Findings from 101 satellite tags deployed on Indian Ocean billfish during the FLOPPED project

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ABSTRACT

The FLOPPED project (2019-2023) aimed to investigate the reproduction zones of five billfish species in the Indian Ocean through a comprehensive data collection initiative, including satellite tagging data and biological sampling. Within the framework of this project, 102 satellite tags were deployed around the Indian Ocean on blue marlin (*Makaira nigricans*; n=43), black marlin (*Makaira indica*; n=16), striped marlin (*Tetrapturus audaxI*; n=5), swordfish (*Xiphias gladius*; n=7), sailfish (*Istiophorus platypterus*; n=30) and a shortbill spearfish (*Tetrapturus angustirostris*,n=1). Tagging and biological sampling were originally focused on six study sites, including Reunion, Mayotte, Mauritius (Rodrigues), Seychelles, Sri Lanka and Indonesia. However, due to logistical complications resulting from the global COVID-19 pandemic, we searched for participants from a broader range of sites among our WPB colleagues to maximise the coverage and representativeness of this dataset. Tags were programmed to release from the fish ("pop") after 3 months and up to 12 months. Four tags are still at sea. The other 96 tags have either popped and reported data (n=75) or have surpassed the programmed time with no data received (n=19). The average duration of tag deployment was about 32% of the programmed time, with a maximum deployment duration of 207 days achieved. Position estimates indicate that most individuals of all species tagged in the south-western Indian Ocean tend to swim to the north-west Indian Ocean off Somalia. Some marlin appeared to have a northeastern trajectory, and one swam directly from Reunion to the southern tip of Madagascar. Marlin and sailfish appear to inhabit the top 200 meters during the day and restrict their depth range to the upper 50-100 m at night. In contrast, swordfish in the southern Indian Ocean appear to inhabit the top 600 meters during the day, and restrict their depth range to the top 200 m at night. While we were able to obtain some data from the longline swordfish tagging experiment, the tagged fish experienced a high rate of mortality, likely due to extended time on the line.

INTRODUCTION

The identification of spawning and nursery habitats for marine species is essential to define management measures. Indeed, it is during these younger stages that most of the natural mortality occurs (greater than 99%; Hjort 1914). In the case of billfish (swordfish, marlin, sailfish), larval survival is particularly critical since these species are very fertile (tens of millions of eggs per female) and thus low variations in larval survival will have a considerable impact on the abundance of the next larval cohort.

The state of these resources is of concern: blue and striped marlin are overfished and the status for the black marlin is unknown since 2018). However, management measures are difficult to develop as these species are by-catch in fisheries that target tuna or swordfish. Swordfish, in contrast, is not currently overfished nor subject to overfishing but exhibits declining biomass trends indicating higher depletion in the southern regions compared to northern regions.

In the framework of the management of swordfish species, the Indian Ocean Tuna Commission (IOTC) has established research priorities focused on these species. Among these, one of the highest priorities is the identification of areas and seasons of reproduction. Indeed, to date, no information is available on this subject for the three species of marlins (blue marlin, *Makaira nigricans*, black marlin, *Makaira indica* and striped marlin, *Tetrapturus audax*) and sailfish (*Istiophorus platypterus*). Some areas have been identified for swordfish (*Xiphias gladius*) as a result of IFREMER projects in southwestern the Indian Ocean (IOSSS, Longline Fisheries Program).

The project Finding Large Oceanic Pelagic Predators Environnemental Distribution (FLOPPED), led by IFREMER, in partnership with the CNRS and the Comite régionale des pêches marines de La Réunion, and working with COOOL, was a three-year project (2019-2021), which was extended to 2023 due to the global pandemic, aimed to provide knowledge on the areas and periods of reproduction of these billfish species and the abundance levels of spawning individuals. This project was funded under Measure 40 of the EMFF. One aspect of this multidisciplinary project was to deploy 100 satellite tags on swordfish, marlin and sailfish in sites around the Indian Ocean over a period of three years (2019-2021).

We present here the results of these tagging efforts.

METHODS

Tagging was led by experienced staff from IFREMER and COOOL who have worked to develop a detailed and regularly updated protocol to maximize the duration of tag deployment, while ensuring the safety, health and wellbeing of both the fish and the crew (see Tagging procedure). Marlin and sailfish were caught by pole and line. Swordfish tagged in this study were caught by longline and were tagged at haul-back, depending on their assessed fitness (see Table 1).

The tags were Wildlife Computers minipat tags programmed to release 3 months (n=13), 6 months (n=57) and 12 months (n=32) after deployment and record depth, temperature and light intensity. The anchorage system evolved throughout the project to improve the duration of the deployment, with a final rigging using a large Domeier anchor, with stainless steel sleeves and a flourocarbon line of 1.20 mm diameter. The length of the line depended on the size and species, i.e. for sailfish and small marlin (50-60 kg) we used 8 cm line length, for all species >60 kg and <140 kg, we used a 10 cm anchorage line, and for all species >140 kg we used 13 cm length.

Tagging procedure

1 - A video should be taken for each tagging event to verify and analyze the procedure.

2 - Once the angler has fought and brought the fish boatside, it should be traced and driven alongside the boat so that it presents a large tagging target. It is generally best to move the boat slowly forward to allow for better control of the fish (Figure 2).

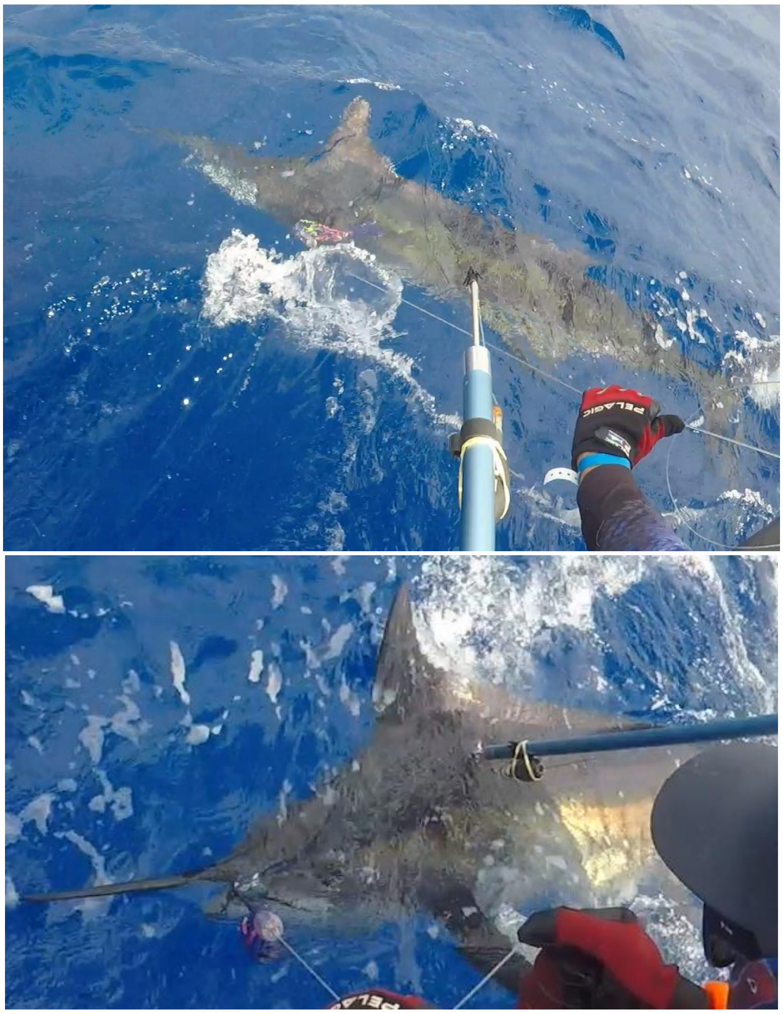

Figure 1. Fish is driven alongside the boat to present a large tagging target (top). The tagging harpoon targets a placement in the pterygiophores (see Figure 3) and the tag is deployed with a firm thrust (do not stab) (bottom).

3 - The fish are brought to the surface where they are assessed for their fitness for tagging (Table 1 for detailed criteria).

It is not recommended to tag fish that are very active or wild when brought near the boat as this can be very dangerous to the crew and the fish themselves, in addition to risking damage to the boat. Furthermore, the more active the fish, the more difficult it is to place the tag in the correct location. The entire tagging process, including the handling of the fish, becomes increasingly difficult in rough seas, which should also be taken into account when deciding to tag.

Table 1. Criteria used to help determine whether a fish is fit to tag or not. If the fish is not fit, it is given time to recover alongside the boat, and released.

Fish fit to tag	Fish not fit to tag
Hook set in the mouth or the rostrum	Point of the hook sticking out around the eye (risk of eye perforation)
A "healthy/lively" fish, with calm and good swimming behaviour	Pale colored fish
Fish with vivid colors	Sign of bleeding in the gills
	Weakened fish, swimming poorly or not at all, moribund
	Fish hooked not in the mouth or rostrum (ex: gill, stomach, back...)
	Fish that does not have an external wound (ex: depredation)

4 - The rostrum of the fish should be held in the hand, preferably by a "snooter". The lasso is placed on the top of the rostrum, pulled tight, and the fish is held in place by tying the line to a cleat on the boat. The snooter allows the fish to be secured while submerged in the water during the tagging process, eliminating the need for a crew member to hold the rostrum of the fish, which can be dangerous. Once the fish is in the tagging position, the person handling the tagging harpoon (the tagger) must stand behind the person handling the fish (the troller) to allow a clean tagging action. The tag should be inserted into the fish in the pterygiophores (Figures 3 and 4) to maximize the chances of the mark holding. This requires access to the back of the fish. Sometimes the back of the fish is not accessible because it can turn sideways. It is the role of the troller to position the fish well.

4 - An attempt to apply the tag should be made only if the fish is calm. The tag should be placed well above the lateral line in the dorsal musculature, away from the head, gills, plates, eyes and other vital organs. Ideally, the anchoring system should be passed through the pterygiophores, which are strong and allow for very good anchorage of the tag (Figure 3). This position of the tag will also promote rapid healing of the wound and minimize the risk of serious injury.

5 - The fish should be tagged with a firm, focused action. Simply place the tag against the side of the fish and push firmly (Figure 2 bottom). Do not stab. The depth of placement of the mark is determined by the length of the stainless steel applicator that extends beyond the tagging harpoon. This applicator should be about 7 cm long, even for the smallest billfish.

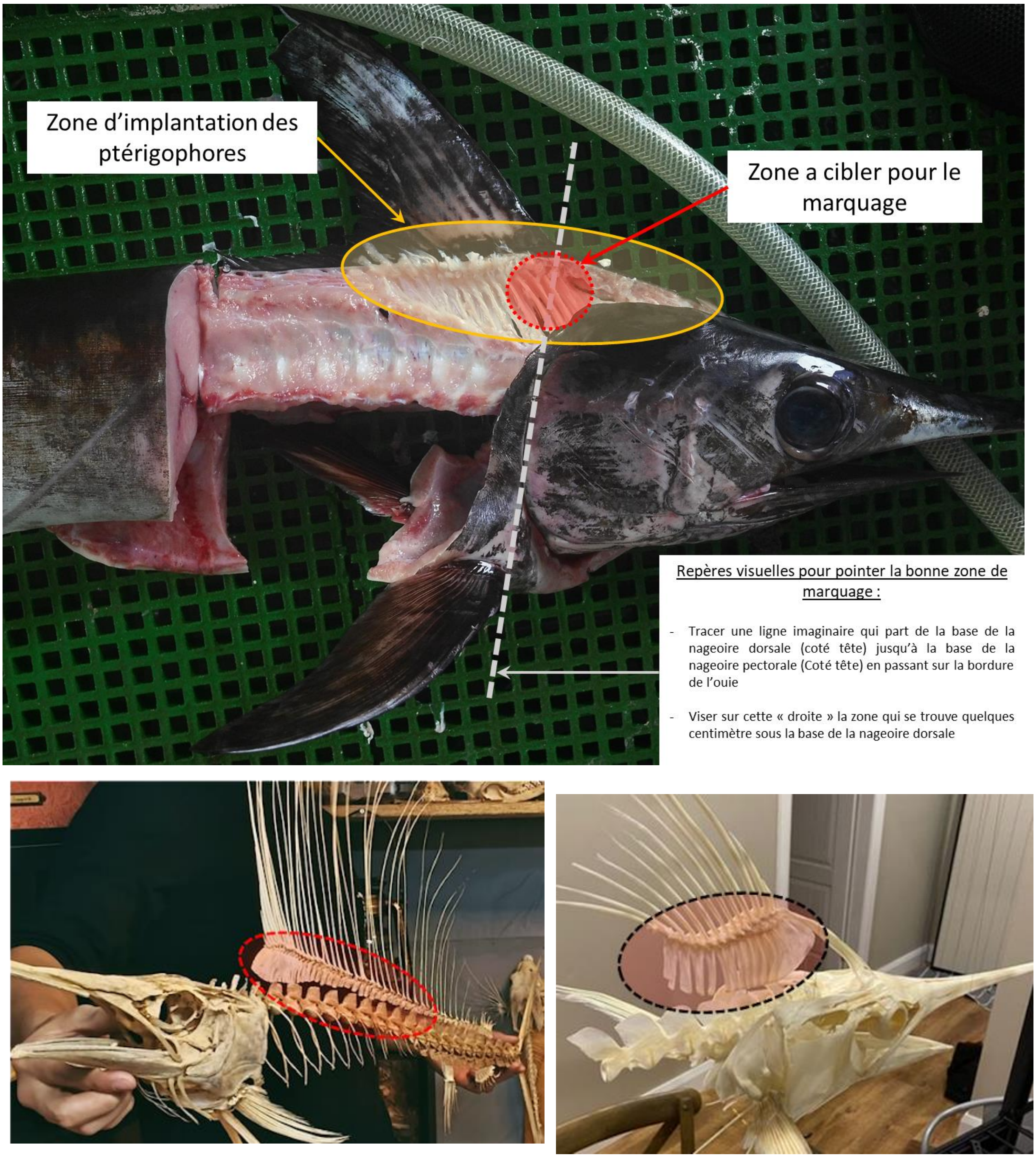

Figure 2. Zone within which to anchor the tag between the pterygiophores of swordfish (top), sailfish (bottom left) and marlin (bottom right).

6 - Before the release, the tagger should estimate the length of the fish (length of the fork of the lower jaw) by using a meter tape (optional).

7 - Once the tag is placed, the tagger must help the angler remove the hook if possible (a disgorger can facilitate this) or cut the line near the fish's mouth.

8 - Revive fish that appear to be exhausted or are having difficulty staying in a swimming position in the water. A commonly used approach for billfish is to hold the fish firmly by its submerged rostrum while the boat moves forward at 2 to 3 knots. This ensures a good flow of water over the gills of the

fish. The fish should not be released until it shows strong signs of life and improvement in skin color, which may take several minutes or more. Great care should be taken during this step, especially in bad weather. The use of a snooter is safer for this step than holding the bill by hand.

9 - The tag information sheet should be immediately filled out and we asked that both the sheet and tagging video be returned to the FLOPPED team as soon as possible.

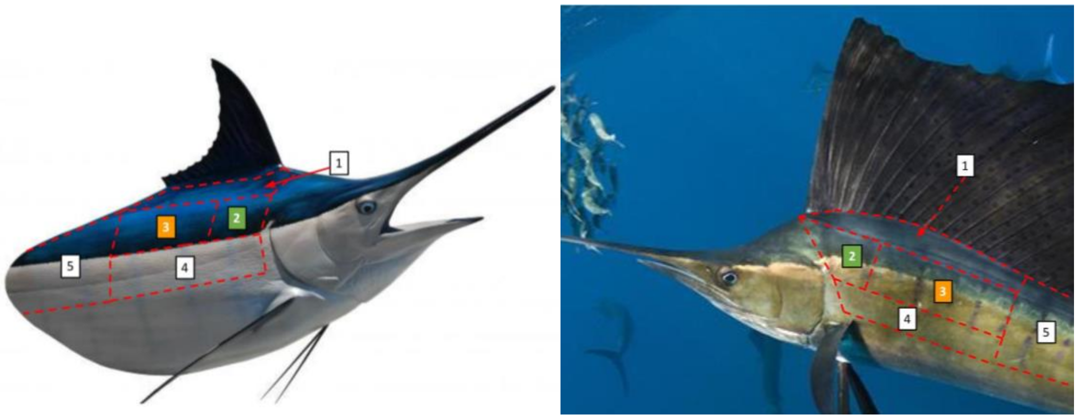

Figure 3. The tag position zones analyzed for marlins (left) and sailfish (right), with optimal positions indicated with the green boxes, and acceptable tag positions indicated with the orange boxes. Tags should not be deployed in the zones indicated by the white boxes.

Table 1. Criteria used to help determine whether a fish is fit to tag or not. If the fish is not fit, it is given time to recover alongside the boat, and released.

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	Weakened fish, swimming poorly or not at all, moribund
	Fish hooked not in the mouth or rostrum (ex: gill, stomach, back...)
	Fish that does not have an external wound (ex: depredation)

Due to the large number of tags that must be deployed in the course of this project, the FLOPPED team has worked to develop a network of sports fishers in the Indian Ocean to aid in tagging efforts. The FLOPPED team provided hands-on training to the fishers when possible, which then allowed the fisher to tag independently.

Swordfish differ from the other species in that they tend to inhabit a much deeper zone, making them difficult to capture alive and in sufficient condition to tag. Throughout the FLOPPED project, we tested different fishing strategies to capture swordfish alive, including tagging of live individuals at the end of a commercial longline, and working with local fishers to test vertical longline techniques, similar to those deployed by Sepulveda et al. 2015 and Romanov et al. 2016.

Tagging expeditions were made to Rodrigues, Mayotte, and Seychelles and locally in Reunion Island. We sent tags to sports fishers in Kenya, which were blocked at customs, as well as to an observer of a Portuguese vessel targeting swordfish and sharks in the southern Indian Ocean. We partnered with the University of Tasmania, who helped us deploy tags in Western Australia; however, we were unfortunately unable to successfully tag in the north central parts of the Indian Ocean basin (Figure 4).

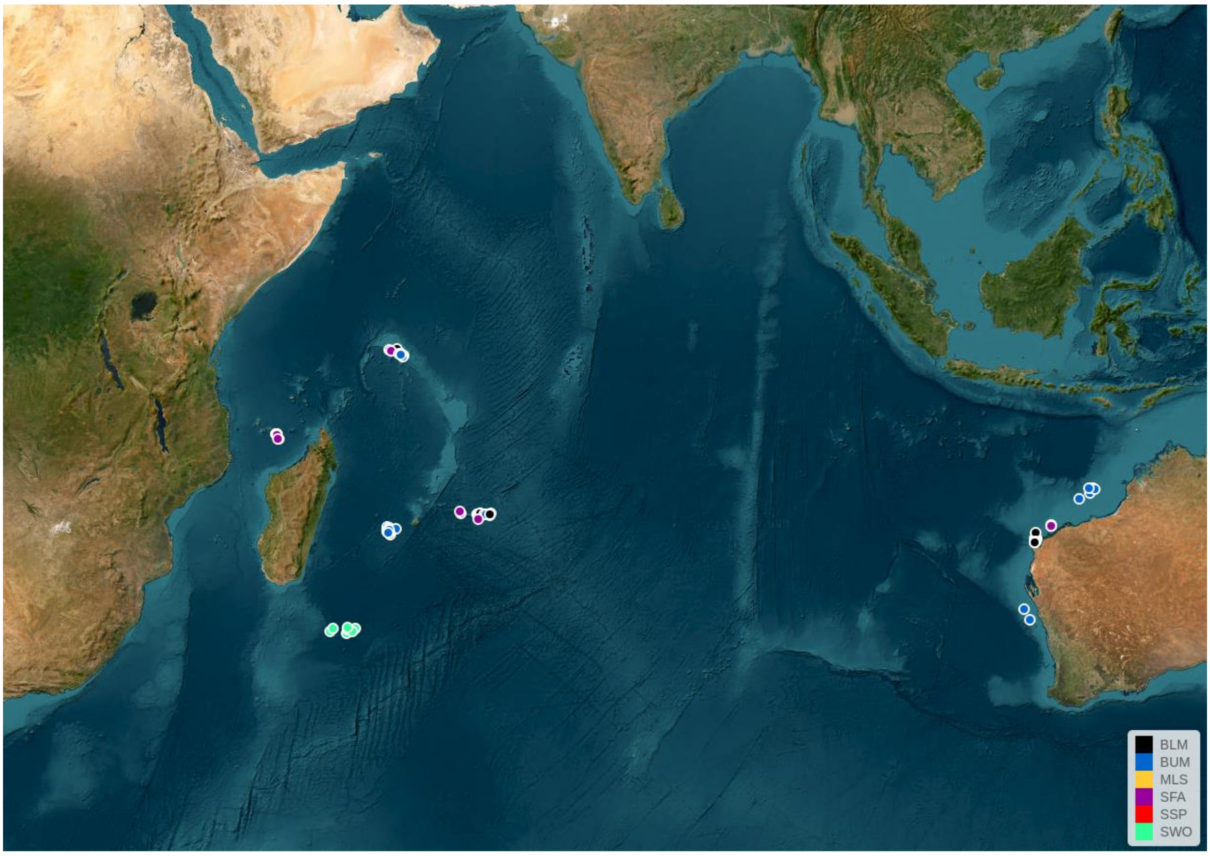

Figure 4: Map showing the different tag deployment points around the Indian Ocean for black marlin (BLM, black dots), blue marlin (BUM, blue dots), striped marlin (MLS, yellow dots), sailfish (SFA, purple dots), shortbill spearfish (SSP, red dot), and swordfish (SWO, green dots) in the waters around Reunion Island, Western Australia, Mayotte, Rodrigues, Seychelles and south Reunion.

Trajectories were analyzed using the multiple modeled speeds (3km/hr, 5km/hr, 10km/hr, 15km/hr, 20km/hr) and the optimum speed was determined using the algorithm scoring delivered by Wildlife Computers analyses and additional criteria to ensure that the trajectory did not cross land and the trajectories themselves were reasonable relative to the biology of the animal. In general, the speeds selected were between 10-20 km/hr.

RESULTS

Since the project began, we have deployed 102 tags on 6 different species, including swordfish, sailfish, and black, blue, and striped marlin and a shortbilled spearfish in 6 different sites (in the waters around Reunion, Mayotte, Rodrigues, south of 25°S of Reunion, Seychelles, and Western Asutralia) (Figure 4, 5).

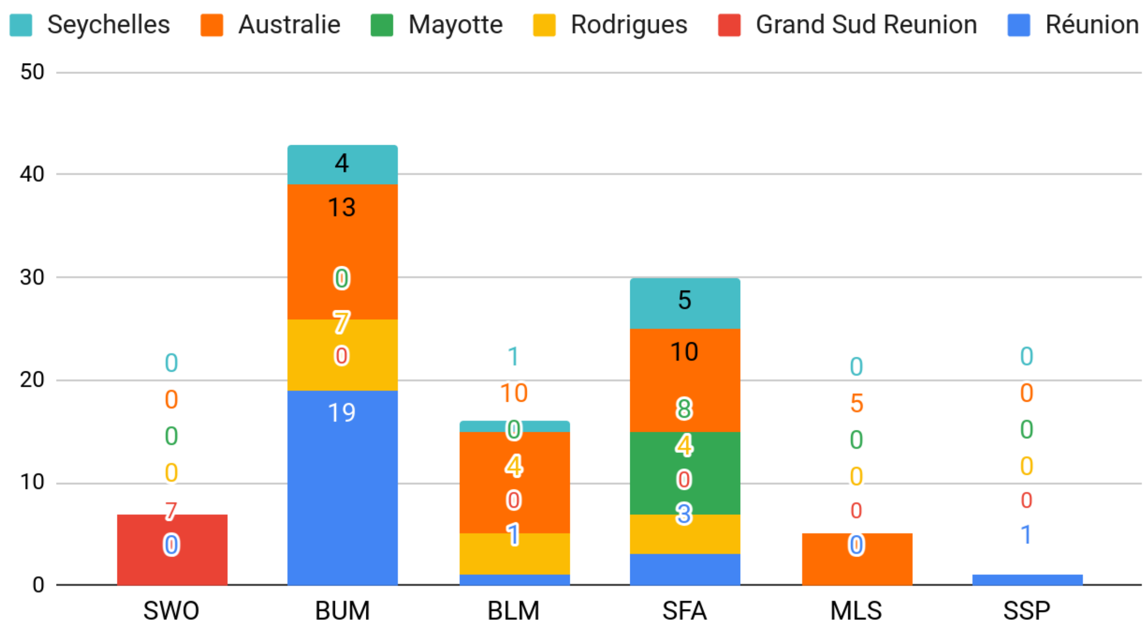

Figure 5. Summary of the 102 tags that are currently deployed, or have popped from tagging sites in the Indian Ocean. Species codes refer to blue marlin (BUM), black marlin (BLM), striped marlin (MLS), sailfish (SFA), shortbill spearfish (SSP), and swordfish (SWO).

Of the 102 tags that have been deployed, 96 have released from the fish and four are still deployed. The average duration of tag deployment was about 32% of the programmed time. The longest deployment was 207 days, or about 7 months. Of the 19 tags that never reported data, 14 of these were programmed to release after 360 days.

Four tags were retained on the fish for < 1 day and did not have sufficient data to calculate positions or trajectories. Forty-six tags in total either released prematurely or were labeled as a "floater", likely either due to an issue with the anchoring system (n estimated to be 3), to an improper tag positionment, or due to a fish mortality. About 20% of the tags deployed experienced a pin-break, a manufacturing error where an external force pulls on the tag and breaks the pin. Nineteen tags never transmitted a signal even after the programmed release date, due as well to manufacturing issues associated with the battery life. In summary, 53% of the tags released earlier than programmed due to deployment issues or mortality and 37% due to manufacturing error.

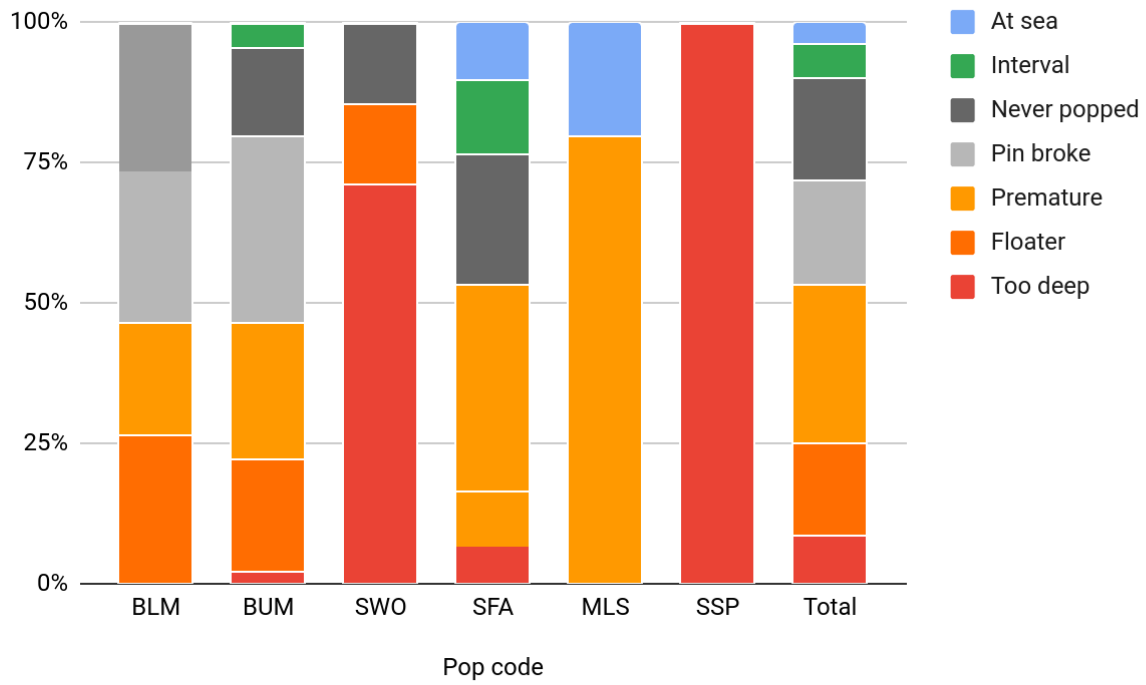

Figure 6. The percent of the time that the code for the release of the tags ("pop") was given by Wildlife Computers per species, and the possible explanations for the release. Too deep - the tag detected that it was getting dangerously close to its maximum structural depth. Floater/Premature - the tag stayed within four meters of a constant depth for more than one day. Pin broke - Some external force pulled on the tether and broke the pin. Never popped - no signal was ever sent by the tag. Interval - the tag ran to the configured end of the deployment and the animal survived. At sea - the tag is currently deployed and no information is yet expected.

The experiment of tagging swordfish from the commercial longliner in the southern Indian Ocean was not successful in terms of fish mortality, and thus tag deployment duration. Swordfish were likely to have been extremely fatigued from remaining on the longline over several hours, and appear to have died not long after the tagging event as the depth of 57% of the just-tagged fish descended to great depths, indicating mortality and sinking, and the tags popped not long after (average deployment duration of 6.4 days, Figure 7), resulting in very short trajectories (Figure 8).

Pole and line tagging of the other species appear to be much more successful with the average tag duration of these events of being 51 days for BUM, 56 days for BLM, 65 days for MLS, and 123 days for SFA (Figure 7). The single SSP that was tagged did not survive the tagging event, and the tag popped before the end of the first day.

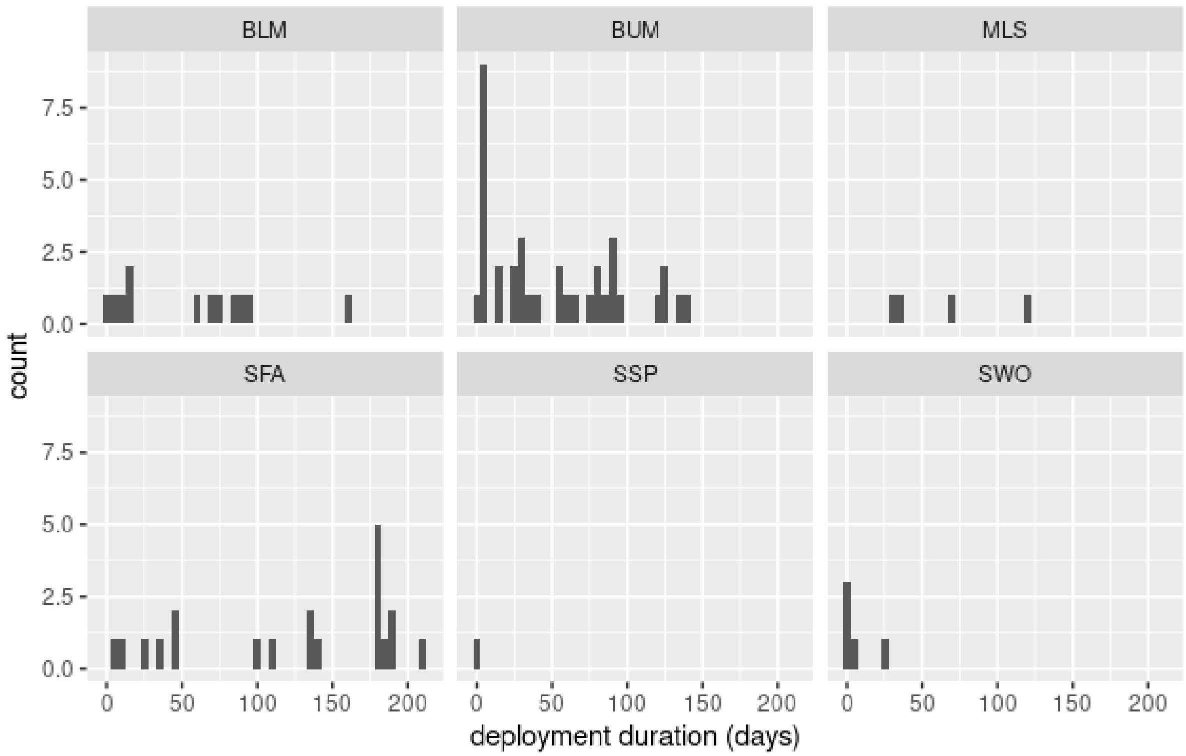

Figure 7. Deployment duration in days of each tag by the species that was tagged. Species codes as in Figure 2.

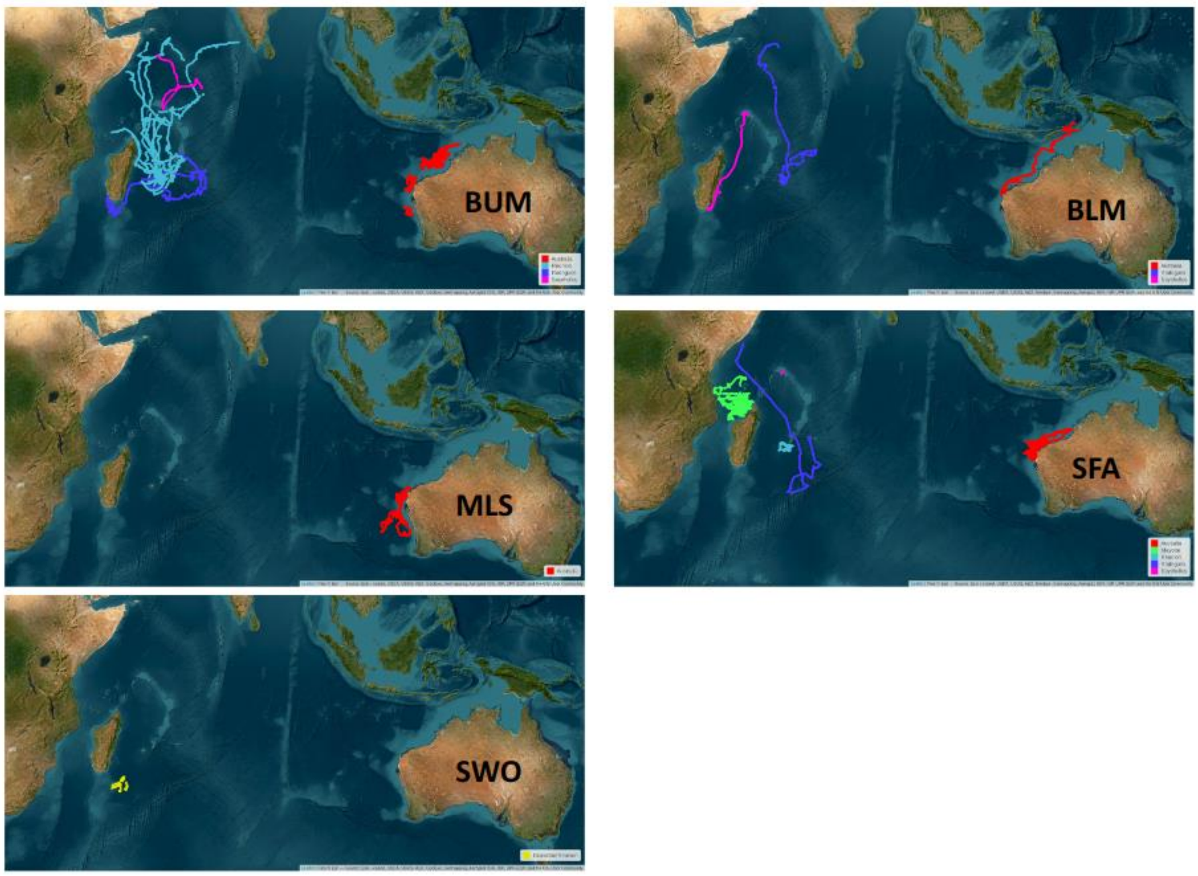

Figure 8. Trajectories of SFA (top left), BUM (top right), BLM (top right), MLS (middle left), SFA (middle right) and SWO (bottom left) tagged in this study. Species codes as in Table 2. SSP is not shown as no trajectory data were transmitted.

Trajectory data across all species tagged do not indicate mixing between the eastern and western basins (Figure 8). In fact, fish tagged off Western Australia appear to remain in the nearshore waters, with only one MLS individual venturing beyond the EEZ and one BLM moving into Indonesian waters. SWO trajectories are too short to identify a pattern, though the tag of one SWO endured for about 1 month, and the individual appears to stay relatively close to the capture site. In contrast, in the western basin, BUM and BLM have much longer trajectories which show a clear south to north movement from the capture sites in Reunion, Rodrigues, Mayotte and Seychelles moving fairly rapidly into the presumed spawning region off the Somali coast. SFA have a more variable pattern of movement, with a high degree of residency in the coastal zones as well as an individual making a long distance trajectory (i.e. between Rodrigues to the southern Somali coast).

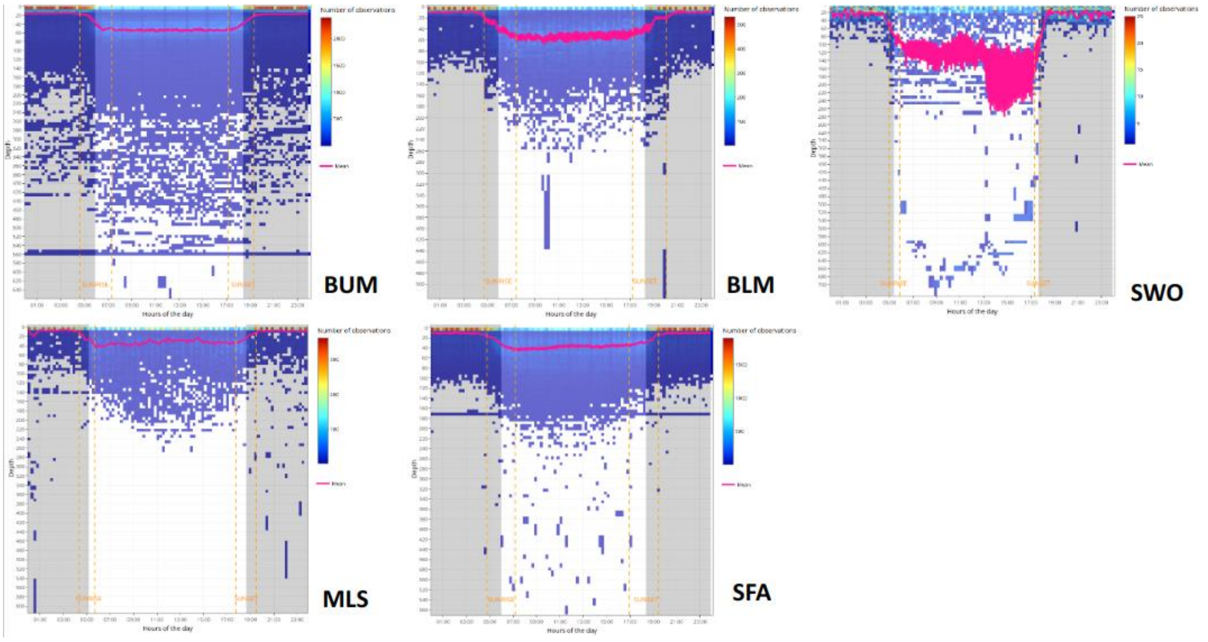

Figure 9. Depth observations depending on the time of day for BUM, BLM, SWO, MLS and SFA. Species codes as in Figure 2.

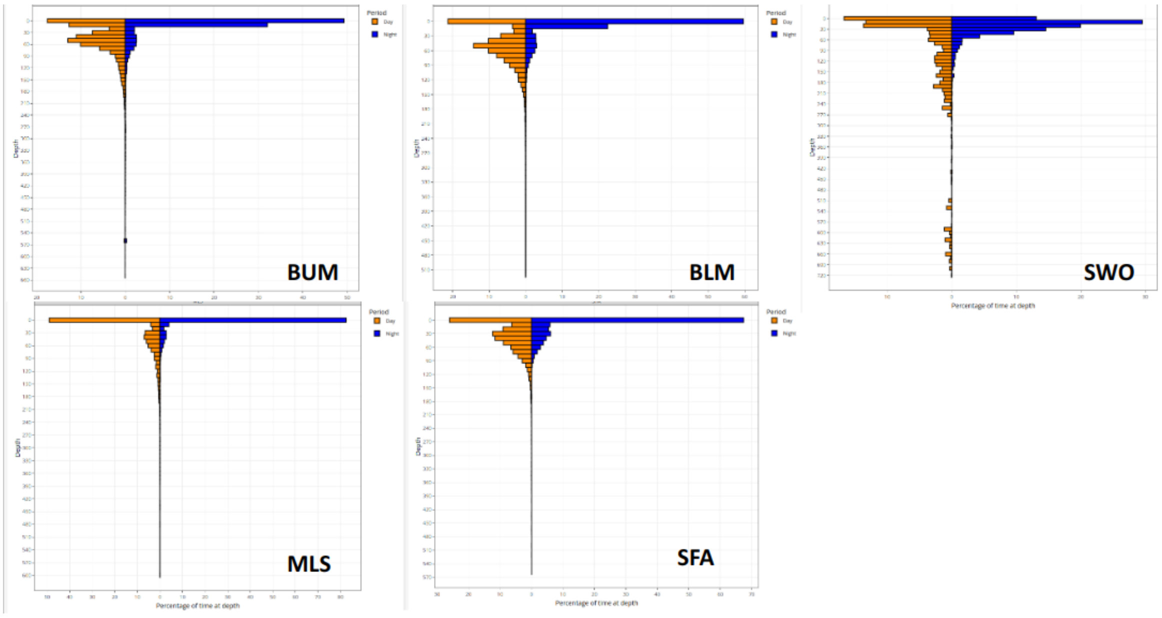

Figure 10. Percentage of time at depth per day (yellow) and night (blue) for BUM, BLM, SWO, MLS, and SFA. Species codes as in Figure 2.

Depth profiles show that all species tagged inhabit deeper waters durign the day and spend mre time in shallower waters at night (Figure 9 and 10). BUM, BLM and SFA appear to spend significant time within the top 100-150 m during the day, MLS spend a larger proportion of the time at the surface with less time down to about 120 m. Swordfish have a deeper distribution overall, with depths ranging up to 600 m during the day and shallower at night (Figure 10). Depths > 600 m in the figures are likely due to fish mortality and sink rather than a true depth range (Figure 9); however, their day-time depth distribution is much more variable than the other four species (Figure 9). At night, they are found at high frequencies throughout the top 100 m, in contrast to other species which spend a substantially larger amount of time at the surface at night (Figure 10). We find that all species spend less time at the surface during the full moon (data not shown).

DISCUSSION

The tagging work package of the FLOPPED project deployed 102 tags on six billfish species found in the Indian Ocean, which is considered a major success given the restrictions imposed by the global pandemic. The data derived from this project can lead to significant insights into movement and behaviour patterns of these species that can have important implications for their assessment and management. We are awaiting the transmission of the final four tags, and a more detailed analysis of the tagging data will continue. In combination with the biological information obtained via the sampling of captured billfish, as well as parallel genetic and larval studies, we hope to better identify the reproductive grounds of these important IOTC species.

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