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Movements and behaviour of yellowfin and bigeye tuna associated to oceanic structures in the western Indian Ocean

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ABSTRACT

We present here preliminary results of PSAT tagging experiments conducted on bigeye tuna *Thunnus obesus* and yellowfin tuna *Thunnus albacares* in the western Indian Ocean. We analysed in this paper the horizontal movements and behaviour of the both tuna species associated to oceanic structures such as mesoscale eddies and fronts.

KEYWORDS

PSAT tagging | Horizontal movements | Oceanic structures | Fronts | Eddies | Thermocline | Yellowfin tuna | Bigeye tuna | western Indian Ocean

1. Introduction

Bigeye tuna *Thunnus obesus* and yellowfin tuna *Thunnus albacares* are common tuna species in tropical regions where they are targeted by various fishing gears, mainly purse-seine and longline.

The regional ecology of yellowfin and bigeye tuna in the Indian Ocean: vertical behavior, habitat preferences, and migrations, is still poorly known despite previous attempts to deploy pop-up satellite archival tags (PSATs) on yellowfin tuna at least (in the BIOT: Schallert et al., 2013; in the Arabian Sea and Bay of Bengal: Premchand et al., 2014, Bright et al. 2017; off Zanzibar and Maldives, IOTC unpublished data).

Between November 2014 and July 2015, we tagged 32 yellowfin and 15 bigeye tuna with PSATs in the western Indian Ocean (Reunion Island waters, east coast of Madagascar and Saya-de-Malha Bank) to study the vertical movements, behavioor, habitat preferences and horizontal migrations of these two tuna species within the framework of IRD and CAP RUN research project PROSPER (PROSpection and habitat of large PElagic fish in the EEZ of Réunion Island) funded by EU (Sabarros et al., 2015).

The vertical behaviour and habitat use of yellowfin and bigeye tuna is described in Sabarros et al. (2015), and we present here the horizontal movements of both tuna species and associated behaviour with hydrodynamic structures of the ocean.

2. Material and Methods

2.1. Tags

Two types of PSATs were used in our tagging experiments: *miniPAT* by *Wildlife Computers Inc.* (Seattle, USA) and *LAT3400* by *Lotek Wireless Inc.* (St. John's, Newfoundland, Canada). We present in this paper data collected by *miniPAT* tags from which we removed premature releases under 15 days and tags that were predated by sharks (Romanov et al., in prep), leaving a total of 16 available tags (Table 1).

MiniPAT tags were programmed to record depth, temperature and light for time periods between 90 and 180 days (Table 1). Depth time series (5-min interval for 90 days deployments, 10-min interval for 180 days) was programmed to be always transmitted by satellite, as well as light levels recorded during twilight periods (used for geolocation), and summarized data such as histograms of binned depth (0-10; 10-30; 50 30; 50-100; 100-150; 150-200; 200-250; 250-300; 300-500; 500-800; >800 m; with 4-hour interval) and binned temperature (0-3; 3-6; 6-9; 9-12; 12-15; 15-18; 18-21; 21-24; 24-27; 27-30; 30-33; >33°C; with 4-hour interval), and profiles of depth and temperature (PDT; 4-hour interval).

2.2. Tuna tagging

Among the 27 *miniPATs* that already transmitted data, 17 were deployed on yellowfin tuna (91-164 cm FL) and 10 on bigeye tuna (101-141 cm FL) at the occasion of 3 tagging cruises carried out by IRD and CAP RUN (PROSPER research project) in the western Indian Ocean (Saya-de-Malha Bank, east coast of Madagascar and Reunion Island waters) in 2015 onboard French commercial longline vessel *Le Bigouden* (21.4 m LOA) (Fig. 1). Tuna were caught using short longline gear (average 313 hooks, range 278-479 hooks) with squid-baited hooks (in 5 sets we used a mix of squid and mackerel bait). The longline was deployed in surface layers during crepuscular periods: dusk and dawn. Very short drifting (period between end of setting and start of hauling, average 3.1 hours, range 1.9-4.0) and soaking time (average 7.5 hours, range 5.9-10.5) were used to maximize the chance of catching tuna alive. Also, branchlines were equipped with circle hooks in order to reduce potential hooking injury. We realized 36 fishing operations over 39 days at sea.

Tuna candidates for tagging were brought onto the deck of the boat using a lifting flexible cradle. To keep the tuna calm inside the cradle while on vessel deck, the eyes of the fish were covered with wet soft synthetic cloth. In most cases a hose with running seawater was immediately placed in the tuna's mouth to ensure gills oxygenation. After removing the hook and ensuring the tuna was in good condition (active fish, with no gill, mouth or gut bleeding, no serious external or eyes injury, etc.), we inserted the tag anchor below the base second dorsal fin through the pterygiophores using an applicator provided by the tag manufacturer. In addition, an IOTC spaghetti tag was placed below the base of the first dorsal fin. The tagged tuna was then measured and carefully released into the ocean using the lifting cradle.

2.3. Horizontal movements

Horizontal movements are presented in two ways. First, based on straight distances between tagging and tag pop-up locations to appreciate the dispersion over the deployment, and secondly as tracks estimated by Wildlife Computers Global Position Estimator 3 (GPE3) (Table 1; Figure 1). GPE3 is a state-space model that uses observations of twilight, sea surface temperature and dive depth to generate time-discrete and gridded probability surfaces from which can be derived the animal most likely location (Wildlife Computers, 2015). Tracks shown in Figure 1 are the most likely positions calculated using 3 $m.s^{-1}$ as the maximum daily speed in the GPE3 model.

Dispersion was defined and calculated as the straight distance between tagging and popup locations divided by the number of days at sea. Displacement was defined as the total horizontal distance travelled using GPE3 tracks, and the displacement rate as this total distance divided by the number of days at sea. Summary results comparing both species are presented in Figure 2.

2.4. Vertical behaviour

Figure 3 illustrates an individual tag deployment (#142826) including the depth profile time series, and interpolated temperature time series with day/night discrimination (see details in Sabarros et al., 2015). Temperature time series (that is not transmitted) was reconstructed by interpolation using Profile of Depth and Temperature data (PDT provided for 4-hour intervals) and depth time series (5-min interval).

PDT was also used to display the vertical thermal structure of the water column and to calculate the isothermal layer depth (ILD = thermocline; Kara et al., 2000) (Figure 4).

2.5. Environmental data

Temperature (at depth) and Sea Surface Height (SSH) data were extracted from Global Ocean Physics Reanalysis (GLORYS2V4) data product provided by EU Copernicus Marine Environment Monitoring Service (CMEMS; http://marine.copernicus.eu). GLORYS2V4 contains daily means of Temperature, Salinity, Currents, SSH, and Sea Ice, at 0.25° horizontal resolution, with 75 vertical levels, forced by ERA-Interim atmospheric variables and covering the 1993-2015 time period, with SEEK/IAU data assimilation of Temperature and Salinity profiles as well as Sea Level Anomalies, Sea Ice Concentration, Sea Surface Temperature and Mixed Layer Depth (CMEMS, 2017).

GLORYS temperature (T_{model}) data were extracted along each individual track integrating the depth component (no interpolation was made). T_{model} was then compared to T_{insitu} that refers the temperature recorded by the tag itself (Appendix 1). T_{insitu} was interpolated from PDT data products as described in section 2.4. The purpose of this comparison was to validate both the estimated tracks and the overall GLORYS2V4 dataset that we used.

SSH was extracted along the track with no interpolation and presented in Figure 3.

3. Results

3.1. Horizontal movements: dispersion versus displacement

Tags pop-up locations demonstrate wide dispersion in the western Indian Ocean: from limited displacements within tagging areas to long-distance migrations towards the South Africa or towards the equator, Mauritius and Seychelles (Figure 1). The longest distance travelled was observed for a YFT (#142826): 3414 km in 54 days, i.e., an average speed of about 63 $km.d^{-1}$. Comparable speeds were recorded for several other YFT tracked for shorter periods (Table 1). Bigeye tuna also demonstrated several long-distant movements: 4570 km and 4190 km with average speeds of 51 and 52 $km.d^{-1}$ respectively (Table 1). Displacement rate, i.e., migratory activity of YFT was more pronounced but also more variable than for BET (Figure 2). In general, dispersion from tagging/release locations was reduced in BET compared to YFT (Figure 2; Table 1).

3.2. Association with oceanic structures

YFT and BET tracks follow the periphery of eddies as well as go across fronts between eddies, and pass by the centre of both cyclonic and anticyclonic eddies (see example in Figure 3).

The example provided in Figure 3 demonstrates that on the yellowfin tuna (tag #142826) crossed thermal fronts at several occasions which corresponds to the sharp breaks in the interpolated temperature time series. This is illustrated by situation A (on 19/04/2015) where the YFT moved through the frontal zone between a cold cyclonic eddy and a warm anti-cyclonic eddy. Also, situation B (on 03/05/2015), illustrates that the YFT visited the centre of a cyclonic eddy (Figure 3).

Figure 4 is a zoom on 10 days of YFT track #142826 where the tuna passed from a warm anti-cyclonic eddy to a cold cyclonic eddy where the MLD was raised, and back to an anti-cyclonic eddy. At night, YFT shallow dives remained in the mixed layer. During the day, the YFT exhibited dives within the mixed layer in the anti-cyclonic eddies and much deeper dives than the MLD while being in the cyclonic eddy despite the MLD being raised.

4. Discussion

4.1. Dispersion versus displacement

In general, YFT dispersed further away from tagging locations compared to bigeye tuna. BET hence demonstrated a certain relative site fidelity compared to YFT. Some YFT can also exhibit very strong site fidelity (e.g., #142814 that remained around Saya-de-Malha Bank for 55 days, and #142828 on the east coast of Madagascar for 51 days). The actual distance covered by YFT and displacement rate was also generally greater than BET suggesting YFT is highly mobile and a more migratory species.

4.2. Behaviour associated to oceanic structures

First of all, we were able validate the use of GLORYS2V4 model data (Temperature and SSH) together with estimated tuna tracks from GPE3 since we found a very descent correspondence between model and *in situ* data. However, it would have been more appropriate to use Sea Level Anomalies (SLA) instead of SSH to normalize the ocean topography bumps and depressions allowing to better identify mesoscale structures such as eddies.

We cannot conclude on the actual tropism and anti-tropism of tuna towards and away from certain oceanic features such as eddies or fronts. Indeed, we may have expected that tuna avoid centres of anticyclonic eddies that are supposedly poor in forage fauna, or that tuna would exploit fronts between eddies. The picture is at the moment not clear yet and requires further investigation.

We did see however interesting patterns such as a difference of relationship to the mixed layer during the night and during the day in a yellowfin tuna track according to the type of eddy encountered.

4.3. Perspectives

For both species, we will continue investigating possible interactions and/or use of oceanographic structures such as fronts, eddies, etc., as well as with the mixed layer, and the potential effect of dissolved oxygen concentration.

5. Acknowledgements

PSS and PB thank EU FEP for funding research project PROSPER 2 including tags and tagging campaigns. Participation of EVR to tagging cruises was ensured by PELICAN project funded by Region Reunion. We thank Adrien Chevallier and all boat crews that were involved in tagging cruises.

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7. Tables

Table 1. Summary of tag deployments. FL: fork length in cm. Dispersion rate ($km.d^{-1}$) is the direct distance between tagging and popup locations divided by days at sea. Displacement (km) and displacement rate ($km.d^{-1}$) are the total track distance and average distance per day.

Manufacturer	Manufacturer Id	PTT	Program	Anchor	Species	FL (cm)	Tagging date	Popup date	Days at sea	Dispersion ($km.d^{-1}$)	Total distance (km)	Displacement rate ($km.d^{-1}$)	Exclusion
Wildlife Computers	14P0458	142807	90d	Wilton	YFT	162	2015-02-18	2015-02-24	6	-	-	-	Deployment < 15d
Wildlife Computers	14P0417	142808	90d	Wilton	BET	101	2015-04-02	-	-	-	-	-	Did not transmit
Wildlife Computers	14P0418	142809	180d	Wilton	YFT	126	2015-02-18	2015-02-23	5	-	-	-	Deployment < 15d
Wildlife Computers	14P0443	142810	90d	Wilton	BET	141	2015-02-16	2015-02-20	4	-	-	-	Deployment < 15d
Wildlife Computers	14P0444	142811	180d	Wilton	YFT	140	2015-02-21	2015-04-09	47	-	-	-	Predated tag
Wildlife Computers	14P0445	142812	90d	Wilton	YFT	92	2015-02-18	2015-02-25	7	-	-	-	Predated tag
Wildlife Computers	14P0447	142813	90d	Wilton	YFT	148	2015-02-21	2015-03-03	10	-	-	-	Deployment < 15d
Wildlife Computers	14P0454	142814	90d	Wilton	YFT	91	2015-02-21	2015-04-17	55	1	1845	34	
Wildlife Computers	14P0455	142815	90d	Wilton	YFT	160	2015-02-18	-	-	-	-	-	Did not transmit
Wildlife Computers	14P0456	142816	90d	Wilton	YFT	131	2015-02-17	2015-03-05	16	37	969	61	
Wildlife Computers	14P0569	142817	90d	Wilton	YFT	118	2015-03-29	2015-06-08	71	22	3539	50	
Wildlife Computers	14P0571	142818	90d	Wilton	YFT	107	2015-03-31	2015-05-10	40	4	1498	37	
Wildlife Computers	14P0574	142819	90d	Wilton	YFT	164	2015-03-28	2015-04-05	8	-	-	-	Deployment < 15d
Wildlife Computers	14P0578	142820	90d	Wilton	BET	126	2015-03-31	-	-	-	-	-	Did not transmit
Wildlife Computers	14P0581	142821	180d	Wilton	YFT	95	2015-03-31	2015-04-08	8	-	-	-	Deployment < 15d
Wildlife Computers	14P0583	142822	90d	Wilton	BET	107	2015-04-02	2015-07-01	90	4	3807	42	
Wildlife Computers	14P0584	142823	90d	Wilton	YFT	154	2015-03-30	2015-04-30	31	22	2024	65	
Wildlife Computers	14P0585	142824	90d	Domeier	BET	104	2015-03-29	2015-06-27	90	4	3949	44	
Wildlife Computers	14P0586	142825	90d	Wilton	BET	119	2015-03-30	2015-06-07	69	2	3296	48	
Wildlife Computers	14P0587	142826	180d	Wilton	YFT	158	2015-03-30	2015-05-23	54	38	3414	63	
Wildlife Computers	14P0590	142827	90d	Wilton	BET	118	2015-03-29	2015-06-02	65	4	2766	43	
Wildlife Computers	14P0591	142828	90d	Wilton	YFT	119	2015-03-29	2015-05-19	51	1	2283	45	
Wildlife Computers	14P0598	142829	180d	Domeier	YFT	151	2015-03-30	2015-05-20	51	2	2223	44	
Wildlife Computers	14P0600	142830	180d	Domeier	BET	141	2015-04-02	2015-07-15	104	-	-	-	Odd behaviour
Wildlife Computers	14P0604	142831	90d	Wilton	BET	122	2015-04-02	2015-07-01	90	4	4570	51	
Wildlife Computers	14P0606	142832	90d	Domeier	YFT	156	2015-03-29	2015-05-04	36	25	1520	42	
Wildlife Computers	14P0745	150814	90d	Domeier	BET	122	2015-07-12	2015-10-10	90	9	3326	37	
Wildlife Computers	14P0797	150815	90d	Domeier	BET	119	2015-07-16	2015-08-03	18	-	-	-	Predated tag
Wildlife Computers	15P0001	150816	90d	Domeier	BET	128	2015-07-17	2015-10-06	81	16	4190	52	
Wildlife Computers	15P0006	150817	90d	Domeier	BET	127	2015-07-17	-	-	-	-	-	Did not transmit

8. Figures

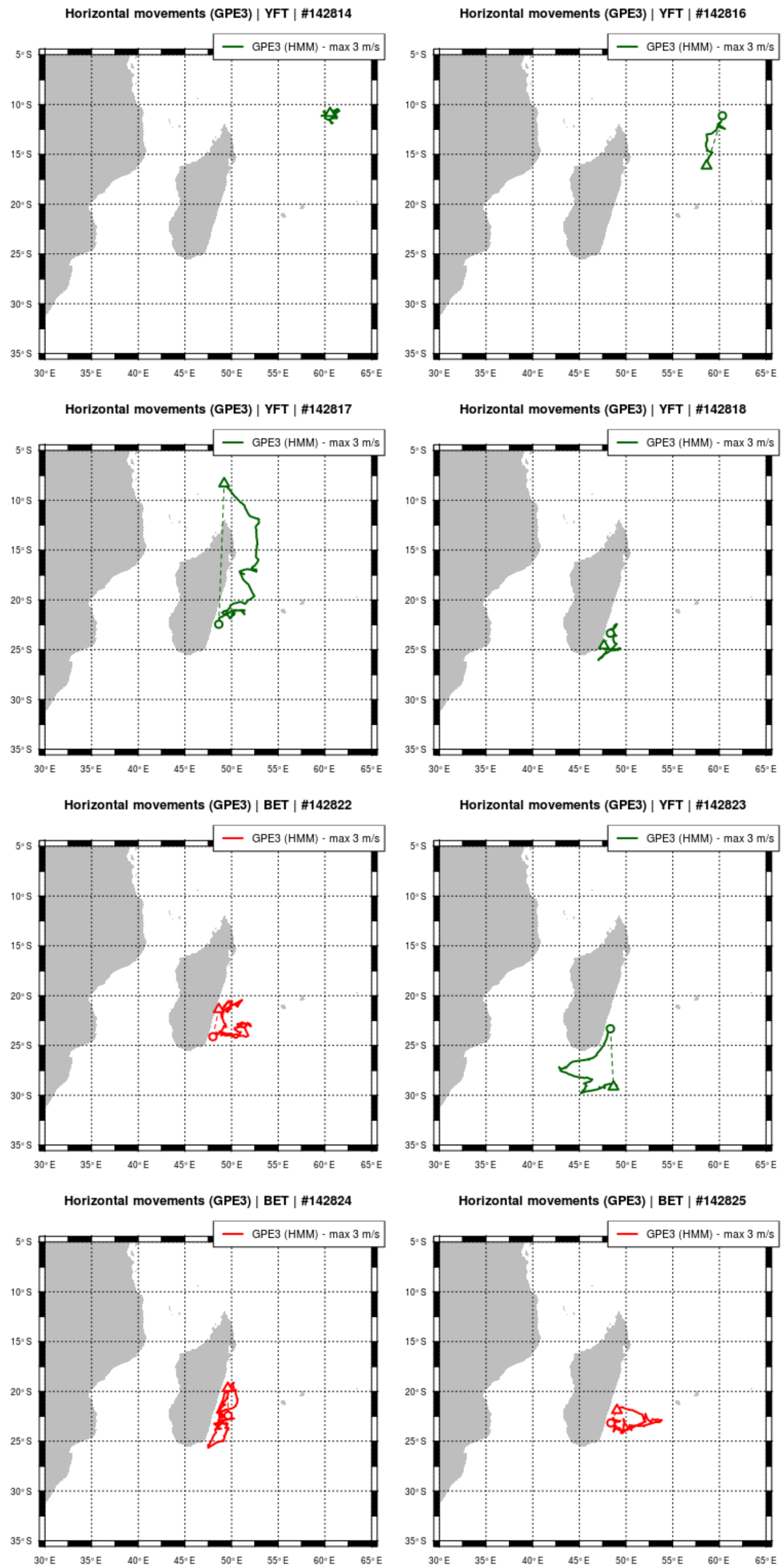

Figure 1. Horizontal movements of yellowfin (YFT) and bigeye tuna (BET) estimated using GPE3 developed by Wildlife Computers. Open circles and triangles represent tagging and popup locations respectively. The dotted line represents the dispersion from the tagging location.

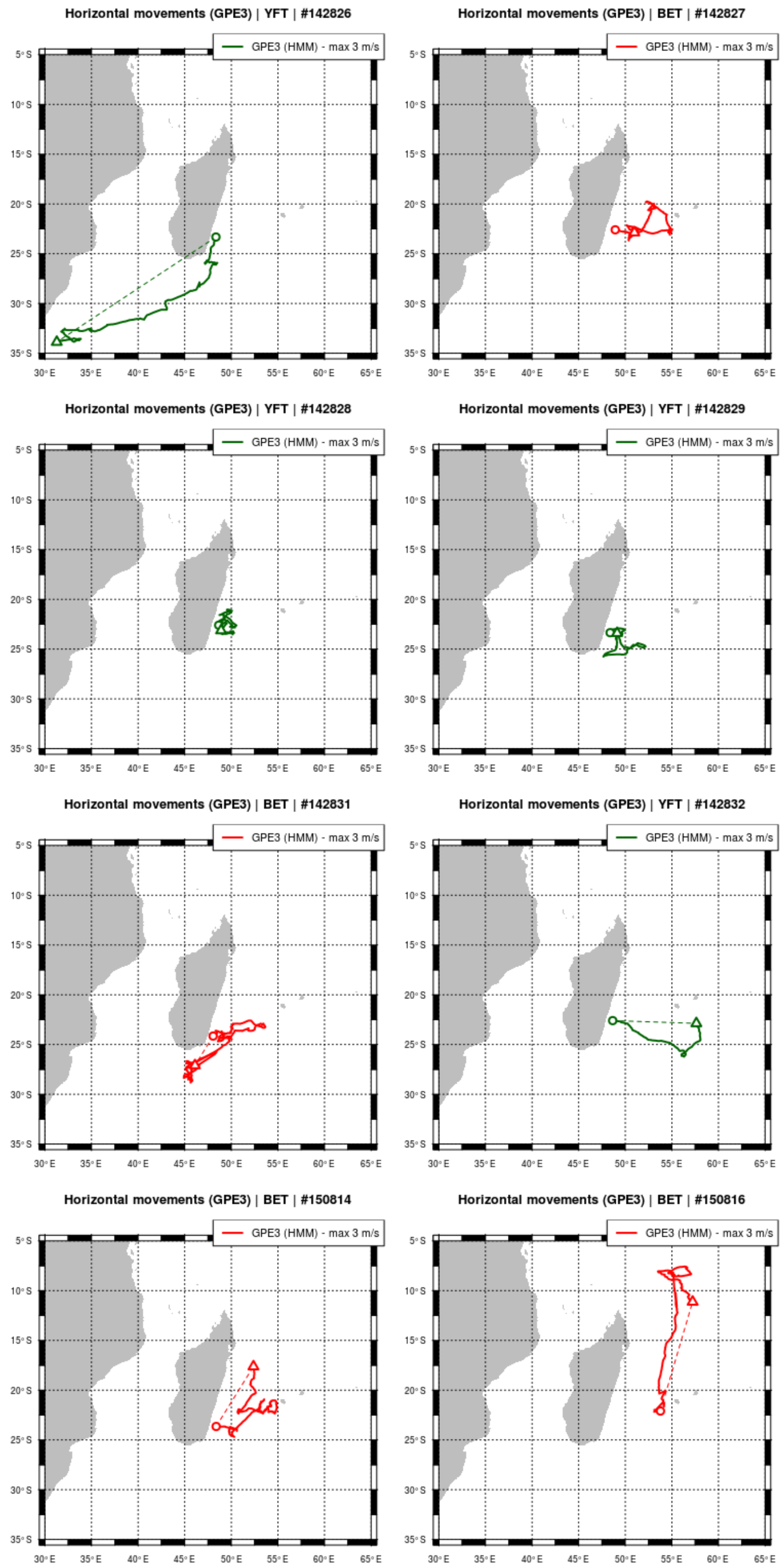

Figure 1 (continued). Horizontal movements of yellowfin (YFT) and bigeye tuna (BET) estimated using GPE3 developed by Wildlife Computers. Open circles and triangles represent tagging and popup locations respectively. The dotted line represents the dispersion from the tagging location.

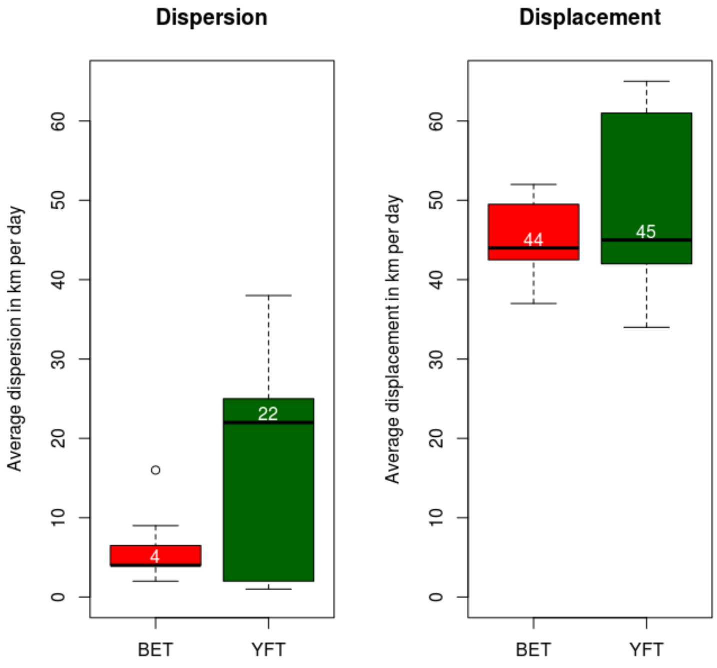

Figure 2. Dispersion rate (km.d^{-1}) and displacement (km.d^{-1}) of yellowfin (YFT; n = 9) and bigeye tuna (BET; n = 7). White numbers are median values.

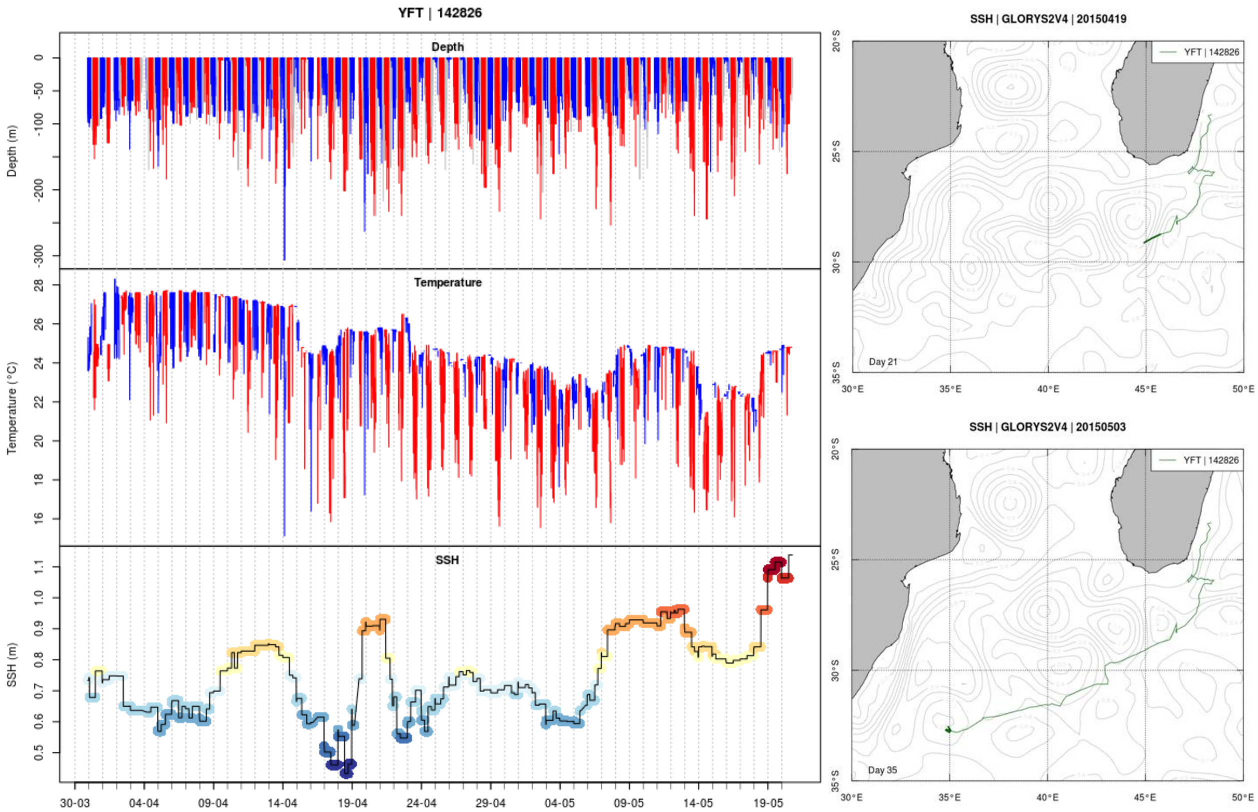

Figure 3. Depth, *in situ* temperature and sea surface height (SSH) profiles for yellowfin tuna tag #142826 and horizontal movements at day 21 (19/04/2015; Situation A) and day 35 (03/05/2015; Situation B). Track for a given day is the solid thick line, while the fine solid line represents the past track. Red and blue sections on depth and temperature profiles represent respectively day and night.

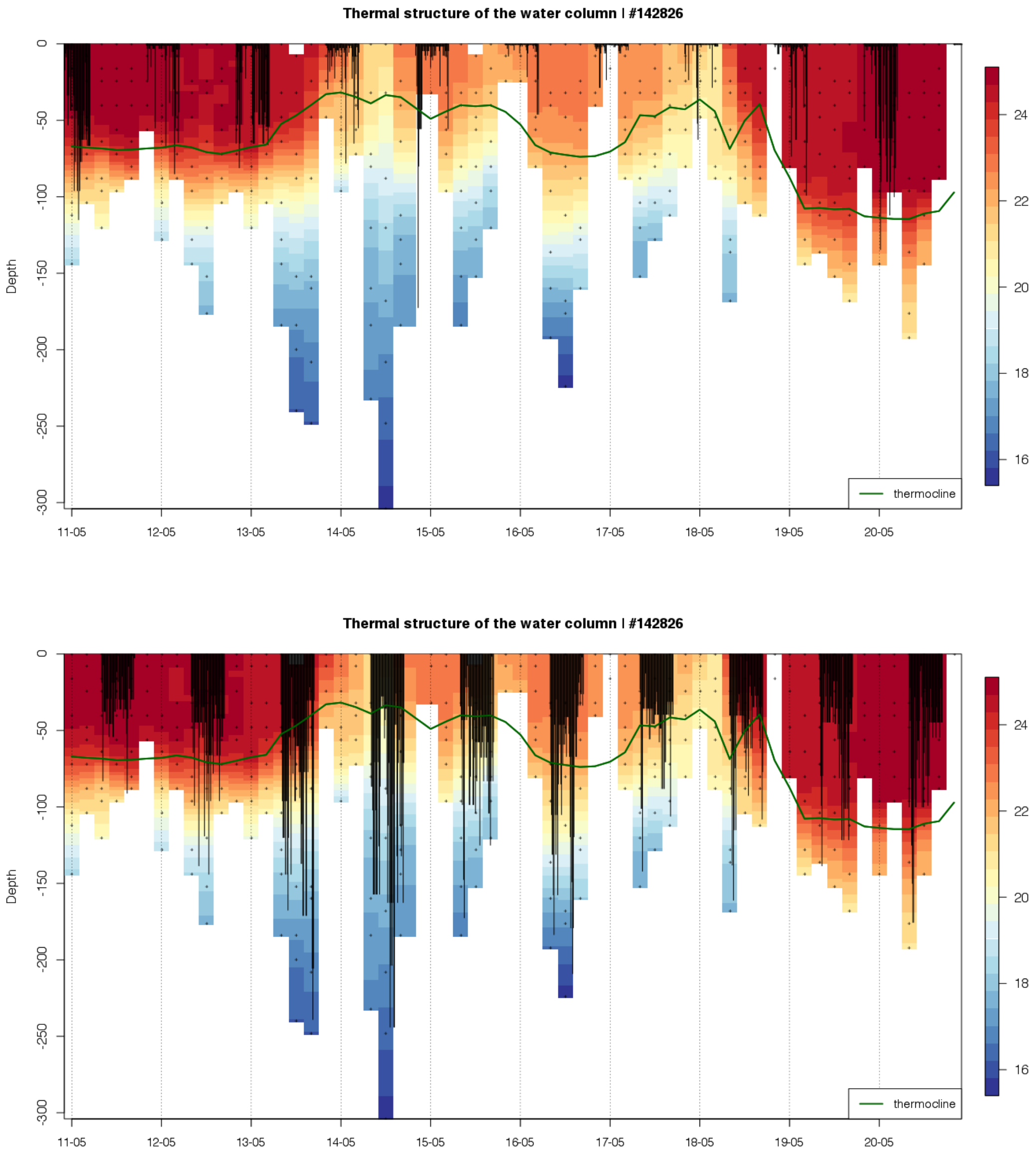

Figure 4. Zoom on thermal structure of the water column and associated night dives (upper panel) and day dives (bottom panel) of yellowfin tuna tag #142826 between 11/05/2015 and 21/05/2015.

9. Appendices

Appendix 1. Examples of T_{insitu} versus T_{model} for YFT #142823 and BET #150816. The broken line is the theoretical 1:1 regression. The solid line is the linear regression between the two variables for which parameters are provided in the upper left corner of the plots.