**FAD Watch: a collaborative initiative to minimize the impact of FADs in coastal ecosystems**

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Abstract

The FAD-Watch project is a first multi-sectorial initiative developed to prevent and mitigate FAD beaching across islands in Seychelles, in which the coastal recovery is applied as a mitigation measure. It is the result of a collaborative work among the Spanish Tuna Purse Seiner fishing representatives (OPAGAC), Island Conservation Society (ICS), Islands Development Company (IDC) and Seychelles Fishing Authority (SFA). The FAD detection system was setup by OPAGAC for 6 buffer areas (Alphonse, Farquhar, Desroches, Poivre, Aride and Silhouette islands), which make possible alerting ICS when FADs crossed buffer areas within 5 and 3 nautical miles of any of these islands. For each intercepted FAD, ICS collected information about the location, habitat type, purse seiner vessel, FAD design, entangled fauna, and fate (removed or not; & disposal method). In order to evaluate the beaching rate and entangling potential of FADs of the target fleet, information was complemented both by buoy tracked data and by data collected on the frame of the voluntary agreement for the application of good practices. FADs tracked in EEZ of Seychelles the 0.8% in 2016 and 0.5% in 2017 impacted the coast of the archipelago. During this period, a total of 19 FADs were intercepted by ICS in the buffer areas. FADs crossing EEZ of Seychelles and the beaching events have been reduced on 20% and 41% respectively, during 2016 to 2017 period. Results show how the FAD-Watch initiative in combination with other mitigation options could add great value to the package of mitigation measures on the reduction of FADs impacts on vulnerable coastal and pelagic habitats.

## 1. Introduction

The introduction of the tropical tuna purse seine (PS) industry in early 1980s in the Indian Ocean has contributed considerably to increase the total tropical tuna catch in the region. The catch growth due to this fishing gear run in parallel with that experienced by other fisheries, mainly driftnets, fresh-tuna longlines and pole and line. Between 2012 and 2016, 37% of the tropical tuna catch corresponded to PS followed by bait-boat and hand-line, longline and gillnet with around 20, 18, and 17% of the total catch, respectively. By species, skipjack (42.9%) and yellowfin (42.8%) are the main target species, followed by bigeye (10.6%) and albacore (3.7%).

The capacity of tuna PS to catch tropical tunas has increased by the use of drifting fish aggregation devices (FADs) and the technology used to locate them, first introduced in the

Indian Ocean in the early 90s (Fonteneau et al., 2013; Lopez et al., 2014). Since then, the use of FADs by PS has been increasing constantly up to 2015 when FAD limitations started to be implemented in the Indian Ocean (IOTC Res. 15/08, 16/01 and 17/08) ). Nowadays, FAD-sets contribution to the total tropical tuna (skipjack, yellowfin and bigeye) catch is around 25-28% in the Indian Ocean, mainly skipjack.

The technological development of associated monitoring equipment (e.g., radio beacons, satellite-linked GPS buoys or satellite-linked echo-sounder buoys) has led to the PS fishery to improve fishing efficiency, in terms of searching time and successful catch rates (Dagorn et al., 2013; Lopez et al., 2014). In parallel to this development, there are concerns about the contribution of FADs to the catch of small yellowfin and bigeye, the increase of bycatch and the potential negative effects on the environment and marine habitats due to ghost fishing, and FAD loss (Dagorn et al., 2013; Filmalter et al., 2013). Many FADs may eventually end up sinking or reaching coastal ecosystems such as beaches, coral reefs or mangroves (i.e. beaching). According to Maufroy et al. (2015) 10% of the total number of FADs deployed by the French fleet in the period between 2007 and 2011 ended up beaching in the coasts of the Indian Ocean. Davies et al. (2017) also detected high potential FAD beaching impact in the Seychelles area, being the estimated beaching rate as higher than 30% in specific deployment seasons. FADs are currently built by highly durable synthetic materials such as netting made from nylon, net corks from Ethylene Vinyl Acetate (EVA), or pipes from polyvinyl chloride (PVC) (Murua et al., 2018). Thus, most of these materials can accumulate for long periods in sensitive marine and coastal ecosystems, as observed during the survey on beaching events in Seychelles Islands (i.e. Desroches, Poivre, St. Joseph, Alphonse, St. Francois, Farquhar and Cosmoledo) conducted by the Island Conservation Society (ICS) for the quantification and evaluation of the beaching events and impacts (Balderson and Martin, 2015). The FADs found in the coast were mainly non-entangling built with synthetic materials (Balderson and Martin, 2015).

Considering all these potential impacts, IOTC has been pioneer in adopting bycatch mitigation measures for the use of non-entangling FADs and promoting the use of more sustainable materials in their construction, such as biodegradable materials. As such, Resolution 13/08 superseded by Resolution 15/08, and then by Resolution 17/08 established procedures on FAD management plans, including the development of improved FAD designs to reduce the incidence of entanglement of non-target species and the impacts on coastal habitats. Resolution 17/08 also establishes a maximum number of instrumented buoys active and followed by any PS at 350 and restricts the annual purchase of instrumented buoys to 700 for each PS vessel.

Likewise, very similar guidelines are being gradually introduced in the other t-RFMOs: IATTC (C-13-04, C-16-01, C-17-02), ICCAT (14-01, superseded by 15-01, 16-01), and WCPFC (CMM-17-01). ICCAT requires the replacement of existing FADs with non-entangling FADs by 2016 and with biodegradable FADs by 2018 (Rec. 16-01) and IATTC by 2019, including the use of biodegradable materials (C-17-02). In the wake of IOTC, the rest of the tRFMO managing tropical tunas have also introduced limits on the number of active FADs: 350 in the Western and Central Pacific Ocean, 500 in the Atlantic Ocean and from 70 to 450 active FADs, depending on the PS size, in the East Pacific Ocean.

Besides the measures proposed by RFMOs, there are also actions carried out by private sector and NGOs that boost the implementation of sustainable fishing standards by tuna processors and retailers (Lopez et al., 2017; Zudaire et al., 2017). And coastal countries like Seychelles are now taking a stronger approach to FAD management in their waters. Seychelles produced its own Fish Aggregating Device Management Plan in 2015. This forms part of the overall policy of the Government of Seychelles on the management of by-catch.

FADs are not new to Seychelles and the concern over their environmental impact has long been under scrutiny. However, the direct and indirect impacts of FADs on marine coastal habitats in Seychelles have been poorly documented (Balderson and Martin, 2015; Davies et al., 2017; Maufroy et al., 2017). Over the past 10 years, the ICS noticed that FAD beachings were becoming increasingly common on the reefs and islets especially in the outer islands of the Seychelles. This led ICS to conduct a baseline survey around St. Francois atoll in 2015 to quantify the beaching events, describing their environmental impact, identifying which vessels/companies are responsible for the FADs and offering advice on mitigation measures to be implemented by the relevant authorities and administrators. The results were presented at the 11th session of IOTC Working Party on Ecosystems and Bycatch and confirmed that entanglement of wildlife is a concern with the use of FADs and 'beached' FADs impacting on coral, with 39% of all FADs found impacting on coral reef habitats (Balderson and Martin, 2015). It also highlighted, another significant problem attributed to FADs being marine pollution. More than 70% of FADs encountered were made of synthetic material.

Following this work, the Spanish Tuna PS fishing representatives (OPAGAC), Island Conservation Society (ICS), Islands Development Company (IDC) and Seychelles Fishing Authority (SFA) signed an agreement to develop a FAD-Watch programme. A one-year MoU was signed on the 5th July 2016, with the aim of preventing and mitigating FAD beachings across islands in Seychelles where ICS has a presence.

With this work, we report progress on the ongoing FAD-Watch programme and provide results regarding: i) Number of FADs followed by the target fleet (15 purse seine vessels associated to OPAGAC) drifting through the EEZ of Seychelles and the buffer areas and ii) Number of beaching episodes in the Seychelles and defined buffer areas estimated by the buoys' tracks during 2016 and 2017. The document also assesses the ecosystem impacts of the target fleet using FADs in Seychelles; how the FAD-Watch programme initiative is assisting the Seychelles to mitigate or eliminate those impacts; and how the lessons learned through the programme can assist implementation of similar initiatives in other areas.

## 2. Material and methods

### *2.1. Arrangements of the FAD-Watch Programme*

ICS is responsible for the implementation and coordination of the FAD-Watch programme, which primarily includes intercepting, removing FADs from reefs and beaches on all islands where teams are present and reporting back to the partners on progress. The FAD detection system was setup by target fleet for Alphonse, Farquhar, Desroches, Poivre, Aride and Silhouette islands (Figure 1). It was setup in such a way that ICS would receive an alert on a dedicated laptop whenever a FAD arrives within 5 nautical miles of any of these islands and a second alert once the FAD is within 3 nautical miles. The two buoy providers servicing the target fleet, namely Marine Instruments and Satlink, configured software on this laptop which provided GPS coordinates, trajectory and estimated projected time of beaching. The system was checked once per week by the ICS officers and Science Coordinator. Once an alert was received the information was then relayed to the respective island teams in order for them to plan and intercept the FAD. ICS teams still needed to remove FADs from reefs and beaches on those islands which were neither detected nor intercepted using this system as they belonged to other fishing companies not part of this programme.

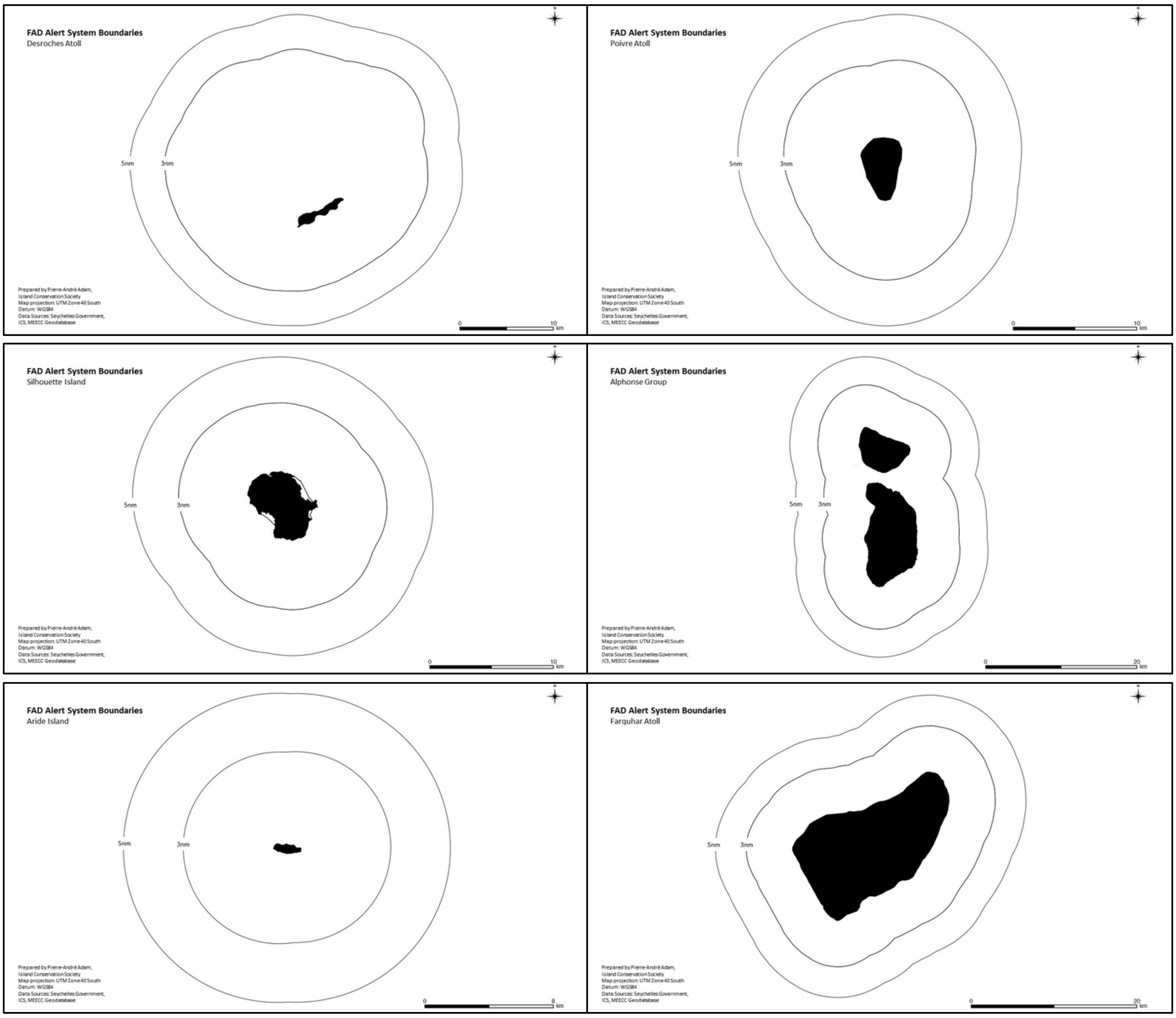


Figure 1. Defined buffer areas (Alphonse, Farquhar, Desroches, Poivre, Aride and Silhouette islands) including the alerts areas, first alert when a FAD is within 5 nautical miles of any of these islands and a second alert once the FAD is within 3 nautical miles.

OPAGAC provided funding for ICS to cover costs of fuel, labour, equipment and project co-ordination through the duration of the programme, which is still ongoing. IDC provides support to ICS on the islands where FAD removal is taking place. This includes the use of boats (18ft fiberglass boat) and skippers, as well as land-based resources such as tractors to move and store FADs once they are removed from the water. Once the FADs are retrieved, when possible, some material, such as rope and wood, is recycled on the island. Other FAD material such as buoys are stored and taken to Mahé on IDC barges where they are disposed and/or recycled in collaboration with the purse seine fleet. Although not undertaken yet, arrangements can be made with support vessels to visit islands to collect FADs for disposal/recycle when needed, with the approval of SFA.

Once a FAD is encountered, ICS collects information about the location and type of habitat in which it was found, information about the vessel that deployed it, and FAD characteristics. A description of the fate of the FAD (removed or not; and disposal method) is also registered.

Figure 2 shows the Concept of Operations of the FAD-Watch Programme. Annex 1 include the forms used by ICS to collect the information.

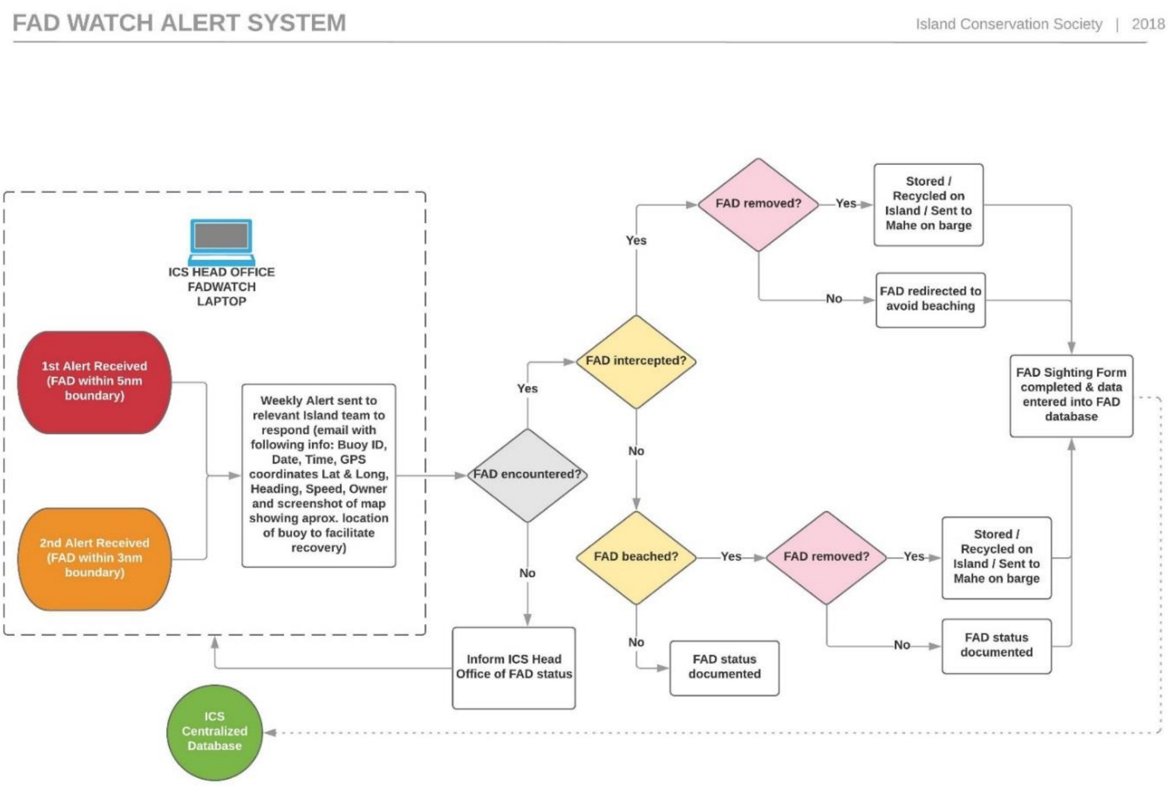


Figure 2. Concept of Operations of the FAD-Watch Programme.

### *2.2 Tracking*

To conduct the analysis presented in this document, the tracks of the FAD buoys of target fleet (OPAGAC) in 2016-2017 period was provided to AZTI directly by the buoy manufacturer companies. Moreover, since September 2015 AZTI is receiving this data on a monthly basis, with a two-month delay with the main purpose of monitoring the number of active buoys (Santiago *et al.*, 2017). Data is received in csv files, independently for each vessel, and contains daily records of all the active buoys managed by each individual vessel. The information included in the csv files is: date [dd-mm-yy], time [hh.mm], individual unique buoy identified code, latitude and longitude [expressed in degrees and minutes in decimal values] and speed [knots].

The following parameters were estimated for the EEZ of Seychelles and for the FAD boundaries identified in the FAD-Watch programme:

(i) total number of buoys recorded (estimated as the number of the unique identifier codes present in the zone);
(ii) entries and exits in terms of number of records (i.e. all crossing events irrespective of the buoy identifier code)

(iii) entries and exists in terms of number of buoys (i.e. number of single buoys respective of identifier code computing a single record for entry and/or exit),

(iv) and number of beaching episodes.

Beaching events were estimated as those observations corresponding to the last record of a buoy that intersect with the land surface of Seychelles, occurring outside the port of Victoria and the velocity of the buoy being less than 0.001 knots. The high spatial resolution map of Seychelles was extracted from the GADM database (www.gadm.org), version 3.6 (released on 6 May 2018) as a shapefile that consisted of four actual files (.shp, .shx, .dbf, .prj). The map overlay analysis was conducted using the function *over* of the R package *sp* (https://cran.r-project.org/web/packages/sp). A geodesic buffer of 0.005 degrees (equivalent to 550m at the latitude of Seychelles) was applied to extend offshore the area of occurrence of potential beaching episodes.

### *2.3 Assessment of FAD design and degree of entangling potential*

Data collected by AZTI between 2015 and 2017 in the context of the voluntary agreement for the application of Code of Good Practices for responsible tuna fishing activities established in 2012 by the two Spanish tuna purse seine associations was used to evaluate the entangling character of the FADs used in the Indian Ocean. The aim of this agreement is to use best fishing practices by reducing mortality of incidental catch of sensitive species (sharks, rays, mantas, whale sharks, and sea turtles) and the use of non-entangling FADs to reduce the entanglement risk. Information regarding the configuration (e.g., type of materials, entangling character and dimensions) of FAD components are collected on a regular basis by observers (physical and electronic monitoring system) (Lopez et al., 2017). The classification criteria for the non-entangling character of FAD mesh size was fixed to 7 cm (i.e. 2,5 inches as used by ISSF to classify low entangling risk material). In this sense, there are 7 FADs categories, defined as follows: 1-Completely Conform (i.e. if mesh material is present the mesh size is ≤ 7 cm or rolled in sausages); 2 - net of >7 cm in the inferior part of the raft; 3- net of >7cm in the upper part of the raft; 4: pieces of net >7cm in the underwater part; 5: underwater part with net >7cm; 6: raft and underwater part with net >7cm, 7- not visible. The non-visible FADs refer to devices visited or encountered but not lifted from the water to avoid interfering with the aggregation underneath, breaking the submerged structure or otherwise correspond to FAD not evaluated by the observer. The characteristics of the FADs used by the target fleet between 2015 and 2017 was used in this work to compare with the entangling character observed by encountered FADs by ICS.

In order to evaluate the entangling potential and character of FADs encountered by the ICS at buffer areas and beaches, ICS registered the FAD design (size and type of frame and shade materials, and associated aggregator), FAD condition at recovery, and the impact it may have had on the marine environment (species entanglement or damage to habitats). The data analyzed in this paper runs from January 2016 until December 2017.

## 3. Results

### *3.1. Number of FADs monitored by the target fleet drifting through the Seychelles EEZ (annual number of buoys within the Seychelles EEZ, monthly entries and exits).*

According to the data received from buoys suppliers 12,051 and 9,638 buoys recorded from the target fleet were found within the EEZ of Seychelles in 2016 and 2017, respectively (Table 1). This shows a decrease of 20% in the total number of buoys found within the Seychelles EEZs from 2016 to 2017. A similar decreasing trend was observed in relation to the number of single buoy entries (7,456 and 6,141 in 2016 and 2017 respectively) and exits (8,849 and 7,493 in 2016 and 2017 respectively) to/from the EEZ with a reduction of 17% and 15% respectively. In both years the number of exits were higher than entries that could be explained by those FADs already within the EEZ before the start of the project or deployments of FADs or buoy exchange events within the EEZ of Seychelles. Analyzing this data by months for single buoy entries, i.e., respective of the buoy identifier code and analyzed independently each month, most of the entries occurred from October to March in 2016, over 900 buoys every month except in January (746 buoys), while in 2017 most of the entries were observed between December and March with a peak also found in July and August (Figure 3). For buoys exits, a similar pattern was observed in both years, buoys departed from Seychelles' EEZ mainly from November to December and from May to July.

Table 1. Number of FADs present in the EEZ of Seychelles in 2016 and 2017. Entries and exits in terms of number of records, i.e. all crossing events irrespective of the buoy identifier code. Number of buoys, i.e. number of single buoys computing a single record for entry and/or exit. Net flow (input-output) and beaching episodes estimated from the daily information of the tracks of the buoys.

| Years | 2016 | 2017 |
|---|---|---|
| Total number of buoys recorded in the EEZ | 12,051 | 9,638 |
| Entries in the EEZ - # records | 11,321 | 9,720 |
| Exits from the EEZ - # records | 13,412 | 11,727 |
| Entries in the EEZ - # buoys (blue) | 7,456 | 6,141 |
| Exits from the EEZ - # buoys (red) | 8,849 | 7,493 |
| Difference of entry/exits of # buoys | -1,393 | -1,352 |
| Number of beaching episodes | 98 (0.8%) | 57 (0.6%) |

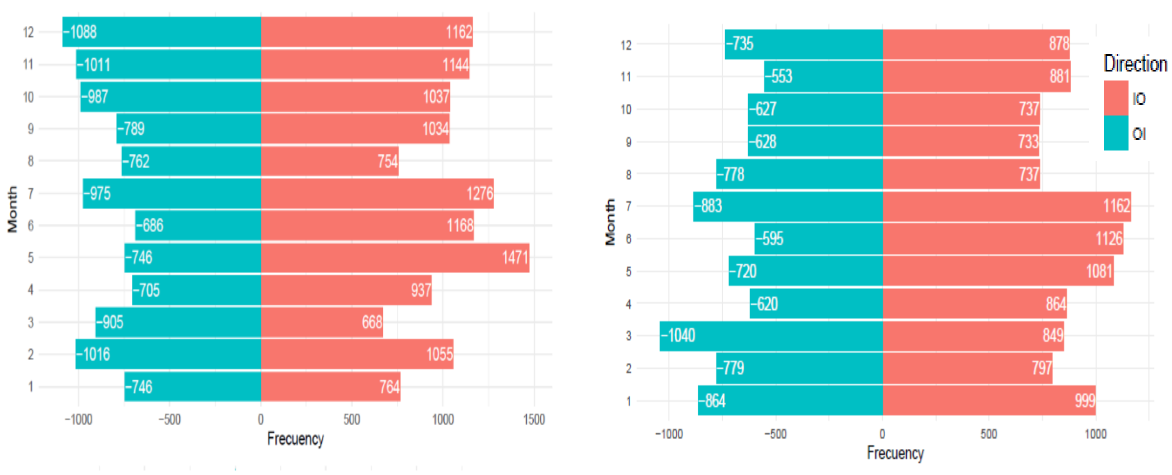


Figure 3. Monthly number of entries/exits of buoys to/from the EEZ of Seychelles in 2016 (left) and 2017 (right). Entries to the EEZ are shown in blue and exist in red.

Most of the buoy entries occurred between latitude 5° South and 7° South, and in lower extent between latitude 0° and 1° South and 10° South and 11° South in both years. Most of buoys exits occurred between latitude 6° South and 7° South in both years, especially in 2017 when buoys exit (2,484 buoys) in this latitude had almost doubled the events of the rest of latitude ranges (Figure 4).

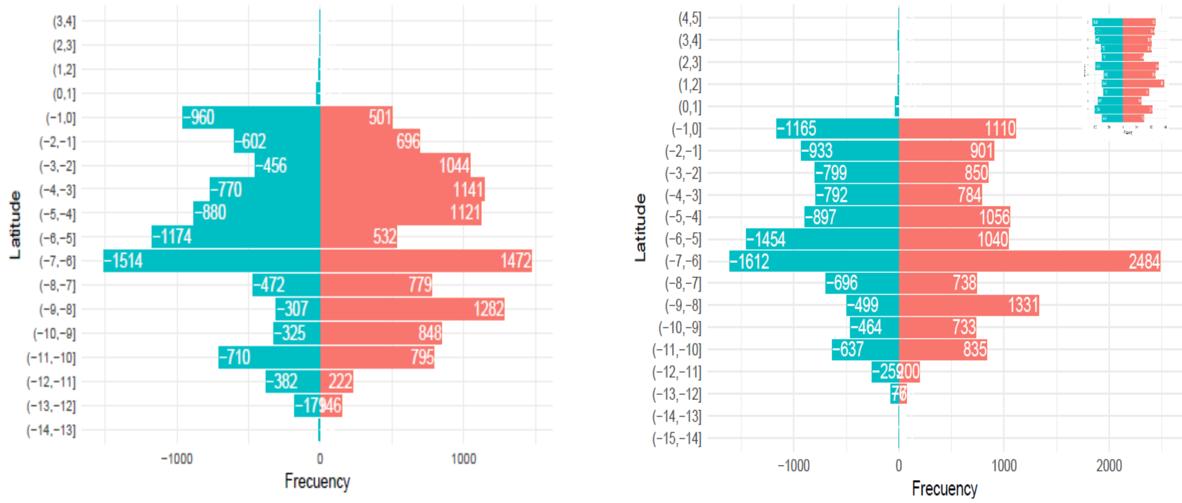


Figure 4. Latitudinal distribution of the number of entries/exits of buoys to/from the EEZ of Seychelles in 2016 (left) and 2017 (right). Entries to the EEZ are shown in blue and exist in red.

### *3.2. Number of beaching episodes in the Seychelles estimated through the buoys' tracks.*

Based on the buoys' track data received from the buoy suppliers and after applying the protocol for beaching episodes described in section 2.2, it was estimated that 98 and 57 buoys ended up beaching during 2016 and 2017, respectively. Similar to the data presented in section 3.1, the beaching episodes in 2017 decreased with respect to 2016, exactly 41% less (Table 1). According to Figure 5 that corresponds to the buoys of the 15 vessels belonging to target fleet, most of the beaching events occurred in the Mahé Plateau with around 40% of the total events observed in both years (Figure 5).

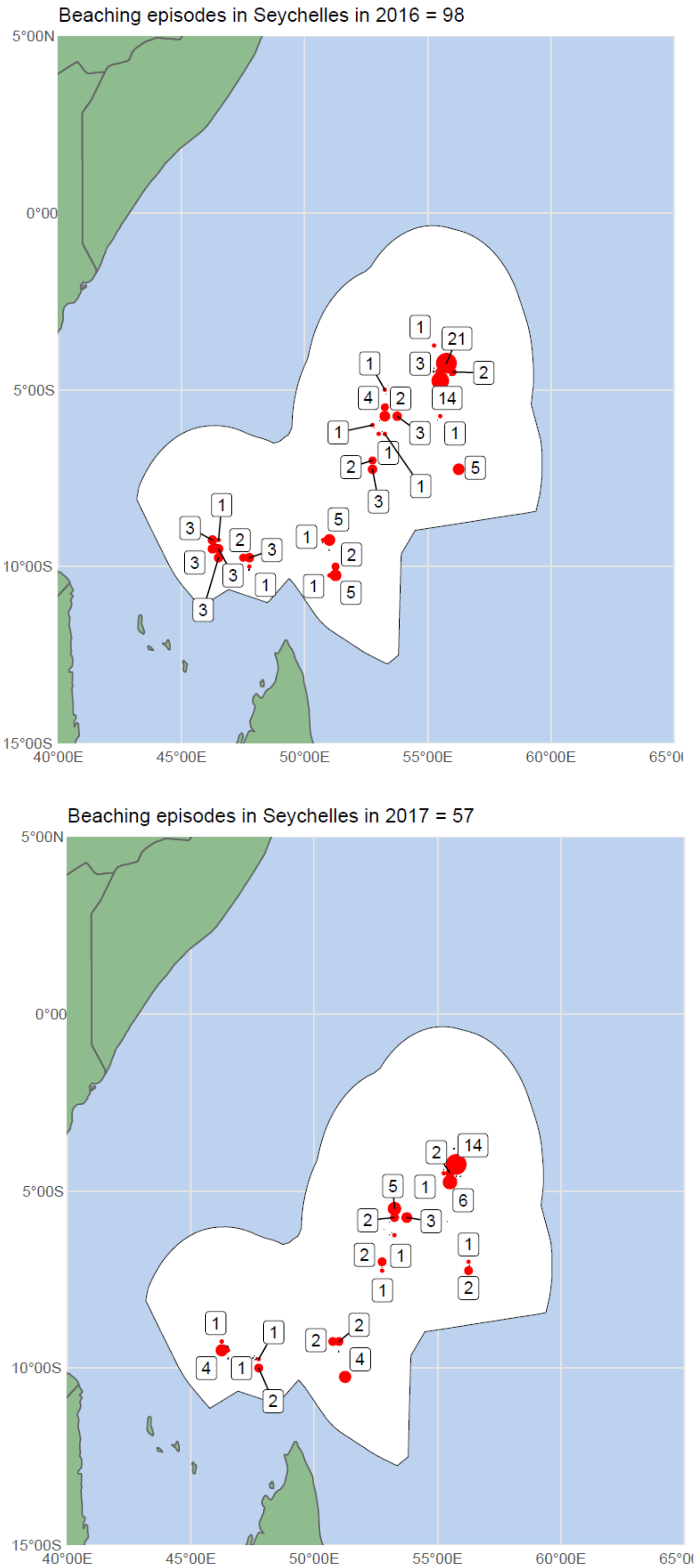


Figure 5. Spatial distribution of the beaching episodes in the Seychelles in 2016 (up) and 2017 (bottom)

***3.3 Number of FADs entering the buffer areas, estimated from the buoy track data, intercepted by ICS over the study period and fate of those FADs. % of FADs at risk of beaching over those transiting the EEZ, buffer areas, and total deployments.***

Table 2 shows the total number of buoys transiting through the FAD boundaries, entries and exits of buoys occurred in each specific area during 2016 and 2017: Alphonse, Desroches, Farquhar, Poivre, Silhouette and Aride. Despite the highest crossing rate found in Alphonse, as reflected by the buoy tracks in specific buffer areas, Farquhar Island had the larger amount of beaching events in 2016 and 2017, 8 and 4 respectively. In relation to the total number of buoys observed in each buffer area, less than 10% of those FADs ended up beaching, with Farquhar and Aride the Islands with the highest percentage in 2016 and Farquhar and Poivre in 2017, 9% and 8% in 2016 and 6% for both in 2017 respectively. Silhouette had no beaching events in both years. Similar to the decrease in the total number of buoys observed within the Seychelles EEZ, each buffer area also recorded a decrease in the total number of buoys as well as entries and exits of buoys occurring between 2016 and 2017.

Table 2. Number of FADs present in the FAD boundaries defined in the FAD-Watch Programme in 2016 and 2017. Entries and exits in terms of number of records, i.e. all crossing events irrespective of the buoy identifier code. And entries and exits in terms of number of buoys, i.e. number of single buoys computing a single record for entry and/or exit. Net flow (input-output) and beaching episodes estimated from the daily information of the tracks of the buoys.

**2016**

| FAD boundary | Alphonse | Aride | Desroches | Farquhar | Poivre | Silhouette |
|---|---|---|---|---|---|---|
| Total number of buoys | 116 | 24 | 96 | 88 | 62 | 40 |
| Entries - # records | 128 | 24 | 101 | 73 | 71 | 44 |
| Exits - # records | 128 | 24 | 102 | 72 | 71 | 44 |
| Entries - # buoys (blue) | 112 | 24 | 91 | 64 | 62 | 37 |
| Exits - # buoys (red) | 115 | 24 | 90 | 70 | 61 | 39 |
| Difference (input-output) | -3 | 0 | 1 | -6 | 1 | -2 |
| Number of beaching episodes | 5 | 2 | 3 | 8 | 4 | 0 |

**2017**

| FAD boundary | Alphonse | Aride | Desroches | Farquhar | Poivre | Silhouette |
|---|---|---|---|---|---|---|
| Total number of buoys | 80 | 19 | 74 | 65 | 31 | 18 |
| Entries - # records | 81 | 18 | 80 | 58 | 36 | 18 |
| Exits - # records | 81 | 18 | 81 | 59 | 36 | 18 |
| Entries - # buoys (blue) | 77 | 18 | 71 | 55 | 33 | 18 |
| Exits - # buoys (red) | 78 | 18 | 70 | 57 | 31 | 18 |
| Difference (input-output) | -1 | 0 | 1 | -2 | 2 | 0 |
| Number of beaching episodes | 3 | 0 | 3 | 4 | 2 | 0 |

According to the data collected by ICS, 19 beaching events that correspond to the target fleet, were recorded in the buffer areas during 2016-2017: out of the 19 FADs, 5 from Alphonse, 1 from Aride, 1 from Bijoutier, 7 from Desroches, 4 from Farquhar, 1 from St Francois. 15 of those FADs (78%) were removed from the ocean/beach, with incineration being the most used method for FAD disposal (Table 3). In addition to the 19 FADs of the studied fleet, more FADs were beached during this period, but the manufacturer was of other vessel companies or unknown. In 36.8% (n=6) of the cases, FADs were found at the beach, followed by 26.3% (n=5) of interceptions at coral reefs and 31.6% (n=6) at Sand/Seagrass flats and 1 at raised sandstone (Table 4).

Table 3. List of disposal methods used for the FAD removed from the ocean/beach during 2016 and 2017 for the target fleet and the total FADs collected (target, non-target and unknown).

| Disposal method | Target fleet | Other fleets | Total Number |
|---|---|---|---|
| Sent to Mahé on Barge | | 3 | 3 |
| Sent to Praslin | 1 | 1 | 2 |
| Recycled on island | 3 | 4 | 7 |
| Stored on island for collection | 2 | 7 | 9 |
| Incinerated on island | 6 | 13 | 19 |
| Landfill on island | 1 | - | 1 |
| Unspecified | 2 | 5 | 7 |
| **Total Number** | **15** | **33** | **48** |

Table 4. Habitat in which FADs were encountered during 2016 and 2017 for the target fleet and the total FADs collected (target, non-target and unknown).

| Habitat | Target fleet | Other fleets | Total Number |
|---|---|---|---|
| Beach | 7 | 56 | 63 |
| Coral reef | 5 | 18 | 23 |
| Raised Sandstone | 1 | 4 | 5 |
| Sand | | 2 | 2 |
| Sand/Seagrass flats | 6 | 4 | 10 |
| Seagrass | | 1 | 1 |
| Seagrass/Beach | | 1 | 1 |
| Seagrass/rubble | | 1 | 1 |
| Unspecified | | 3 | 3 |
| **Total Number** | **19** | **90** | **109** |

***3.4 Number of FADs intercepted by ICS and estimated FADs numbers at risk of beaching in Seychelles on the 2011-2017, for the monitored and non-monitored fleet.***

From 2011 to 2017 ICS intercepted a total of 335 FADs from which 75 corresponded to target fleet vessels, 118 to other fishing vessels and 142 were of unknown origin. In the period between 2016 and 2017 a total of 109 FAD were found by ICS, from which 19 corresponded to target fleet vessels, 37 to other fishing vessels and 53 were unknown (Table 5). 84% of the FADs found had a buoy attached and many had the name of the vessel written on the buoy. However, this information cannot be used to identify the ownership as it refers to the first owner, while since the deployment the ownership change could have occurred.

Table 5. Number of encountered FADs of the target fleet (OPAGAC), other vessels, or unknown

| Year | Target fleet | Other fleets | Unknown | Total Number |
|---|---|---|---|---|
| 2011 | | | 1 | 1 |
| 2012 | 1 | 1 | 9 | 11 |
| 2013 | 1 | 6 | 12 | 19 |
| 2014 | 15 | 20 | 34 | 69 |
| 2015 | 39 | 44 | 43 | 126 |
| 2016 | 8 | 6 | 11 | 25 |
| 2017 | 11 | 31 | 42 | 84 |
| **Total Number** | **75** | **108** | **152** | **335** |

### *3.5 Non-entangling FADs used by target fleet in the Indian Ocean; evolution in recent years*

Under the frame of the Code of Good Practices Programme, between 2015 and 2017, 294 fishing trips on purse seine and supply vessels were evaluated on the target fleet. The design of the FADs was assessed when the devices were encountered at sea because of casual or planned encounter with followed or foreign FADs (i.e. at arrival), and then, when placed at sea after the encounter or as a result of a new deployment (i.e. at departure). The characteristics of 21,052 FADs were evaluated at arrival and 29,544 at departure (note that the same object could be double counted as subjected to the two evaluations, i.e. at arrival and at departure) (Table 6).

Table 6**.** Number of evaluated FADs "at arrival" (when encountered at sea because of casual or planned encounter with followed or foreign FADs) and "at departure" (when placed at sea after the encounter or as a result of a new deployment) by year from 2015 to 2017

| Year | At arrival | At departure |
|---|---|---|
| 2015 | 563 | 912 |
| 2016 | 10881 | 13296 |
| 2017 | 9610 | 15336 |
| Total Number | 21054 | 29544 |

In the Indian Ocean from 2015 to 2017, 36.6% of the FADs at departure (e.g. a first deployment, after a casual encounter or after a planned activity) were classified as not visible (Category 0). Considering the FADs that could be evaluated by observers, 82.3% of the FADs at departure were non-entangling in 2017. The non-entangling classification followed the definitions of the Code of Good Practices, including lower entanglement risk FADs, that are constructed with non-entangling mesh (i.e. mesh size < 7 cm) if the open net is present or enrolled in sausages, and non-entangling FADs constructed with no meshed material as referred in the ISSF classification criteria (ISSF, 2015). As shown in Figure 6 (left panel), a stepped improvement is observed since 2015. It raised from 33.7% in 2015 to 72.7% in 2016 and the highest values during 2017 (82.3%).

A similar pattern is observed when analyzing characteristics of visible FADs at arrival or when encountered at sea (which could refer to followed FADs or FADs encountered by chance). Discarding for the analysis the non-visible cases (53.6% during the study period), the encountered FADs classified as non-entangling increased from 30.3% in 2015 to 73.6% in 2016 and 78.3% in 2017 (Figure 6); which reflects the effort of the fleet to replace traditionally used entangling material by non-entangling materials in the construction of FADs. Nowadays, the use of entangling FADs at sea, is a residual component of the total numbers of evaluated FADs at sea, and thus, potentially minimizing the impacts of this fishing devices on sensitive fauna. Since 2016, for the target fleet, 117 entangling events have been registered in the Indian Ocean, which corresponds to an entanglement rate of the 0.005 (nº of entanglement events/nº of FADs observed).

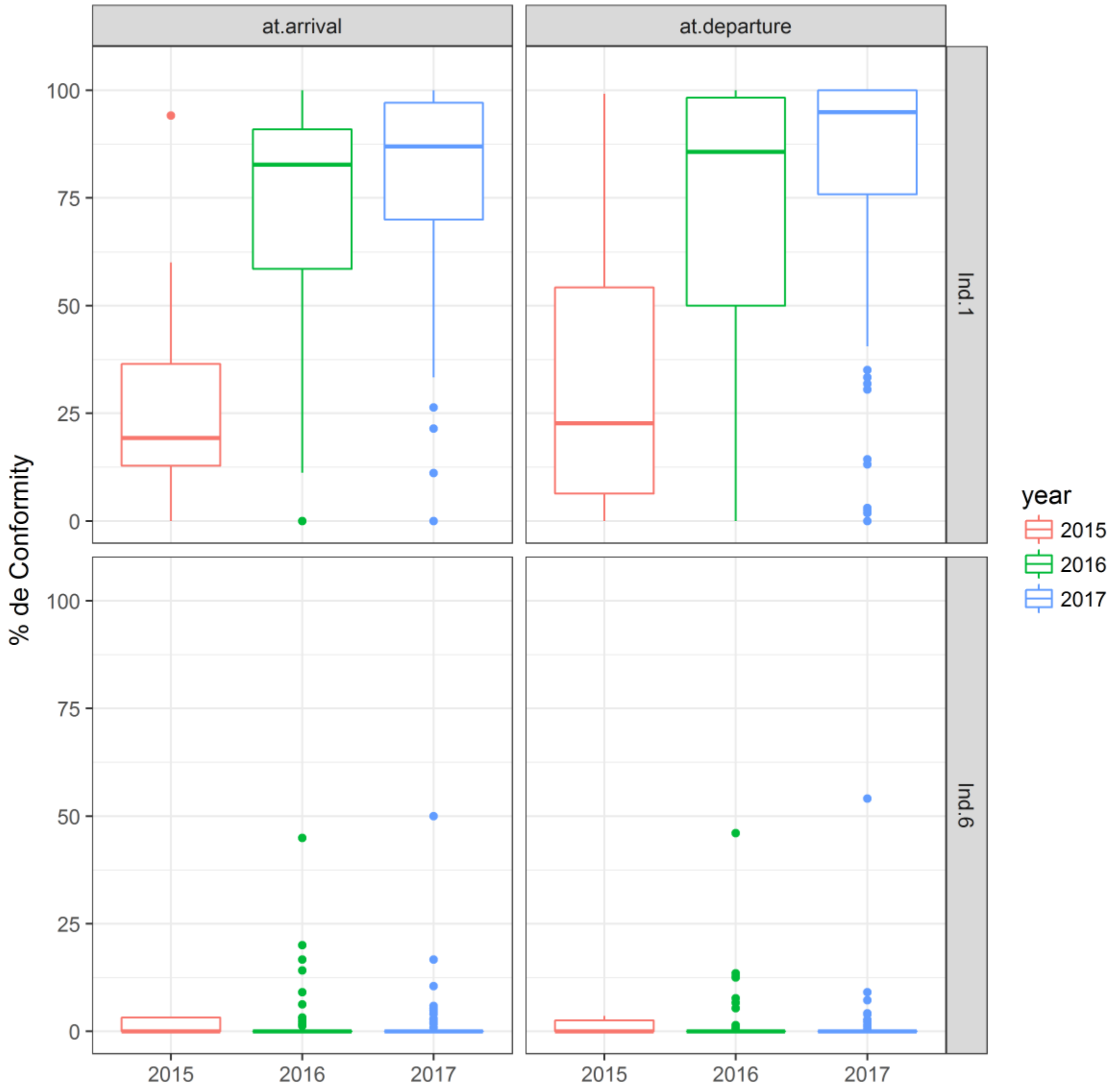


Figure 6. Evolution of the Index 1 (totally conform with non-entangling characteristics) and Index 6 (raft and underwater part non-conform as non-entangling). FAD categories in the Indian Ocean since the beginning of the program (without considering FAD unobserved/unknowns which represent a 34.5% of observations at departure and 53.4% at arrival). The left panel corresponds to the characteristics of FADs at arrival or when encountered at sea casually or intentionally; the right panel refers to the characteristics at departure or left in the water in a deployment or after any interaction.

### *3.6 Design of FADs intercepted by ICS by the target fleet and other fleets, marine fauna entanglements (if any), type of release and fate of the individuals.*

ICS collected information about the materials used for the construction of different components of the FADs (i.e, raft, submerged structure and shade material) from 2011 to 2017. According to this data, the raft of the recovered FADs was generally constructed with bamboo (52.8%), the submerged structure by net in sausages (34%) or synthetic rope (10%) and the primary shade material was fishing net (64%). Focusing on 2016 and 2017 bamboo was used for raft construction in 48% of the cases, for submerged structure net in sausages was used in 33% and synthetic ropes in 9% and shade fishing net was used in 62% of the FADs intercepted.

From the total of 335 FADs intercepted during 2011 and 2017, in 74% of those entanglement of marine fauna was not observed. Coral colonies were the main marine fauna found entangled in FADs, corresponding to 23% of the cases. Out of the 78 coral colonies entangled in the FAD nets 12 were still alive, 13 were dead and the remainder were unspecified. In the case of turtle entanglements (5 individuals), 2 turtles were entangled in curtain nets and 2 were entangled in synthetic rope. Entangled species included 1 Leatherback turtle entangled in a FAD on Aride Island which was alive and released; 1 Olive Ridley encountered dead in a FAD on Alphonse; 2 Hawksbill turtles were found dead on Desroches and St Francois and 1 Hawksbill turtle was found alive on Desroches. Of the 3 turtles that died 2 of the FADs had curtain nets. Except for the Leatherback entangled and released alive that corresponded to a target fleet vessel, the rest of the FADs manufacturers were unknown. Seagrass was recorded to have been entangled in 5 FADs, all of which were recorded on Desroches. FADs generating these entanglements consisted of 2 bamboo frames, 1 bamboo and steel frame, 1 plastic frame and 1 steel frame. Regarding the submerged structure 3 FADs had sausage nets and 2 had synthetic nets, and of the 3 that had sausage nets one had 5 trailing sausage nets, one had 4 trailing sausage nets and one had 1 trailing sausage net.

## 4. Discussion

### *4.1 Evaluation of FAD-Watch activities and overall success of the Programme*

The increasing use of FADs has raised concerns about the potential impacts on target stocks, other vulnerable species and the marine environment (Dagorn et al., 2013). One of the potential impacts in coastal areas is the vulnerable habitat destruction and its accumulation as marine debris with potential economic and ecological consequences. The potential impacts and mitigation options must be analyzed evaluating possible solutions in each step of the fishing operation and FAD life time. The coastal FAD recovery, in combination with other mitigation measures, such as the use of biodegradable FADs and limitation of number of FADs, is one of the best options to be implemented to reduce the potential beaching events and the associated impacts (Davies et al., 2017; Moreno et al., 2018a). In this sense, the FAD-Watch Programme is the first initiative for coastal recovery, quantification and characterization of the beaching events in the Indian Ocean and worldwide.

In regards of the increasing concern, although in general few evaluations have been conducted, some recent works have assessed the fate of the FADs, potential coastal impacts or have detected FAD accumulation zones in the Indian Ocean (Balderson and Martin, 2015; Maufroy et al., 2015; Davies et al., 2017; Maufroy et al., 2017, Moreno et al., 2018a). In the opinion and knowledge of fishermen, the beaching is the second cause of FAD loss after robbery (Moreno et al., 2018a). The potential beaching events detected from trajectories of French fleet beacons occur over in Somalia, the Seychelles, the Maldives and Sri Lanka (Maufroy et al., 2015). The same areas were also identified by skippers operating in the area, except for Sri Lanka (Moreno et al., 2018a). These events depend on season and deployment areas, but the risk of beaching was estimated in an overall high, of 32.3% (Davies et al., 2017). Simulation models show that Seychelles reefs are highly exposed, with the highest probability of suffering beaching from FADs deployed between March and May, and mainly occurring north Mozambique Channel and north west Seychelles (Davis et al., 2017; Maufroy et al., 2017). This could cause physical damage on coral reefs and seagrass meadows, and ghost fishing if non-entangling FADs or low entangling risk FADs are used, as observed by Balderson and Martin (2015) which could take a long time to recover. In addition, the entanglement of vulnerable wildlife is also a concern with the use of FADs and 'beached' FADs impact (Filmalter et al., 2013; Moreno et al., 2018c).

Results of the present work show that the beaching episodes in Seychelles differ from those predicted by Maufroy et al. (2015) and Davis et al. (2017). Though the buoy track analysis, results show that from FADs tracked in EEZ of Seychelles, only 0.8% in 2016 and 0.5% in 2017 impacted the coast of the archipelago (Table 7). The percentage of potential beachings is reduced to 0.1-0.2% if the number of beached FADs in the buffer areas (i.e Alphonse, Aride, Desroches, Farquhar, Poivre and Silhouette) is considered (a total of 22 and 12 beachings in 2016 and 2017 respectively). In contrast, it seems that the crossing rate is high, as reflected by the buoy tracks in the EEZ and in the specific buffer areas (i.e. input – output). The number of encounters at buffer areas during 2017 by ICS (n=11) was lower than the one estimated from tracking data (n=12), which accounts for active buoys beached. This difference can be due to operational issues as poor connectivity that end in delays in relaying information from Mahé to islands and bad weather affecting planning logistics, thus hindering the interception of FADs at sea before beaching. As a result, 38.5% of the total FADs (n=42) and 78% of the target fleet FADs (n=15) detected could be recovered and handled on land during 2016 and 2017. The designs of the target fleet's submerged structures of FADs encountered during 2016 and 2017 (i.e. duration of FAD-Watch programme) were mainly of low entanglement risk or non-entangling (78%, n=15), composed by synthetic rope (n=4) or sausages (n=11). In this sense, since 2011 in the frame of ICS coastal monitoring programme (Balderson and Martin, 2015) and FAD-Watch programme 5 entanglement events with vulnerable fauna have been registered by ICS in 335 FADs encountered (1.4%), which reflects the low occurrence of these cases as a result of the use of improved FAD designs. In the case of the target fleet and on the frame of the FAD-Watch (2016-2017), coral colonies and seagrass were found entangled in 9 of the 19 cases, and a turtle could be released alive in one of the cases, due to early detection and quick response of the team. The results could be improved by the adjustment of the programme to ensure the early detection, such as tuning the alert system and improving the internet connection, and by the cooperation with other associations which could allow to extend the detection of all FADs around the buffer areas.

Table 7. Description of studies addressing beaching potential percentage. Period, area and method applied in the study are also noted.

| Author/Project | Beaching potential % | Period | Study area | Method |
|---|---|---|---|---|
| Maufroy et al., 2015 | 9.9% | 2007-2011 | Indian Ocean | Buoy data |
| Davis et al., 2017 | 32.3% | 2006-2014 | Indian Ocean | Modelling |
| FAD-Watch (Present study) | 0.8 and 0.5% | 2016-2017 | Seychelles EEZ | Buoy data |

In addition to FAD detection and recovery, results also show how other mitigation options applicable in prior steps of the fishing operation and FAD life cycle (i.e. FAD limitation and improved FAD designs) can result on a gradual decrease of potential impacts associated with the FAD use (Davies et al., 2017; Moreno et al., 2018b). Buoys track results show how the number of buoys tracked in the EEZ has reduced significantly from 2016 to 2017 (decrease of 20% or 2,413 buoys only considering the target fleet). This may be a consequence of the limits on active buoys adopted by the IOTC (Res 15-08; Res-16-01; Res 17-08) which resulted in gradually decreasing the number of monitored and effective FADs at sea, contributing to the reduction of the potential beaching risk as the one observed, i.e. 41% of reduction from 2016 to 2017 estimated by buoy track data in Seychelles archipelago.

The designs of non-entangling raft and subsurface structures that were set to reduce the entanglement of sharks, sea turtles or any other species have been implemented as sustainable fishing standards tool by the fishing companies in the frame of the Code of Good Practices Programme of ANABAC and OPAGAC (Lopez et al., 2017). The use of non-entangling FADs is well accepted by the EU fleet (Murua et al., 2018) and is a generalized pattern in the OPAGAC fleet as shown in the result section (82.3% of the FADs deployed by skippers during 2017). The effort made by the fleet is gradually replacing the traditional FADs in the water by non-entangling FADs as shown by the characteristics of the FADs found in the water, with a high percentage being non-entangling (78.3%) during 2017, reducing the potential entanglement risk for sensitive fauna, such as turtles and sharks. The perception of fishers is that the probability of entanglement is negligible as the events are isolated, which is in line with the observations at buffer areas and at the Indian Ocean overall in the frame of the Code of Good Practices Programme.

Moving to non-entangling FADs constructed entirely without any net, as proposed by ISSF, will help to eliminate the potential entangling risk, detected when netting material is deteriorated over time as observed by ICS in some of the low entangling risk FADs encountered. Moreover, the biodegradable FADs with the objective to eliminate all synthetic material from the FADs construction while maintaining the non-entangling character might reduce the residence time at sea due to the material's reduced lifetime, which will suppose a significant progress to a sustainable fishery by decreasing the associated impacts (Moreno et al., 2018a). This solution is thought to provide the lowest impact of FADs on the marine ecosystem, as it solves two problems at once: ghost fishing and marine pollution. It should be highlighted that currently there are projects in the 3 oceans (Atlantic, Indian and Pacific) where the fishing industry is cooperating with the scientific sector to test new prototypes of FADs built mainly with biodegradable materials (Moreno et al., 2017; Zudaire et al., 2017; Moreno et al., 2018b), being the Indian Ocean project supported by IOTC Commission through Resolution 18/04 on BIOFAD experimental project.

These results show how the FAD-Watch initiative has helped to construct a cooperation between different stakeholders, to provide means to increase the early detection of FADs in sensitive habitats before impacting the coast. The collaborative effort is contributing to prevent marine litter accumulation in areas of ecological and economical interest, reduce the physical damage on vulnerable coastal habitats and entanglement risk of vulnerable fauna and enhance early release if applicable. The FAD watch programme, in combination with another mitigation option such as improving drifting FAD designs and the use of biodegradable FADs, an option already adopted by the fleet, and other regulations in force (i.e. FAD limitation); greatly contributed to mitigate the impacts of FADs on vulnerable coastal and pelagic habitats (Davis et al., 2017; Moreno et al., 2018c).

### *4.2 Prospects of the FAD-Watch Programme*

The FAD-Watch programme is the first multi-sectorial initiative developed to deal with FADs impacts in sensitive coastal areas, in which the coastal recovery is applied as a possible and promising mitigation measure. It is an example of how combining efforts of the stakeholders and integrating it in a package of mitigation actions (e.g. FAD limitations and improvements on FAD design) achieves promising scenarios.

With high resolution buoy tracking data and development of simulations models, areas and seasons with high risk of beaching are being detected (Davis et al., 2017; Maufroy et al., 2017). These works supported with biodiversity evaluation studies should provide with valuable information to detect and delimit sensitive areas in the Indian Ocean and other regions. While the project makes early detection and recover FADs with beaching risk possible, the implication of other fleets working in the area would help to improve the results, increasing the early detection of all tracked FADs and supplying with the necessary human and material resources to the organization responsible for the coastal recovery and effective action. During the study practical challenges and limitations were detected which should be solved and considered for the startup of a potential future initiative. To ensure a quick response in remote spots technical glitches such providing each team with tools to receive real-time information and setting up an automated alert system at any buffer area cross should reduce any time delay caused by relaying information from switchboard to each work team. Weather conditions were also detected as being one of the main difficulties. Thus, work equipment available or provided (e.g. boats) should be adapted for environmental conditions in the region. On the other hand, other aspects as simplifying FAD design, such as reducing the submerged structure length and gradual implementation of biodegradable and non-entangling FADs now tested by the fleet under different programs (Moreno et al., 2017; Zudaire et al., 2017; Moreno et al., 2018b; Moreno and Restrepo, 2018), would contribute to reducing coastal impacts and would facilitate the labour on coastal recovery programmes.

## 5. Recommendations

- Extend the agreement to other fishing associations to collaborate in the project in order to cover all FAD crossing through Seychelles EEZ and defined buffer areas. This would allow to increase the rate of FAD interception in sensitive marine habitats with high beaching risk.
- Development of a framework including the stakeholders involved, for the detection of other sensitive areas in Seychelles and the region.
- Seek the engagement of the buoy suppliers to keep providing buoy track data for those FADs currently deactivated after being lost or abandoned by its vessel.
- Gradual modification of FAD design at a short-medium term directing the changes towards Biodegradable NEFAD implementation.
- Undertake an analysis to identify the cost benefit of removing an individual FAD in terms of marine pollution, tourism/eco-tourism, boat navigation and marine wildlife protection/conservation.
- All these measures and investments should be carefully assessed by identifying the cost-benefit of removing FADs from the ocean, reef or beach in terms of marine pollution, tourism/eco-tourism (e.g. clean up, guest views/experience), boat navigation (e.g. safety reasons) and marine wildlife protection/conservation.

## 6. Conclusion

This is a world first initiative for collaboration between different stakeholders in mitigating the immediate impact of FADs beaching. It is the first time such an arrangement has been made between a fishing association working in close collaboration with an environmental NGO, and a Government on such a subject. The success of this initiative should encourage other fishing associations to join, so that it could be possible to increase the degree of achievement of the mitigation measures proposed by this pilot project. Having the cooperation of all PS fleets will also allow to obtain a better picture of FAD use in the region and it would make possible to better assess FAD generated impacts in the coastal area of Seychelles. We believe that actions like this, in combination with other mitigation measures already proposed by the different t-RFMOs, will enable to reduce the beaching events and its associated impacts. In view of the results, this initiative could also be promoted and implemented in other regions, adapting the mechanism to new regions and conditions.

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Annex 1

# FAD Sighting Data Form

Form No:

Data from this form is being collected by Island Conservation Society (ICS) from across the Indian Ocean to help gain a better understanding on the number of Fishing Aggregation Devices (FADs) washing up on beaches and being entangled on coral reefs. From your helpful contributions ICS will be able to document the number, distribution and type of these polluting FADs in our ocean and work towards their clean-up.

Please gather as much of the following information on *any* FAD or FAD debris that you encounter in your area.

Thank you for your contribution.

**Name:** *Click here to enter text.* **Organisation:** *Click here to enter text.* **Contact number:** *Click here to enter text.*

**Contact address/email:** *Click here to enter text.*

Sighting Information

**Date:** *Click here to enter a date.* **Island:** *Click here to enter text.* **Location (if no GPS):** *Click here to enter text.*

**UTM co-ordinate: Zone** *Click here to enter text.* **Latitude:** *Click here to enter text.* **Longitude:** *Click here to enter text.*

**Habitat** (please tick): ☐Beach ☐Sand/ seagrass flats ☐Coral reef ☐Free-floating

FAD Information

**Satellite buoy attached?** ☐Yes ☐No **Manufacturer:** *Click here to enter text.* **Serial number:** *Click here to enter text.* **Vessel name:** *Click here to enter text.*

**Size of Frame:** *Click here to enter text.* **Frame materials:** ☐Bamboo ☐Plastic ☐Wood ☐Steel ☐Tree log

**Shade material:** ☐Fishing net ☐Shade Cloth ☐Plastic sheet ☐Palm fronds or other biodegradable material

**Aggregator:** ☐Curtain net ☐Sausage net ☐Synthetic rope ☐Plastic bag ☐Palm frond ☐Biodegradable rope

Other (please state) *Click here to enter text.*

**Depth of Aggregator (m):** *Click here to enter text.* **Condition:** ☐New ☐Beginning to break ☐Mostly fallen apart

*Use the space below for comments or drawings that aid FAD description:*

*Click here to enter text.*

Impact on Marine life

**Species Entanglement?** ☐Turtle ☐Shark ☐Coral ☐Fish ☐Other *Click here to enter text.* **Status:** ☐Dead ☐Alive

**Species** (if known): *Click here to enter text.*

**If FAD is entangled on coral reef please state the approximate size of the area impacted:** *Click here to enter text.*

**FAD removed?** ☐Yes ☐No **Disposal Method:** *Choose an item.*

**Photographs of FAD?** ☐Yes ☐No **If yes, please send with form.**

**Please return completed forms and associated photographs to Island Conservation Society, Pointe Larue, P.O. Box 775, Victoria, Mahé, Seychelles or email to science@ics.sc. For more information please contact ICS here via emal or tel. +248 4375354**

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