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Environmental impacts and causation of 'beached' Drifting Fish Aggregating Devices around Seychelles Islands: a preliminary report on data collected by Island Conservation Society

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Abstract

In the past decade the number of Drifting Fish Aggregating Devices (DFADs) deployed by tuna purse seine vessels has risen sharply. The increased number of deployments has seen an increased number of lost DFADs. These lost DFADs continue to drift with ocean currents and a large number eventually come into contact with land and 'beach', becoming stuck in a wide range of habitats. Here we detail the first attempt to assess the environmental impact and causation of lost DFADs that have become beached on and around Seychelles islands. The data presented shows that vessels owned by Spanish companies are responsible for 76% of the DFADs found beached in the study area. The data also shows that there has been a move by the fishing industry towards 'non-entangling' DFADs that make use of 'sausage nets' to reduce the entanglement of sharks and turtles in the open ocean but that these devices still pose an entanglement risk when they come into contact with coral reefs. We highlight the difficulties caused by a lack of available information on DFAD deployment numbers and locations and make recommendations including the removal of all nets from DFAD construction and increased use of bio-degradable materials.

Introduction

Since the mid 1980's purse seine fishermen across the world's oceans have developed the use of drifting fish aggregating devices (DFADs) to increase their catches of tropical tunas. Initially radio beacons and reflectors were attached to naturally floating objects such as logs and as the technique developed fishermen started to construct purpose built DFADs (Davies, et al., 2014). Over the past two decades DFADs have become an increasingly important part of the purse seine tuna fishery and have dramatically improved searching efficiencies so that now over half the world's tuna is caught using this fishing practice (Lopez, et al., 2014). In the Western Indian Ocean (WIO) where this study takes place, DFADs are especially prevalent. The Spanish fleet which uses more DFADs than any other now records 83% of its catch around DFADs as opposed to free schools (Fonteneau & Chassot, 2014).

The number of DFADs that are deployed each year is not accurately known as there has been a severe lack of information made available to researchers (Maufroy, et al., 2015), mainly due to fishermen's concerns over the sensitivity of the data. This is beginning to change with Regional Fisheries Management Organisations (RFMOs) now calling for FAD management plans to include data collection on numbers of DFADs deployed (e.g. Indian Ocean Tuna Commission (IOTC) Resolution 13/08). However there are still big gaps in the records and considerable disparities between fishing nations in terms of the type and amount of data that is made available.

A number of researchers have attempted to quantify the amount of annual DFAD deployments. Baske, et al., (2012), used several sources to suggest that the number of annual DFAD deployments globally was between 47,000 and 105,000. In the Indian Ocean it has been suggested that in the last decade the number of DFAD deployments has risen by 70% (Fonteneau & Chassot, 2014), with the number of new buoy deployments of EU and Seychelles flag purse seiners being 10,500-14,500 in 2013.

Environmental Impacts of DFADs

There are a number of concerns about the environmental impacts of DFADs. Entanglement of marine life within the net of the DFAD itself has been shown to be having a major impact on pelagic species such as sea turtles and sharks. Sea turtles, particularly the vulnerable Olive Ridley Turtles (ORTs) (*Lepidochelys* olivacea) (Abreu-Grobois, et al., 2008), spend their juvenile years associated with floating objects in the open ocean. ORTs are attracted to DFADs and can become entangled in the nets which have been shown by researchers to be composed of the mesh size most dangerous to turtles (Stelfox, et al., 2014).

An estimated annual DFAD entanglement mortality of 480,000-960,000 silky sharks (*Carcharinus falciformis*) in the Indian Ocean (Filmalter, et al., 2013) is a similar figure to the combined world fisheries catch of Silky Sharks (400,000-2million), a situation that clearly needs addressing (Filmalter, et al., 2013). These concerns have lead towards changes in FAD design to try to limit entanglement (Tolotti, et al., 2015). Net curtains are being replaced by rolled net 'sausages' (Franco, et al., 2009) and smaller mesh sizes are being used in so called 'Ecological FAD' designs. The non-entangling nature of these DFAD designs has been called into question as sausage nets have been shown to unravel and small mesh netting can tear creating larger holes, as such the International Seafood Sustainability Foundation (ISSF) has refined its definition of 'non-entangling' FADs to only include those that contain no netting in the construction (ISSF, 2015).

As well as impacts on non-target species there are growing concerns about the effect of DFADs on the tuna fisheries themselves. The use of DFADs has significantly increased the catches of juvenile bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) causing a reduction in yield per recruit (Dagorn, et al., 2013) and average sizes that are well below that of first spawning (Fonteneau & Chassot, 2014). Although significant stock declines have not yet been observed, with so many unknowns with regards to the effect of this type of fishing pressure surely a precautionary approach to FAD use should be adopted.

One environmental impact that has so far received little coverage in the literature is that of DFADs beaching on coral reefs and islands. Despite the sophisticated satellite tracking buoys now used on DFADs an estimated 9.9% of them become beached (Maufroy, et al., 2015). These beaching events generally occur due to the DFAD drifting outside of the main fishing grounds and malfunction/or loss of the tracking buoy. In the Indian Ocean this could be 1,000-1,400 beaching events per year from DFADs deployed by the EU and Seychelles flagged fishing fleet alone. These figures are probably an underestimation of the number of beaching events as they do not account for the DFADs that are dumped at sea with no Satellite buoy attached. As DFADs are built primarily from non-biodegradable materials this is a significant source of marine pollution that adds to the environmental impact already caused by 'ghost nets' from other forms of fishing such as trawling and gill nets (Stelfox, et al., 2014). There is no clear consensus on whether DFADs breach international laws on marine pollution, but certainly if the DFAD structure is dumped after use this would appear to violate MARPOL Annex V (FAO, 2009). The dumping of DFADs would also likely contravene the London Convention (Fonteneau & Chassot, 2014). In 2013 the IOTC did not adopt a resolution proposed by France to prohibit the abandonment of DFADs, instead it made clear that measures should be included in FAD management plans of individual member nations.

Island Conservation Society is an NGO that has conservation centres on 5 islands that are spread out across the Seychelles EEZ and are therefore well placed to bear witness to lost FADs which litter the area. This study represents the first attempt to make a full survey of DFADs on these islands and present information on their distribution and composition. In the longer term this project aims to fully describe the impact of DFADs on Seychelles islands and the wider region. The specific objectives are to quantify the number of DFADs that are 'beaching', describe their environmental impact, identify which vessels/companies are responsible for the DFADs and offer advice on mitigation measures to be implemented by the relevant authorities and administrators.

Methods

Study Site

This study is centred on the Republic of Seychelles, particularly the area known as the Outer islands. DFAD beaching has been recorded by Island Conservation Society (ICS) staff around the islands: Desroches, Poivre, St. Joseph, Alphonse, St. Francois, Farquhar and Cosmoledo (Figure 1). These islands are spread out across the vast EEZ of Seychelles which covers 1,374,000km². The islands support regionally significant populations of nesting Green and Hawksbill turtles as well as millions of nesting seabirds. The coral reefs are some of the healthiest in the world with intact and resilient ecosystems high in biomass (Amla, 2015; Friedlander, et al., 2014).

The meteorology of Seychelles is dominated by two monsoon seasons which are named after the direction of the prevailing winds: the Northwest (NW) monsoon and the Southeast (SE) monsoon. The NW monsoon occurs during the austral summer from November to April and is characterised by light winds (<10knots). The SE monsoon occurs during the austral winter from May to October and is characterised by strong winds (>20knots). It has been observed that a greater amount of marine debris accumulates on the islands during the SE monsoon (Duhec, et al., 2015).

Figure 1. Study site (red box), the Outer islands where DFADs have been recorded.

DFAD Data Collection/Collation

ICS staff have been removing DFADs from the reefs and beaches of Seychelles islands for a number of years and began recording information of these beaching events in 2011. Initially the data was recorded in an *ad hoc* fashion (not during systematic surveys). The majority of the data was collected when DFADs were actually removed from where they had beached. The initial data did not include information on DFAD construction or environmental impact, but where possible this information has now been obtained from photographs taken at the time.

In 2015 data collection methodologies were reviewed and a database of all DFAD beaching events was created. Data collection parameters were chosen in order to determine which fishing vessel/fleet the DFAD came from and the environmental impact caused (Table 1). In April 2015 ICS teams conducted DFAD surveys around St. Francois and Farquhar atolls to determine the number of DFADs currently beached at these locations (Figure 2). A total of 96 DFADs were found during these

Figure 2. Locations of DFADs found in 2015 during a systematic survey of St. Francois atoll, Seychelles.

surveys, the results of which were added to the database.

Where possible, DFADs have been removed from the ocean and beaches where they were found. Some of the materials can be reused locally on the islands e.g. nets can be used for hammocks or chicken pens. Other materials can be burnt such as bamboo. The majority of the synthetic materials are sent to the main island of Mahe for proper disposal. When found, the satellite buoys have been collected and stored as evidence.

Table 1. DFAD measurements recorded during field surveys undertaken by Island Conservation Society across Seychelles.

Parameter	Details
Habitat	The habitat where the beaching occurred
Satellite Buoy Manufacturer/Serial	If a satellite buoy is still attached these details

number/Vessel details	help determine where the DFAD came from
Size of Frame	In m^2 the size of the frame that holds the DFAD together at the surface
Frame/Shade materials	The materials that the frame is made from e.g. bamboo and what material is stretched across e.g. shade cloth
Aggregator type/materials	The design of the sub-surface aggregator e.g. sausage net or curtain net and the materials these are made from e.g. synthetic or bio-degradable
Depth of the Aggregator	In metres the depth the sub-surface section hangs down to
Condition	DFAD is still as new or has started to break apart
Entanglement	Details of any species entangled alive or dead e.g turtles
Impacted area	In m^2 the approx. area affected by the DFAD

Data Management for Analysis

Data collection methodologies were revised throughout the time period of study and therefore where blanks in the database could not be filled by looking at photographs taken at the time of the beaching event for analysis purposes those DFAD records were filtered where appropriate.

Where the vessel name was available on the DFAD the IOTC internet database 'Historical Record of Authorised Vessels' was used to gather information including: IOTC number, flag, gross tonnage and vessel ownership (http://www.iotc.org/vessels/date). In the 4 instances where the DFAD was shared between 2 or more vessels, an equal share of the DFAD was attributed to each vessel (see Appendix 1).

The size and composition of the fishing fleets operating in the area of interest changes every year. In order to compare the number of DFADs found between the 3 main fleets of France, Spain and Seychelles an average number of purse seine vessels for each country operating during the time period of 2011-2015 was derived from (Chassot, et al., 2014) and (Chassot, 2015, pers. comm).

Without having access to confidential DFAD deployment information it is not possible to know how long a device has been in the water before it 'beached'. It is however possible to know the maximum amount of time that the device could have been in the water based on the age of the operating vessel determined from online sources (www.shipspotting.com), and the potential age of the satellite buoy type i.e. when that model was first manufactured derived from various online sources. The year that the vessel was first licensed to fish in the IOTC region is also an indicator.

Results

DFAD quantification

214 separate DFADs were recorded by ICS between 2011 and 2015. Of these, 210 were recorded as beached after they had become stuck and were no longer drifting. As the majority of the data was recorded opportunistically then there would have been DFADs passing by that were missed and these figures therefore represent the minimum number of DFADs that beached on the islands during this time period. Of the DFADs, 128 (60%) were found with a Satellite buoy attached, and it was possible to determine the fishing vessel that was using the DFAD for 115 (90%) of these. Of the

DFADs where the structure was considered to be 'New', 90% still had a satellite buoy attached whereas for DFADs where the structure had 'mostly fallen apart' this figure dropped to 55%.

DFAD origin

The results showed that 50% of the DFADs that were found came from Spanish flagged vessels (Figure 3). The Seychelles flagged vessels are also all owned by Spanish based companies, therefore 76% of the DFADs found came from Spanish owned and operated vessels. 91% of the DFADs found came from vessels with flags of France, Spain and Seychelles.

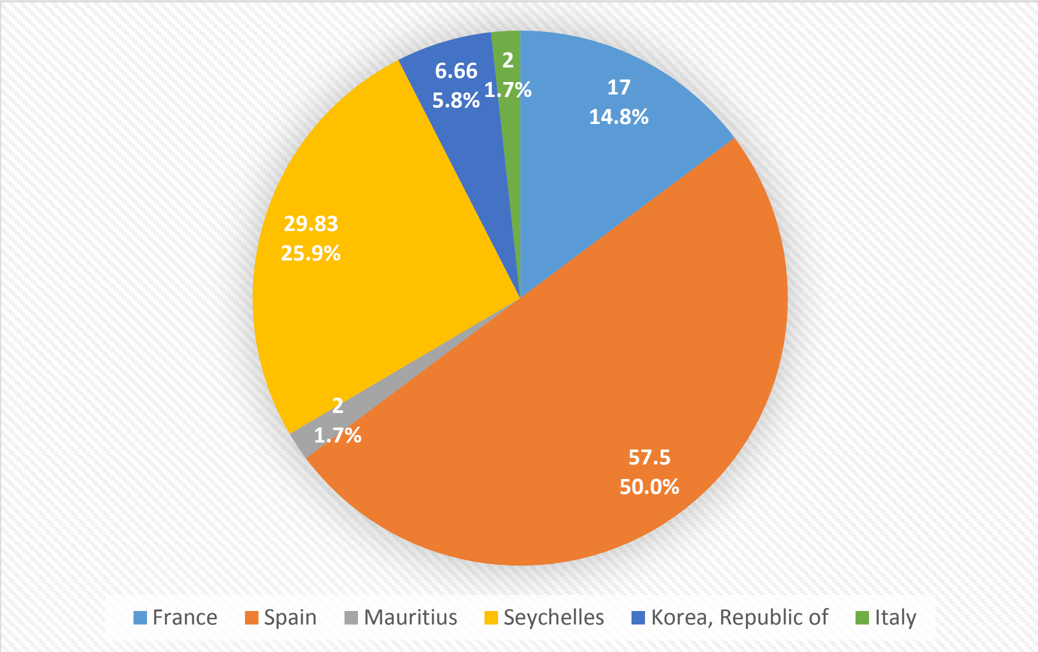

Figure 3. Number of DFADs by flag as surveyed by Island Conservation Society across Seychelles.

Spanish flagged vessels accounted for 3.89 DFADs per vessel compared to French flagged vessels which accounted for 1.29 DFADs per vessel (Table 2). Full coverage was achieved for the Spanish fleet, as DFADs were found for all vessels listed as contributing data to the National Plan of FADs and therefore fishing in the area (Delgado de Molina, et al., 2014).

Country Flag	Vessels#	DFADs#	DFADs per vessel
France	13.2	17	1.29
Spain	14.8	57.5	3.89
Seychelles	8.5	29.83	3.51

Table 2. Number of DFADs per vessel recorded by Island Conservation Society across Seychelles.

Spanish companies dominate the tuna purse seine fleet in the WIO and this is reflected in the number of DFADs that are found from vessels of each company (Figure 4). Albacora, Inpesca and Echebastar, all Spanish companies were the top 3 contributors and are responsible for 59.4% of the DFADs found. DFADs were found from 38 vessels in total. One vessel 'Txori Gorri' owned by Inpesca accounted for 9 DFADs (7.8%) of the total found (see Appendix 1). Inpesca as a company accounted for 5 DFADs per vessel (Figure 4).

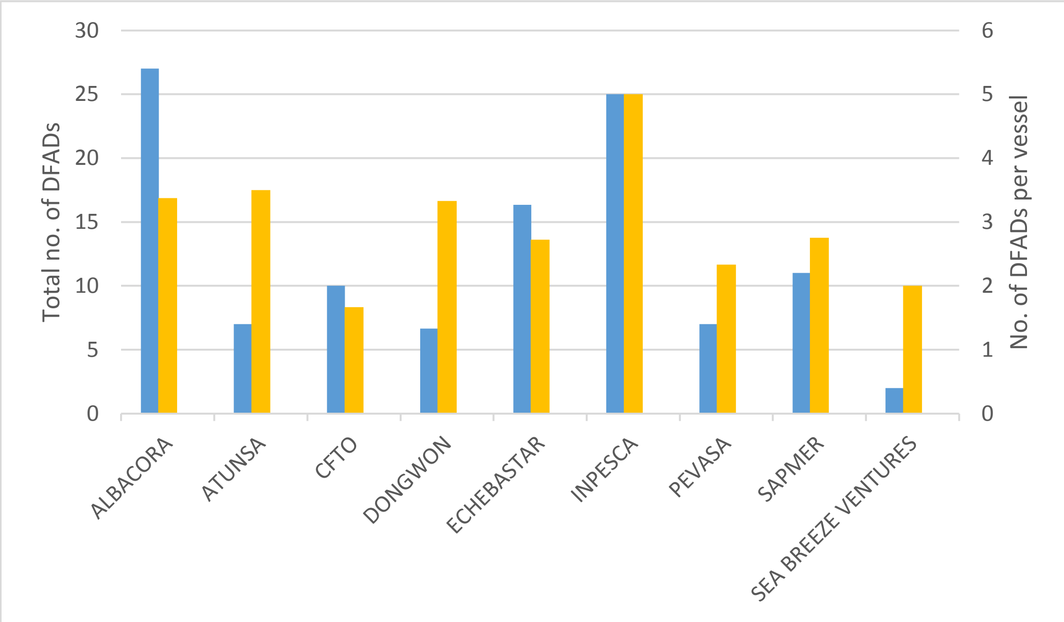

Figure 4. Number of DFADs by parent company as surveyed by Island Conservation Society across Seychelles .

Condition and lifespan of DFADs

The age of the DFADs i.e. the amount of time that they have spent in the water is very desirable information, but unfortunately very difficult to ascertain. It was found that 96% of the DFADs with buoys attached were deployed since 2009 (this is the earliest year that the models of Satellite buoys found were manufactured). However without access to DFAD deployment data, the age of the DFADs could not be defined any further. A DFAD was found from the vessel Jai Alai on 8th June 2015, and the vessel was delivered to its owners from the shipyard on 7th March 2015 (Zunibal, 2015). Therefore it is possible to say that there was a maximum time of 3 months at sea before beaching.

In terms of DFAD construction there was a relatively low proportion (18.4%) of DFADs that had hanging curtain nets as the aggregator. The use of fishing nets rolled up into a sausage (sausage net) was found to be the most common form of aggregator (62.1%). What was apparent was a lack of bio-degradable materials used in DFAD construction. In all the DFADs observed the aggregator components were made entirley of synthetic materials. Of DFADs using curtain nets that could be identified to a vessel 100% were from Spanish companies. Where the aggregator was recorded for

Figure 5. A DFAD consrtucted without netting

Figure 6. Synthetic rope with salt bags attached

French vessels, 77% used sausage nets, with the others using synthetic rope.

The materials used to cover the raft of the DFADs were also entirely synthetic. 85% of DFADs had fishing net stretched across the frame, whilst 44% had shade cloth or a combination of both fishing net and shade cloth. Of DFADs that still had the aggregator part attached (119) only one was found to have no netting used in its construction. This FAD was constructed using a steel frame with shade cloth stetched across (Figure 5), the aggregator was a synthetic rope hanging down from the centre to a depth of >30m, attached to the rope were woven sacks (salt bags) placed at regular intervals (Figure 6).

Environmental impact

DFADs were found to be impacting coral reef more than other habitat zones. 39% of the DFADs were found attached to reef. The netting and ropes of the DFADs becomes caught more easily on corals and once attached rarely drift away again. This was seen particularly in the lagoon of St. Francois atoll, where DFADs are able to cross over the shallow waters of the sea grass flats but once in the lagoon become caught on coral bommies. The construction material of the aggregator was found to be a factor with 23.8% of DFADs using synthetic rope as the aggregator found on coral reef habitat

Figure 5. Coral entangled in DFAD netting

Figure 6. An Olive Ridley Turtle entangled in DFAD netting

compared to 48.9% for DFADs using nets (Figure 7).

Sea turtles were found entangled in 4 DFADs (2%), including an Olive Ridley turtle, which are very rarely seen in the area (Figure 8). The other 3 turtles found were Hawksbill turtles, only 1 of the turtles found was still alive. A dead Green turtle was found entangled in a DFAD on Desroches island in August 2012, but was not included in the database due to a lack of information. The marine organisms most impacted by DFADs are corals with 37% of DFADs found with corals entangled in the structure, 100% of these were DFADs using nets as the aggregator. 46% of DFADs using sausage nets were found with corals entangled in the nets.

Discussion

DFAD origin and loss rates

40% of the DFADs found did not have a satellite buoy attached. This meant that it was not possible to determine which fishing vessel had released these DFADs. It is impossible to know whether an individual DFAD was lost whilst it had a tracking device attached to it and then the buoy came off while it was drifting or 'beached' or if the satellite buoy was deliberately removed and the DFAD discarded by the fishermen as it had come to the end of its 'life' or to sabotage the fishing operations of another company/vessel. There is very little information available on the topic of deliberate discarding of DFADs (Macfadyen, et al., 2009) as any such action would contravene MARPOL Annex V (IMO, 2015). It is clear however that this practice does occur because France submitted a request to the IOTC calling for a ban on such practices, stating: “observers on board tuna fishing purse seiners operating in the Indian Ocean report a significant number of Fish Aggregating Devices (FADs), constructed with fragments of nets, being abandoned at sea without any tracking beacon.” (IOTC, 2013). If significant numbers of DFADs are being abandoned without tracking devices this could mean that predicted beaching rates of 9.9% (Maufroy, et al., 2015) are an underestimate as they are based on tracks of DFADs with Satellite buoys. If there is to be greater reporting of DFAD deployments by fishing vessels there should be a requirement for vessel owners to prove that lost DFADs have not been deliberately abandoned.

The ratios of the amount of DFADs found for each country flag are consistent with the estimated numbers of DFADs deployed by each country reported in the literature (Scott & Lopez, 2014; Fonteneau & Chassot, 2014). The DFADs per vessel figures indicates that Spanish vessels lose 3 times as many DFADs as French vessels, which is consistent with the top estimate of the ratio of the number of DFADs deployed by Spanish vessels compared to French vessels (3:1) (Fonteneau & Chassot, 2014). This indicates that as DFAD usage increases there is no increase in the rate of DFAD loss. This is probably due to the fact that the Spanish fleet employs specialised support vessels to manage the deployment and collection of DFADs. This ratio may be used as empirical evidence from which to estimate total expected DFAD loss for the entire fleet if deployments are recorded in a more systematic manner and the data made available.

The fact that purse seiner vessel ownership changes between companies and vessels are sometimes renamed as well as being moved to fish in different oceans makes comparisons between fishing companies difficult. In trying to compare the number of DFADs found from each company, it is important to try and understand the potential for vessels from each company to lose DFADs. Attempts to show why more DFADs per vessel have been found for one company compared to another fell short because of a lack of data (owing to confidentiality). Fishing strategy (number of DFADs deployed) is not uniform across the Spanish fleet, figures obtained for 2013 (without vessel names attached) showed that the vessel deploying the most DFADs (3368) put out over 4 times as many as the vessel deploying the least (775) (Delgado de Molina, et al., 2014). Without knowing the amount of DFADs seeded by each vessel it is not possible to make accurate comparisons. Inpesca, had the highest number of DFADs found per vessel but it has a fleet of boats which are on average younger and larger than the other companies (see Appendix 1) and uses a higher ratio of support vessels to fishing vessels than other companies (Chassot, 2015, pers. comm), which could mean that these boats are simply capable of deploying more DFADs and the rate of loss is the same.

DFAD design to reduce environmental impact

DFAD design is clearly being driven by changes in policy and the DFAD management plans submitted by IOTC members, which in turn are driven by studies from various research organisations. DFADs using open curtain nets were shown to have very high levels of by-catch, particularly sharks and turtles (Filmalter, et al., 2013), and this lead to DFAD management plans requiring vessel owners to take steps to reduce entanglement. France has been much more forceful in regard to the wording of the DFAD management plans for DFAD design stating: “It is forbidden for fishing and support vessels to launch a FAD that was not designed to reduce to zero the risk of turtle and shark entanglement.” (IOTC, 2015) The implications of this are seen in the data as none of the DFADs that used curtain nets (the most likely to cause entanglement) were identified as belonging to French flagged vessels or companies.

The definition of ‘non-entangling’ DFADs has come under scrutiny recently. The use of rolled up fishing nets (sausage nets) was promoted by ISSF as being ‘non-entangling’ as they significantly reduced the rate of entanglement of sharks and turtles. This advice has clearly been listened too as 62.1% of DFADs found had sausage nets attached, and for French DFADs this rose to 77%. However it was witnessed several times throughout the course of the DFAD surveys that when DFADs get caught on coral reef the ropes that keep the sausage net rolled up can get cut and the sausage begins to unravel. When this happens the DFAD is no longer a ‘non-entangling’ device. In time further research through this project may provide further evidence of the impact of this, as several sausage net DFADs remain in situ from previous surveys and return surveys will be conducted. As previously stated ISSF have issued new guidelines that call for the removal of all netting from DFAD design (ISSF, 2015). However, during the course of this research only 1 DFAD with no netting components was encountered. Further data collection from beached DFADs will show whether new guidelines are being adhered to.

The entanglement of wildlife is clearly a concern with the use of DFADs and 'beached' DFADs impact heavily on coral. 39% of all the DFADs found were impacting coral reef habitat. When netting is used in the aggregator it is more likely to become tangled and caught on coral whereas when rope is used the DFAD can pass by the reef more easily and instead 'beach' on sea grass beds or beach or possibly avoid beaching altogether. Sausage nets were designed to prevent entanglement of sharks and turtles but do not prevent entanglement of corals as the data showed that 46% of sausage net DFADs had corals entangled in the net. For the instances where synthetic rope DFADs were found on coral reef habitat none of these devices had actually entangled coral meaning there would be much less chance of the coral being broken. This adds further support to the calls to remove all forms of netting from DFAD design.

Conclusion

Attempts have been made to improve DFAD construction and lessen the environmental impact to marine life but problems still remain. In particular with respect to the number of lost DFADs that beach and cause significant marine pollution and associated disposal implications on remote Seychelles islands. This study has shown that the continued use of nets causes entanglement and destruction of corals which are a vital component of the ecosystem.

As RFMOs encourage member states to adhere to their agreements and develop FAD management plans, there are some clear conclusions found from this study and associated messages that RFMOs should recommend and consolidate across the fishery:

- DFAD deployments should be recorded and their trajectories monitored to gain a better appreciation of the ratio of loss from which more reasonable quotas may be developed based on known environmental impacts.
- Increased data sharing between fishing companies and RFMOs/NGOs would lead to a greater understanding of DFAD loss and ways to mitigate the environmental impact.
- Measures should be taken to prevent DFAD 'dumping', which contravenes MARPOL Annex V. These could include requirements to place vessel ID markings on DFAD structure (frame, aggregator) not just the satellite buoy and increased vessel monitoring through on-board observers and CCTV.
- All nets should be removed from DFAD design, and only those DFADs without nets should be described as 'non-entangling', this supports the recent guidelines set out by ISSF.
- Synthetic materials should be replaced with bio-degradable materials such as: hemp or sisal ropes and palm leaves. This would lessen the long term impact of beached DFADs.
- Increased investment in technology could lead to the use of self-propelled DFADs that could maintain position in the ocean, thus reducing the rate of DFAD loss and the overall numbers of DFADs used.
- The fishing industry should take responsibility for the DFADs that have already been lost and pay for their clean up. This would require proper disposal of nets, old tracking buoys should be recycled properly, as often when they are found the components are still functional.
- A precautionary approach should be employed in relation to DFAD numbers until the full impacts on fish stocks and ecosystems of mass DFAD use are known.

This project will continue to collect information on beached DFADs in the future. A main aim of the project is to encourage other organisations and individuals to collect data on DFADs that they find, which will increase the coverage of the dataset across the Seychelles Islands and the wider Indian Ocean region. To facilitate this an online data submission platform is being established by Island Conservation Society.

References

Abreu-Grobois, A., Plotkin, P. (IUCN SSC Marine Turtle Specialist Group) 2008. *Lepiodochelys olivacea. The IUCN Red List of Threatend Species. Version 2015.2.* [Online]
Available at: http://www.iucnredlist.org/details/11534/0
[Accessed 12 August 2015].

Amla, H., 2015. *Seychelles News Agency: National Geographic expedition leader rates Seychelles ocean, coral health among best in the world.* [Online]
Available at:
http://www.seychellesnewsagency.com/articles/2595/National+Geographic+expedition+leader+rates+Seychelles+ocean,+coral+health+among+best+in+the+world
[Accessed 10 July 2015].

Baske, A., Gibbon, J., Benn , J. & Nickson, A., 2012. *Estimating the use of drifting Fish Aggregation Devices (FADs) around the globe,* s.l.: Pew Environmental Group.

Chassot, E. et al., 2014. *Statistics of the European Union and associated flags purse seine fishing fleet targeting tropical tunas in the Indian Ocean 1981-2013.,* Victoria: Indian Ocean Tuna Comission.

Dagorn, L., Holland, K. N., Restrepo, V. & Moreno, G., 2013. Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on the pelagic marine ecosystems?. *Fish and Fisheries,* Volume 14, pp. 391-415.

Davies, T. K., Mees, C. C. & Milner-Gulland, E. J., 2014. The past, present and future use of drifting fish aggregating devices (FADs) in the Indian Ocean. *Marine Policy,* Issue 45, pp. 163-170.

Delgado de Molina, A. et al., 2014. *Spanish Fish Aggregating Device Management Plan. Preliminary data in the Indian Ocean.,* Victoria: Indian Ocean Tuna Commision.

Duhec, A. V., Jeanne, R. F., Maximenko, N. & Hafner, J., 2015. Composition and potential origin of marine debris stranded in the Western Indian Ocean on remote Alphonse Island, Seychelles.. *Marine Pollution Bulletin,* pp. 76-86.

FAO, 2009. *Fisheries and Aquaculture Technical Paper 523: Abandoned, lost or otherwise discarded fishing gear.,* Rome: Food and Agriculture Organization of the United Nations.

Filmalter, J. D. et al., 2013. Looking behin the curtain. *Frontiers in Ecology and the Environment,* 11(6), pp. 291-296.

Fonteneau, A. & Chassot, E., 2014. *Managing tropical tuna purse seine fisheries through limiting the number of drifting fish aggregating devices in the Indian Ocean: food for thought.* s.l., IOTC.

Franco, J., Dagorn, L., Sancristobal, I. & Moreno, G., 2009. *Design of Ecological Fads,* s.l.: Indian Ocean Tuna Commission.

Friedlander, A. M. et al., 2014. Coexistence of Low Coral Cover and High Fish Biomass at Farquhar Atoll, Seychelles. *PLOS one,* 9(1).

IMO, 2015. *International Maritme Organisation - Prevention of Pollution by Garbage from Ships.* [Online]
Available at:
http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Pages/Default.aspx
[Accessed 22 July 2015].

IOTC, 2013. *Procedures on a fish aggregating devices (fads) management plan, including more detailed specifications of catch reporting from fad sets, and the development of improved fad designs to reduce the incidence of entanglement of non-target species,* Victoria: Indian Ocean Tuna Commission.

IOTC, 2013. *S17-PropS[E] Prohibiting the abandonment of fish aggregating devices (FADs) on the high seas in the IOTC area of competence. Submitted by France (OT).* s.l.:Indian Ocean Tuna Commision.

IOTC, 2015. *Collection of Fish Aggregating Device Management Plans, Prepared by IOTC Secretariat,* Victoria: Indian Ocean Tuna Commision.

IOTC, 2015. *IOTC compliance report for: Seychelles,* Victoria: Indian Ocean Tuna Commission.

ISSF, 2015. *ISSF Guide for Non-Entangling FADs,* s.l.: International Seafood Sustainability Foundation.

Lopez, J., Moreno, G., Sancristobal, I. & Murua, J., 2014. Evolution and current state of the technology of echo-sounder buoys used by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. *Fisheries Research,* Issue 155, pp. 127-137.

Macfadyen, G., Huntington, T. & Cappell, R., 2009. *Abandoned, lost or otherwise discarded fishing gear. UNEP Regional Seas Reports and Studies, No. 185; FAO Fisheries and Aquaculture Technical Paper, No 523.,* Rome: UNEP/FAO.

Maufroy, A., Chassot, E., Joo, R. & Kaplan, D. M., 2015. Large-Scale Examination of Spatio-Temporal Patterns of Drifting Fish Aggregating Devices (dFADs) from Tropical Tuna Fisheries of the Indian and Atlantic Oceans. *PLOS one,* 10(5).

Scott, G. & Lopez, J., 2014. *The use of FADs in tuna fisheries.,* s.l.: European Union.

Stelfox, M. R., Hudgins, J. A., Ali, K. & Anderson, R. C., 2014. *High mortality of Olive Ridley Turtles (Lepidochelys olivacea) in ghost nets in the central Indian Ocean,* s.l.: Indian Ocean Tuna Commission WPEB10-28.

Tolotti, M. T. et al., 2015. Banning is not enough: The complexities of oceanic shark management by tuna regional fisheries management organizations. *Global Ecology and Conservation,* Volume 4, pp. 1-7.

Zunibal, 2015. *Jai Alai Launching.* [Online]
Available at: http://zunibal.com/en/jai-alai-launching/
[Accessed 10 July 2015].

Appendix 1

Vessel Name	Year built	Tonnage (GT)	IOTC #	Flag	Owner	Parent Company	#DFADs	%
Alakrana	2006	3716	IOTC00907	Spain	Echebastar Fleet S.L.	ECHEBASTAR	4.0	3.5
Albacan	1991	2347	IOTC00159	Spain	ALBACORA S.A.	ALBACORA	4.5	3.9
Albacora Cuatro	1974	2082	IOTC00161	Spain	COMPAÑIA EUROPEA DE TUNIDOS S.L.	ALBACORA	7.0	6.1
Albatun Dos	2004	4406	IOTC00811	Spain	ALBACORA S.A.	ALBACORA	3.0	2.6
Artza	200	3870	IOTC00814	Seychelles	ATUNSA N. V.	ATUNSA	3.0	2.6
Avel Vad	1996	1598	IOTC00373	France	COMPAGNIE FRANCAISE DU THON OCEANIQUE	CFTO	3.0	2.6
Belle Rive	2013	2667	IOTC0015113	Mauritius	Indian Ocean Ship Management Services	SAPMER	2.0	1.7
Belouve	2012	2667	IOTC0014063	France	ARMEMENT SAPMER	SAPMER	2.0	1.7
Campolibre Alai	1989	2214	IOTC00171	Spain	Echebastar Fleet S.L.	ECHEBASTAR	2.0	1.7
Cap Saint Vincent	2000	1606	IOTC00670	France	COMPAGNIE FRANCAISE DU THON OCEANIQUE	CFTO	2.0	1.7
Cap Sainte Marie	1998	1596	IOTC008410	France	COMPAGNIE FRANCAISE DU THON OCEANIQUE	CFTO	1.0	0.9
Demiku	1977	2232	IOTC00140	Seychelles	Echebastar Fleet S.L.	ECHEBASTAR	5.3	4.6
Doniene	1996	3674	IOTC00172	Spain	ATUNEROS CONGELADORES Y TRAN. FRI. S.A.	ATUNSA	4.0	3.5
Draco	2006	3296	IOTC003606	Seychelles	Overseas Tuna Company N.V	ALBACORA	3.0	2.6
Elai Alai	1993	2217	IOTC00175	Spain	Echebastar Fleet S.L.	ECHEBASTAR	1.0	0.9
Erroxape	1977	2199	IOTC00141	Korea, Republic of	DONGWON FISHERIES CO., LTD	DONGWON	4.3	3.8
Felipe Ruano*	1989	2110	IOTC00176	Spain	PESQUERIA VASCO MONTAÑESA S.A.	PEVASA	2.0	1.7
Franche Terre	2009	2664	IOTC008743	France	ARMEMENT SAPMER	SAPMER	6.0	5.2
Galerna II	2014	3445	IOTC0015507	Seychelles	Overseas Tuna Company N.V	ALBACORA	1.5	1.3
Galerna III	2014	3445	IOTC0015856	Seychelles	Overseas Tuna Company Naamloze Vennootschap	ALBACORA	2.0	1.7
Intertuna Tres	2000	4428	IOTC00138	Seychelles	INTERTUNA N.V	ALBACORA	5.0	4.3

Intertuna Uno	1980	2167	IOTC00136	Seychelles	Intertuna Ltd	ALBACORA	1.0	0.9
Itsas Txori	2013	2994	IOTC0015353	Spain	COMPAÑIA INTERNACIONAL DE PESCA Y DERIVADOS S.A	INPESCA	3.0	2.6
Izaro	1976	2706	IOTC0015361	Seychelles	Hartswater Limited	ECHEBASTAR	3.0	2.6
Izurdia	2004	4089	IOTC00879	Spain	ATUNEROS CONGELADORES Y TRAN. FRI. S.A.	ATUNSA	3.0	2.6
Jai Alai	2015	2706	IOTC0016019	Seychelles	Hartswater Limited	ECHEBASTAR	1.0	0.9
Manapany	2010	2664	IOTC009131	France	ARMEMENT SAPMER	SAPMER	1.0	0.9
Playa de Anzoras	1999	2446	IOTC00186	Seychelles	Sea Breeze Ventures Limited	SEA BREEZE VENTURES	2.0	1.7
Playa de Aritzatxu	2002	2458	IOTC00187	Spain	PESQUERIA VASCO MONTAÑESA S.A.	PEVASA	4.0	3.5
Playa de Noja*	1989	2110	IOTC00176	Spain	PESQUERIA VASCO MONTAÑESA S.A.	PEVASA	1.0	0.9
Talenduic	1992	2109	IOTC00368	France	COMPAGNIE FRANCAISE DU THON OCEANIQUE	CFTO	1.0	0.9
Torre Giulia	1997	2137	IOTC00345	Italy	INDUSTRIA ARMATORIALE TONNIERA SPA	CFTO	2.0	1.7
Trevignon	2006	2319	IOTC003810	France	COMPAGNIE FRANCAISE DU THON OCEANIQUE	CFTO	1.0	0.9
Txori Argi	2004	4134	IOTC00812	Spain	COMPAÑIA INTERNACIONAL DE PESCA Y DERIVADOS S.A.	INPESCA	6.0	5.2
Txori Aundi	1983	2020	IOTC00815	Seychelles	INPESCA FISHING LTD.	INPESCA	3.0	2.6
Txori Gorri	2007	2937	IOTC008281	Spain	COMPAÑIA INTERNACIONAL DE PESCA Y DERIVADOS S.A.	INPESCA	9.0	7.8
Txori Toki	2000	4134	IOTC00193	Spain	COMPAÑIA INTERNACIONAL DE PESCA Y DERIVADOS S.A.	INPESCA	4.0	3.5
XIXILI	1978	2201	IOTC00143	Korea, Republic of	DONGWON INDUSTRIES CO., LTD.	DONGWON	2.3	2.0

*Felipe Ruano and Playa de Noja are physically the same vessel but the name was changed from Felipe Ruano to Playa de Noja in 2012. The name Felipe Ruano was found on 2 DFADs and this has been maintained in the database as it gives some indication as to the age of the devices.