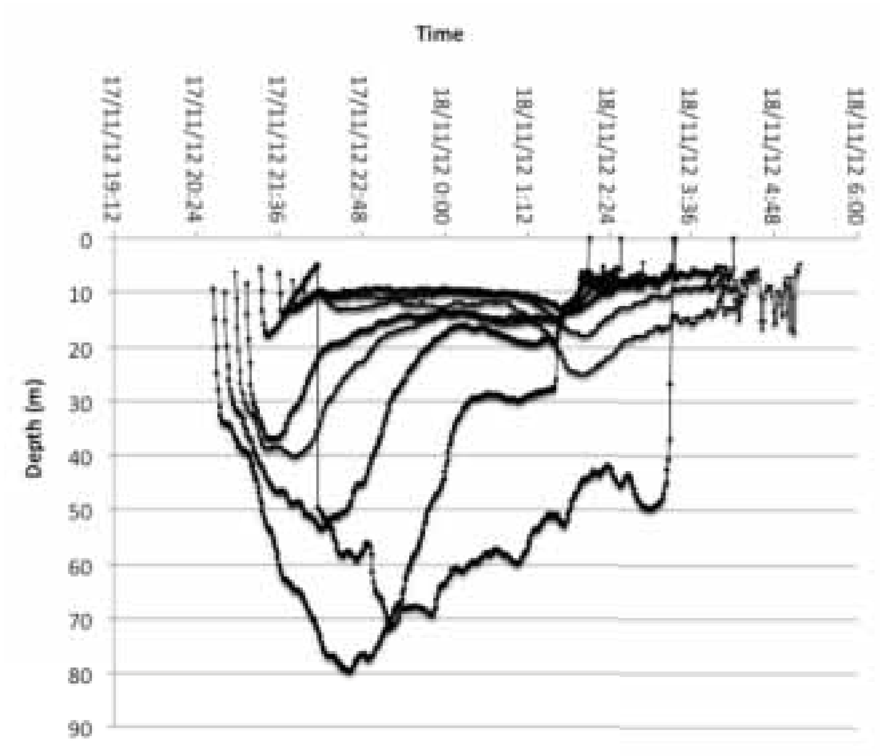


Longline n° 4

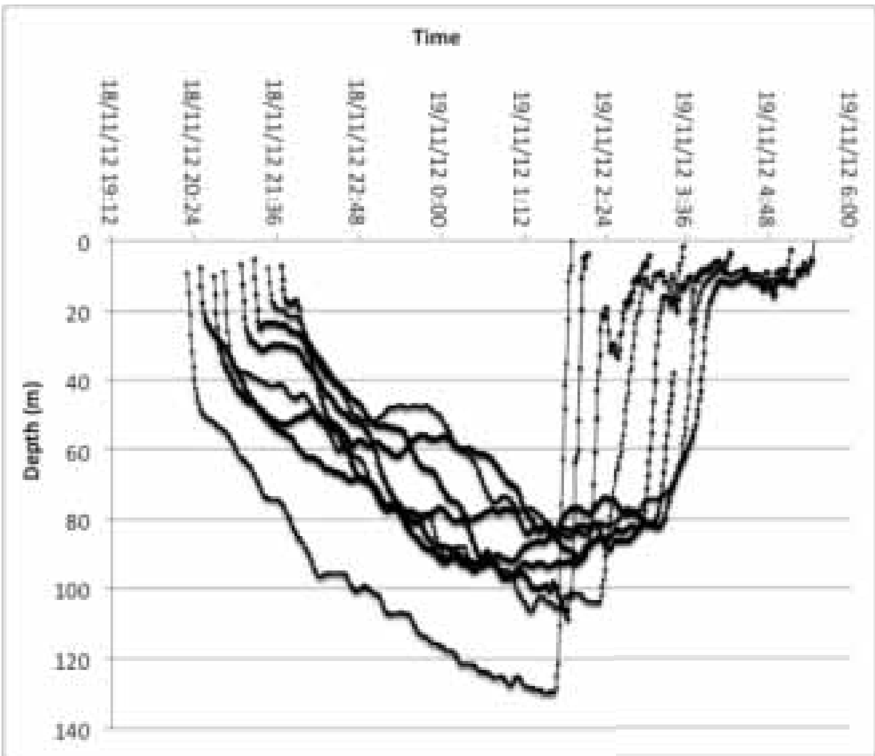


Longline n° 5

Figure 17 (ctd) – Depth profiles recorded by TDRs at the deepest fishing point of the mainline for several baskets.

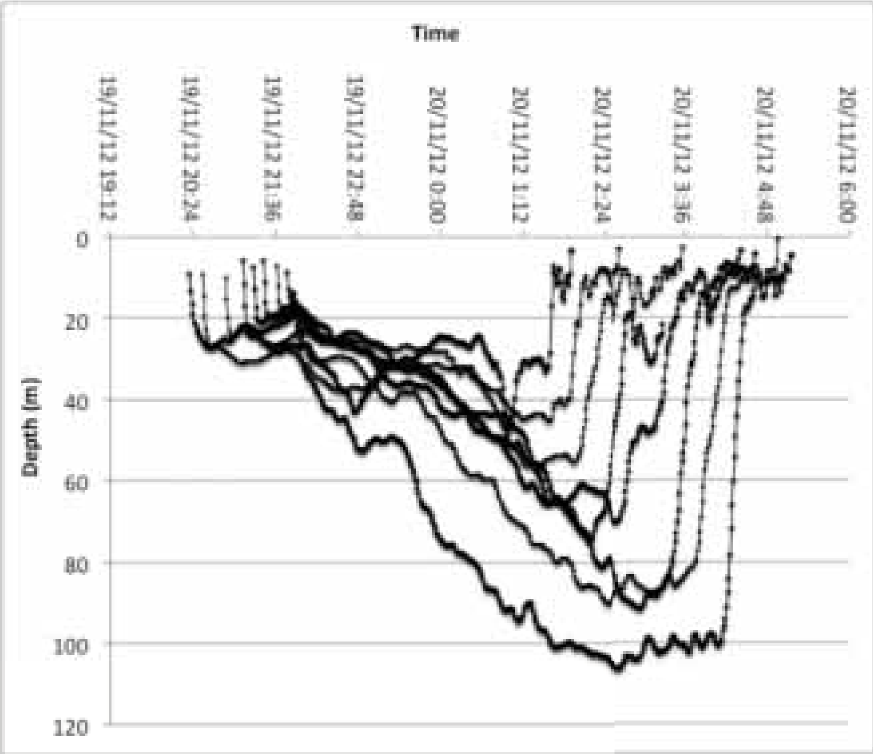


Longline n° 6

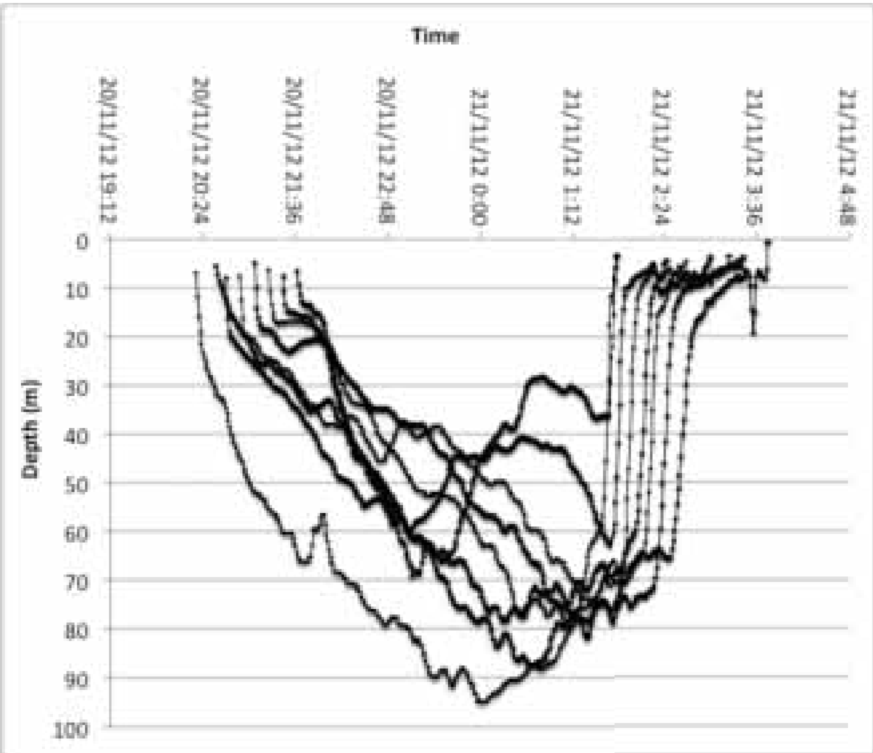


Longline n° 7

Figure 17 (ctd) – Depth profiles recorded by TDRs at the deepest fishing point of the mainline for several baskets.



Longline n° 8



Longline n° 9

Figure 17 (ctd) – Depth profiles recorded by TDRs at the deepest fishing point of the mainline for several baskets.

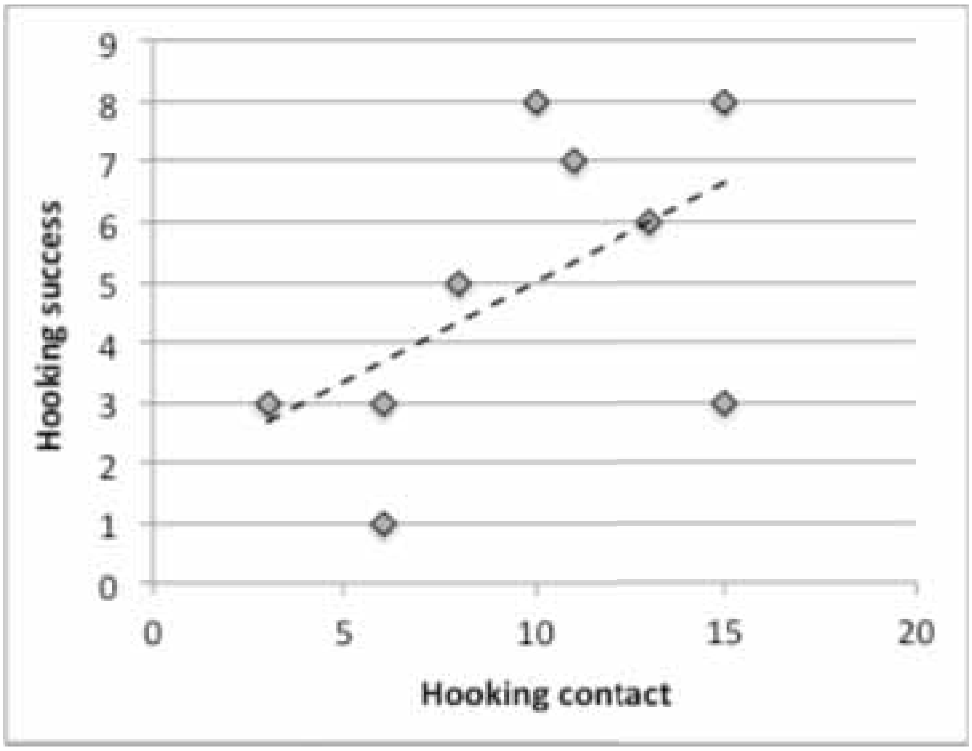


Figure 18 – Relationship between hooking success and hooking contact recorded at the scale of the longline fishing operation.

Table 7 – List of species and number of capture by species recorded by longline fishing operation.

Species	3-Alpha Code	LL1	LL2	LL3	LL4	LL5	LL6	LL7	LL8	LL9	Total
Coryphaena hippurus	DOL	1	2		1	1					5
Cubiceps gracilis	CBG				1	1					2
Gempylus serpens	GES			2				1		1	4
Isurus oxynrhinchus	SMA						1				1
Lepidocybium flavobrunnueum	LEC							2	1	1	4
Prionace glauca	BSH	1	4		2	1		2		1	11
Pteroplatytrygon violacea	PLS	1							1		2
Ranzania laevis	RZV				1						1
Thunnus alalunga	ALB		2			1					3
Thunnus obesus	BET					1					1
Xiphias gladius	SWO			1	2	3		1	3		10
	Total	3	8	3	7	8	1	6	5	3	44

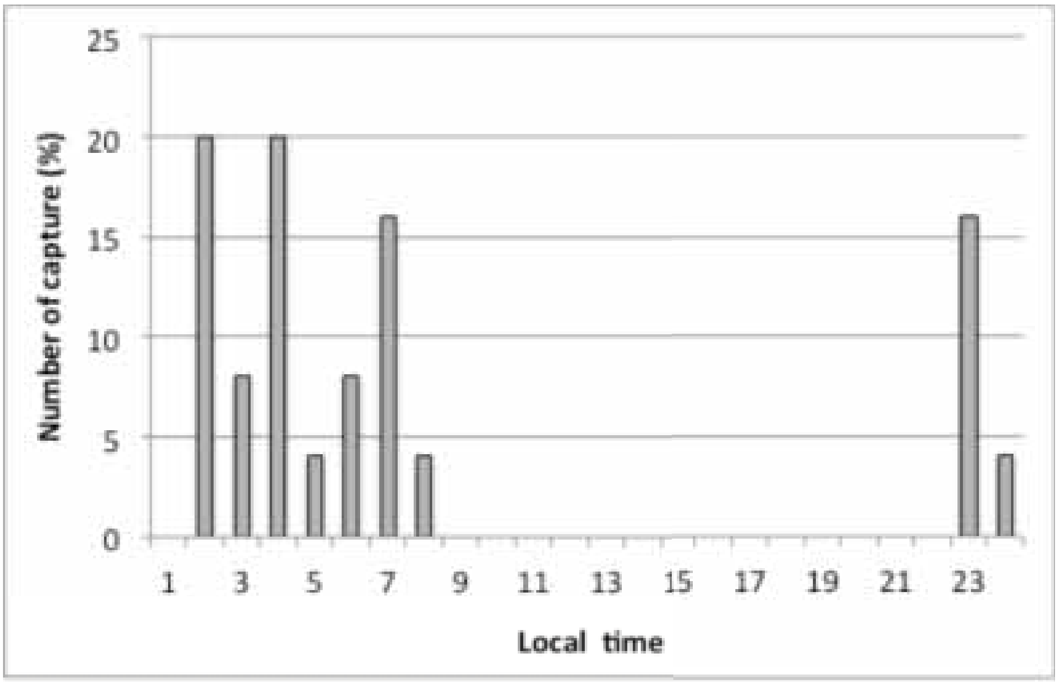


Figure 19 – Hourly occurrence (%) of capture during the fishing time.

5.3 Deployment of electronic tags on swordfish

A total of 10 swordfish were caught but only 3 met the criteria required for tagging (Table 8). Unfortunately, each tag underwent a premature release. Two PSATs (11P0492 and 11P0498) planned for 180 and 360 days respectively, popped off after 19 and 24 hours, respectively. In contrast, the tag #11P0500 planned to stay on the fish for 180 days, popped off after 88 days, providing valuable information on vertical movements for that swordfish.Out of 10 caught swordfishes 3 individuals were successfully released with PSAT tags (Table 6).

Table 8 – Metadata of PSAT deployment on swordfish

Nb day	Tag origin	N° Tag	code species	date	Lat (°S)	Long (°E)	Release time	Length (ELF cm)	N° capture
180	SWIOFP	11PO500	SWO	15/11/12	23.971	49.775	3:40	150	LL3/n°1
180	SWIOFP	11PO492	SWO	19/11/12	23.94	53.127	2:29	140	LL7/n°1
360	SWIOFP	11PO498	SWO	20/11/12	23.598	54.195	3:49	125	LL8/n°4

Horizontal movements

The processing of horizontal movements uses the light sensor data and a methodology called geolocation. Such processing has not been performed yet on this particular fish. We just present the tagging and pop off locations of the three tags (Figure 20). The swordfish 11P0492 and 11P0498 lost their tags very quickly, so the movements are not representative. The tags have drifted to the east and north directions. In contrast, the tag 11P0500 popped off in the South-East of Madagascar, at a linear distance of 630 miles (or 1170 km). Indeed, the actual distance travelled by the fish is much longer as it did not follow a straight line. However, interesting information is that the fish headed for the south of the Mozambique Channel, a region known for its high catch rates for swordfish. It has been hypothesized that swordfish may be attracted to this region (which is highly productive in relation with mesoscale eddies created at the South of Madagascar) and may remain a substantial amount of time with limited movements outside the region (concept of viscous population). More tagging data are necessary to support this hypothesis, but this complements the results of another tagging experiment (Oct 2011) where the 4 swordfish tagged in the Mozambique remained in the region and did not move towards the east of Madagascar.

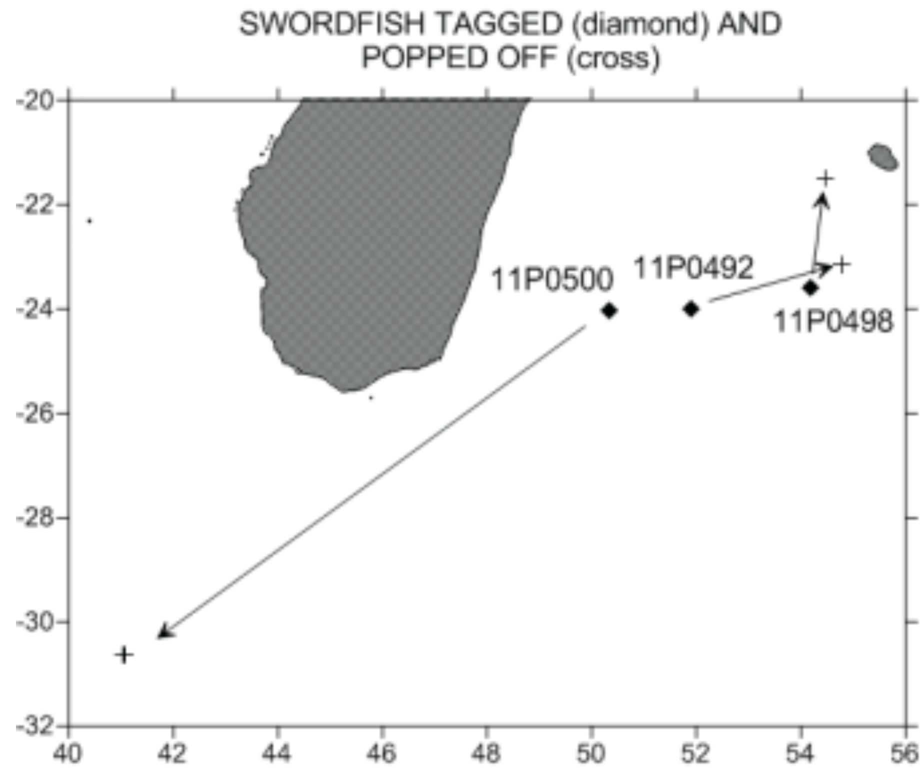


Figure 20. Tagging and pop-off locations of the three swordfish tagged during the cruise.

Vertical movements

Results are only presented for the swordfish tag 11P0500.

The depth and temperature data recorded buy the tag, from 15/11/2012 to 9/02/2013 show that vertical movements look rather cyclical and range from the surface to 800m. This is very similar to what was observed during the first tagging experiment on the Mozambique Channel (Oct 2011). The range in temperature is 9-28°C, showing that swordfish can bear huge temperature gradients within a short period of time. A better delineation of the water masses crossed by the swordfish will be done by defining time windows and analyzing the temperature-depth profiles (Figure 22, left). Indeed, we can identify two groups of dots in the upper 300 m, which are related to different water masses, probably when the fish leaves the tropical gyre and enters the south Mozambique Channel.

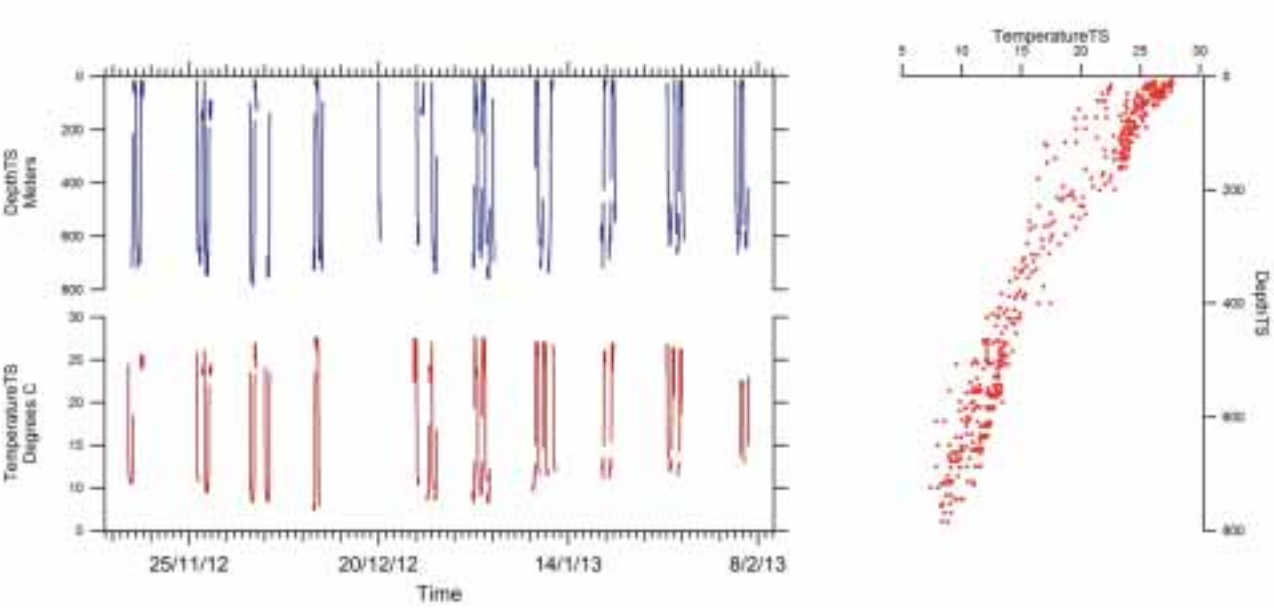


Figure 21. Depth (in blue) and temperature (in red) recorded by the tag during the vertical movements of the swordfish 11P0500 (left), and distribution of temperature vs depth (right). The time range represented is from 15 November 2012 to 9 February 2013 (minor ticks every single day and major ticks every 5 days)

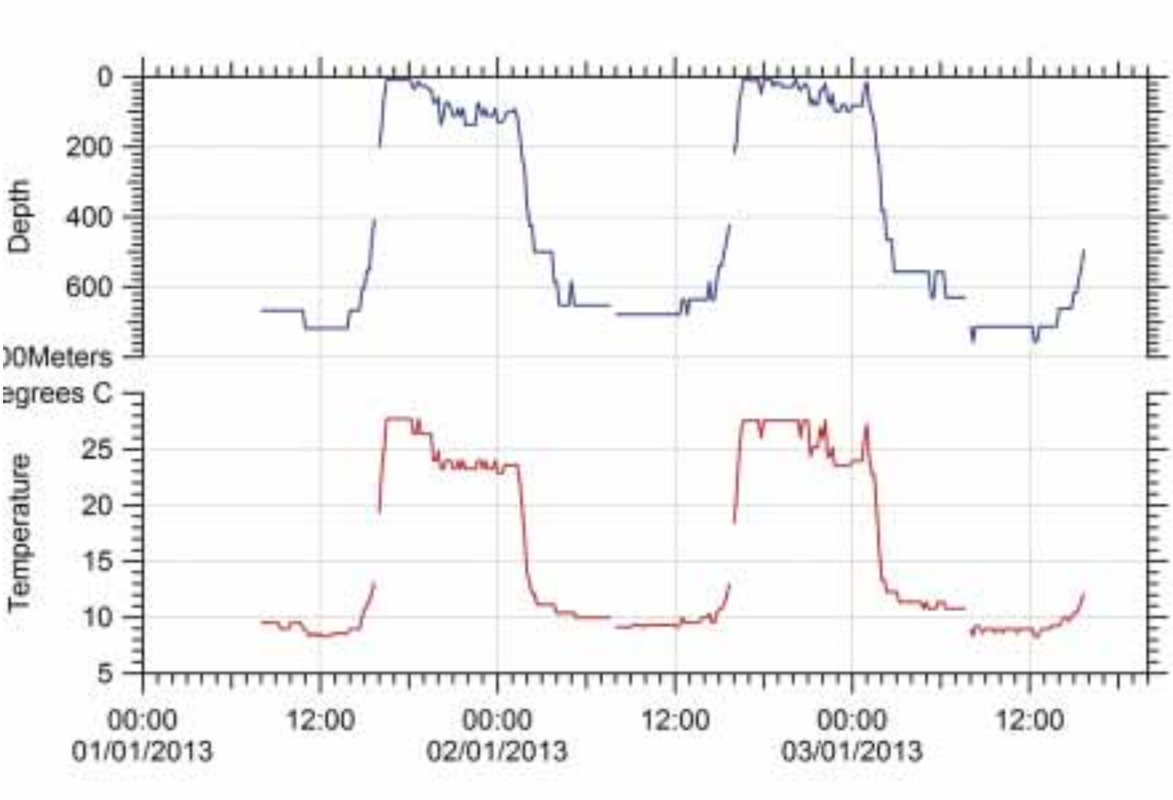


Figure 22 - Vertical movements of swordfish 11P0500, from 1st to 3rd January 2013. Depth is represented in blue and temperature in red.

The cyclical nature of the vertical movements becomes obvious by plotting temperature and depth during a short time window, for instance between the 1st and 3rd of January 2013 (Figure 22). The fish remains in the deep layers during the day and in the upper 100 m during the night, showing a clear diel cycle. The fish initiates a steep ascent around 4.00 pm and remains in the subsurface layers until 1.00 am. Then it begins a steep descent which ends around 3.00 am at around 600 m and below. This explains why the fish becomes accessible to the longline gear at dusk and until the middle of the night. The vertical movements can follow a very regular pattern for several consecutive days, as observed in the previous tagging experiment and also in other regions of the world.

6 Conclusion

The objectives of the cruise SWOPAT 2 was only partly reached as the number of swordfish tagged was less than expected. Firstly, swordfish were not abundant at the time of the cruise, as per the reports of the commercial fleet. Secondly, there are huge constraints for tagging fish in the most appropriate way, and this is clearly explained in this report. Very strict criteria must be met to maximize the rate of success, which barely exceeds a worldwide average of 30%. We achieved such a rate during the two tagging cruises (Oct 2011 and the present one). The fishing protocol used to catch and tag swordfish, under the guidance of Karen Evans (CSIRO), was found appropriate and will be used for further tagging experiments. Finally, this cruise allowed us to collect additional valuable information on the habitat of large pelagic fishes, the trophic ecology of large marine predators and on the environment (CTD and XBT profiles and fluorometer calibration).

This tagging cruise is the last one organised in the framework of SWIOFP. However, we plan to continue similar experiments under national and/or regional projects that will contribute to expand the set of observations initiated during SWIOFP and provide to regional fisheries organizations scientific basis for appropriate management of this resource in the South West Indian Ocean.