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TOWARDS BIODEGRADABLE FADS:
Evaluating the Lifetime of Biodegradable Ropes in Controlled Conditions

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Abstract

The present study summarizes the results of a project to test the lifetime and robustness of biodegradable ropes to be used on FADs. Tests were conducted in a controlled environment in the Maldivian waters. Three types of biodegradable ropes were tested following their evolution and fate over one year at sea: (i) twisted 100 % cotton rope; (ii) twisted 50% cotton and 50% sisal rope; and (iii) cotton, sisal and linen rope with loops. Samples were deployed in June 2016 in 2 different sites simultaneously, in an atoll lagoon waters attached to a mooring rope, simulating a FAD in oceanic waters and in a shallow lagoon close to the reef in Maniyafushi island, K. Atoll in the centre of the Maldives, simulating the arrival of a FAD to the coast. Results show different robustness of the ropes, being the strongest the ones made of sisal and cotton. However, not only robustness is important when selecting a given rope but also other characteristics need to be taken into account as being easy to handle, degrading after a given amount of time for it to be useful for fishing purposes, cost and availability of the ropes close to the fishing grounds. Taking into account all of these criteria, 100% cotton rope (20 mm diameter, 4 strands in torsion Z) was identified as the most appropriate to be tested at FADs in real fishing conditions. Those results as well as future directions for the successful use of biodegradable materials at FADs are discussed.

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Executive Summary

One of the impacts related to the use of Fish Aggregating Devices (FADs) is the impact caused by FAD structure, which is mainly made of plastic-based materials. Due to the complex fishing strategy with drifting FADs, a high percentage of FADs deployed by a given vessel end up sinking, lost, discarded or abandoned. Impacts caused by lost and abandoned FADs, especially when they are stranded are damage to coral reefs or other benthic ecosystems, ghost fishing, marine litter and interference with other economic activities, such as tourism.

Scientists working on FAD research as well as fishing industry, well aware of the impacts that FAD stranding events can cause on reefs and in coastal ecosystems, have been working since 2007 to develop FAD structures that minimize this impact (Franco et al. 2019; Goujon et al. 2012; Lopez et al. 2016; Moreno et al. 2017). Among other experiments, trials with FADs made of diverse materials from natural origin were conducted in real fishing conditions. One of the main difficulties encountered during the trials at sea was the lack of sufficient observations during the life of experimental biodegradable FADs. Fishing companies in general deployed few FADs to test at sea. This is mainly due to the fact that a given vessel cannot rely on a high number of experimental FADs to fish, as their success is under trial. In addition, the cost of FAD´s tracking buoys and the communications needed to track them is high, thus the number of experimental FADs they trialed is usually limited. Given this, and the fact that a high percentage of FADs deployed by a given vessel is found and appropriated by other vessels, or end up lost or sinking, the numbers of experimental FADs deployed by fishing companies individually has not been sufficient to get results on the evolution of biodegradable FADs as well as on their operational lifetime.

Due to the lack of data on the behavior of biodegradable materials while testing experimental FADs in real fishing conditions, ISSF in collaboration with FAO Common oceans Tuna project, launched a project aimed at evaluating the fate of 3 different types of biodegradable ropes, under controlled conditions. Specific objectives were to (i) select the most appropriate biodegradable materials and ropes among those with potential to be used on FADs, and (ii) observe their fate in controlled conditions.

In order to address the first objective, ISSF held meetings with fishers and rope manufacturers to know the features needed for a biodegradable rope to be used successfully at FADs. Among others, being 100% from plant origin, availability close to the fishing ground, cost, degradation after one year of usefulness and being easy to handle onboard were identified as important features for biodegradable material to be a successful alternative to current plastic components used on FADs. As a result, 3 different ropes were selected (i) 100% twisted cotton rope, (ii) twisted cotton and sisal rope and (iii) cotton, sisal and linen looped rope. Once a selection of biodegradable ropes was done, in order to achieve the second objective, ISSF, in collaboration with the Marine Research Centre in the Maldives and the International Pole and Line Foundation (IPLNF), tested selected biodegradable ropes in Maldivian waters, monitoring in controlled conditions, their degradation during one year.

Biodegradability was tested by measuring breaking strength at regular intervals. Results showed that the most resistant rope was the cotton and sisal twisted rope, followed by the 100% cotton rope that had similar performance. However, taking into account the degradation needed after the useful lifetime for FADs, costs and other criteria for the biodegradable materials to be successfully used at FADs, 100% cotton rope appeared to be the most appropriate rope to be tested in real fishing conditions at FADs.

Research Questions

- Which is the best definition for a biodegradable material to be used at FADs?
- What are the features needed for a given biodegradable material to be used successfully at FADs?
- What are the most appropriate biodegradable materials and ropes among those with potential to be used at FADs?
- What is the lifetime of biodegradable materials when in open ocean?
- What is the lifetime of biodegradable materials when they arrive to the coast and/or gets stranded?

1. Introduction

A major impact derived from Fish Aggregating Devices (FADs) is that resulting from their own physical structure (Figure 1). Abandoned, lost or otherwise discarded FADs can end up stranded in coastal areas, sometimes in vulnerable marine ecosystems such as coral reefs, causing damage (Maufroy et al. 2015). In addition, following stranding, those FADs with netting in their submerged structure can cause ghost fishing, even if tied in bundles to prevent entanglement, because with time the netting becomes unraveled.

Figure 1. Underwater view of a FAD (© FADIO/IRD/ Ifremer/ Marc Taquet)

Other impacts related to the loss and abandonment of FAD structures is its contribution to marine debris causing accumulation of plastics at sea. This is a problem that affects all fishing gears at a global level, adding to the massive production of anthropogenic plastic marine debris. Plastic-based nets can take centuries to degrade. They accumulate year after year, and when they finally end up breaking down into smaller microparticles, they enter into the marine food web. Other impacts associated with FAD structures is their interference with other economic activities, such as tourism, marine transportation and aquaculture.

The solution must include finding alternatives to plastics, applying good practices to avoid fishing gear abandonment and loss, and retrieving unutilized fishing gears at sea. Each fishery should search for solutions best suited to their fishing operations.

In the case of FADs used by purse seine tuna fleets in the tropical area of the Indian, Atlantic and Pacific Oceans, the impact caused by their structure has triggered a response by coastal countries affected by their strandings, by scientists and research institutes working on FAD fishing, as well as by fishing industry, conscious of potential impacts caused from this loss, abandoned or discarded fishing gear. Currently, there are several Fisheries Improvement Programs (FIPs) of tuna fleets operating in the tropical regions of the three oceans, and all have identified importance of moving towards biodegradable FADs as a key action.

A direct outcome are some initiatives, both by the fishing sector and research institutes, to develop biodegradable FAD structures that work for fishing during a set time and thereafter degrade, thereby minimizing the effect of their loss. Among other experiments, trials with FADs made of materials from natural origin were conducted in real fishing conditions (Franco et al. 2019; Goujon et al. 2012). One of the main difficulties encountered during the trials at sea was the lack of sufficient observations during the life of experimental biodegradable FADs. Fishing companies in general deployed few FADs to test at sea. This is mainly due to the fact that a given vessel cannot rely on a high number of experimental FADs to fish, as their success is under trial and not yet known. In addition, the cost of FADs' tracking buoy and the communications needed to track the FAD is high, thus the number of experimental FADs they can trial is usually limited. Given that and the fact that a high percentage of FADs deployed by a given vessel is fished and appropriated by other vessels, or end up lost or sinking, the numbers of experimental FADs deployed by fishing companies individually has not been sufficient to get results on the fate of biodegradable FADs as well as on their lifetime in terms of usefulness for fishing.

Due to the lack of data on the behavior of biodegradable materials while testing experimental FADs in real fishing conditions, ISSF in collaboration with FAO Common Oceans Tuna Project, launched a project aimed at evaluating the evolution over time, under controlled conditions, of three different biodegradable ropes. The ropes being tested are expected to be used in the future as the submerged appendage of FAD structures so that when FAD stranding events occur the impact on the habitat is reduced, compared to the impact caused by current FADs that are using plastic derived components and thus remain at sea for years . This project comprises one of the first steps of the road map that ISSF has defined to move towards the use of biodegradable FADs (Figure 2). This document summarizes the research conducted.

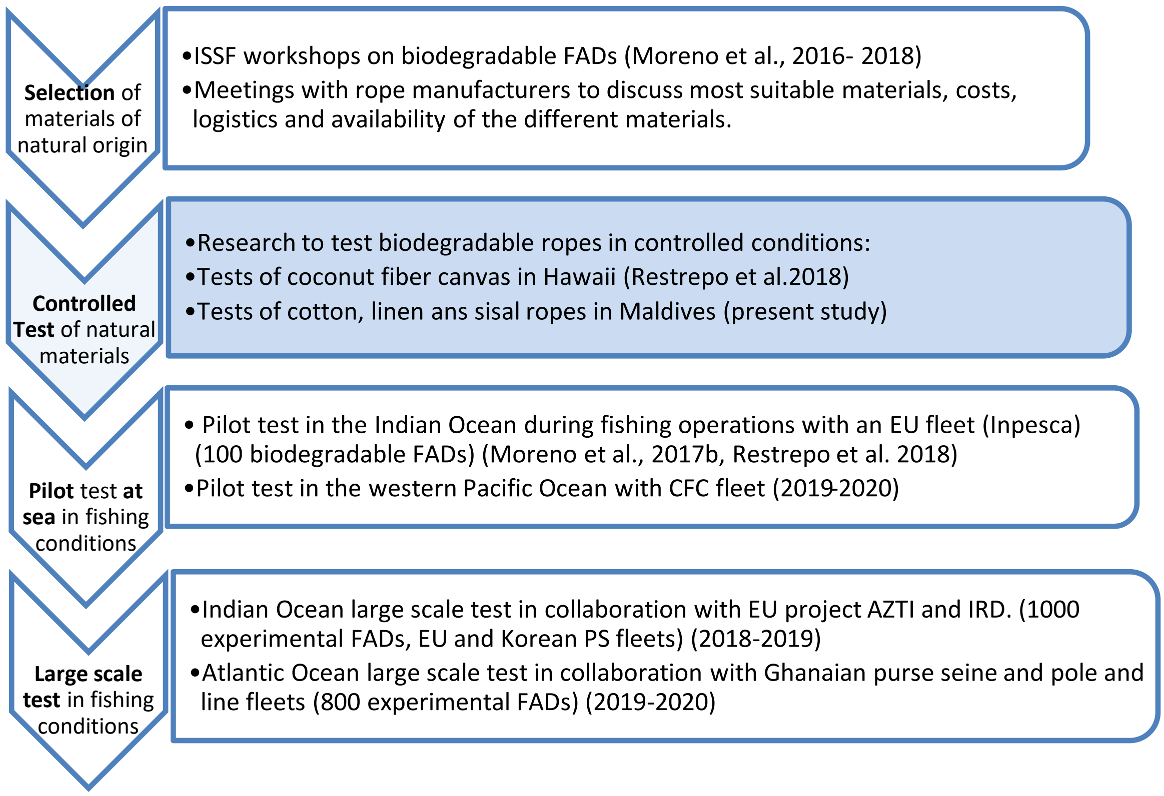


Figure 2. Diagram showing ISSF´s road map towards the use of biodegradable FADs

2. Objectives

The general objective of the project was to identify the most promising biodegradable materials to be used on FADs. This objective would allow moving towards the second step i.e. fishers testing biodegradable FADs in real fishing conditions, with a greater chance of success.

Specific objectives to achieve the general aim of the project were:

(i) to select the most appropriate biodegradable material and ropes among those with potential to be used on FADs
(ii) to study in controlled conditions the behavior of selected materials with time, measuring their breaking strength.

3. Material and Methods

1.1 Biodegradable ropes selection for the tests

Which is the best definition for a biodegradable material to be used at FADs?

This is one of the first questions to address when looking for an alternative to current plastic components at FADs. The term "biodegradable" is applied to materials or substances that are subject to a chemical process in which microorganisms in the environment convert the original material into natural substances such as water, carbon dioxide, etc. The process of biodegradation depends on the surrounding environmental conditions (e.g. location, composition of the medium and temperature), on the material and on the application (i.e., thickness). It is necessary to account for the time frame required to consider it as being biodegradable. In the case of FADs, a workshop with scientists and fishers on biodegradable FADs showed that the time needed for a biodegradable FAD to be useful for fishing was a maximum of one year (Moreno et al. 2016, 2018). Thus, after one year, the FAD should degrade as fast as possible.

Although knowledge of the time-frame needed for a FAD to be useful for fishing, the absence of a clear regulatory framework defining the standards of biodegradable materials in the marine environment, prevents a clear definition for the type of materials that could be permitted in biodegradable FADs construction (Zudaire et al. 2018).

In order to move forward on the use of biodegradable FADs, we adopted the following criteria of a biodegradable material for our tests at sea:

"A non-entangling material made of 100% plant fibers that are sustainably harvested".

What are the features needed for a given biodegradable material to be used successfully at FADs?

In order to select the most appropriate materials to be tested in controlled conditions, a series of meetings with fishers, rope manufacturers and scientist were held. In addition, during regular skipper workshops, ISSF scientists discussed with fishers about the potential for different materials as well as the features needed for a given material to be used to construct FADs (Murua et al. 2018).

Many different materials from natural origin were considered, such as linen, cotton, manila hemp, sisal, coconut fiber, jute, etc. From what we learnt during workshops and from previous experience testing coconut fiber in Hawaii (Restrepo et al. 2018), in order to select the most appropriate materials for the tests the following criteria was taken into account:

- 100% natural origin: ropes should be made of 100% vegetal fibers.
- Accessible & Available in great quantities: The material should be available in great quantities in order to replace current materials used at FADs.
- Available as close as possible to fishing grounds: to avoid ecological and economic costs of the transportation.
- Feasibility to be processed to make ropes: In order to replace current materials used at FADs and avoid the use of nets (to follow the non-entangling FADs designs), ropes were considered the most appropriate configuration of the natural fibers to be tested.
- Rope diameter and material easy to handle onboard: in order to construct the FADs the diameter as well as the material of the rope should allow easy handling onboard.
- Cost: The cost of a regular non-entangling FAD without the buoy, is around $300- $500 depending on the size of the FAD. In order to replace current FADs the cost of a biodegradable FAD should not be significantly higher compared to traditional FADs.
- Strength to last a year: Most of the fleets in the workshops held by ISSF set a maximum of one year as the ideal lifetime for a FAD to be productive for fishing.

Based on these criteria, the following ropes were selected as the most suitable for our tests (Figure 3):

Type 1: Twisted 100 % Raw cotton rope: 20 mm diameter, 4 strands in torsion Z, 1645 Kg breaking strength
Type 2: Twisted 50% cotton and 50% sisal rope: 20 mm diameter 4 strands in torsion Z, 1144 Kg breaking strength
Type 3: Cotton, Sisal and linen rope with loops (similar to those used in mussel farming but made of natural origin): 16 mm diameter core with loops, 194 Kg breaking strength

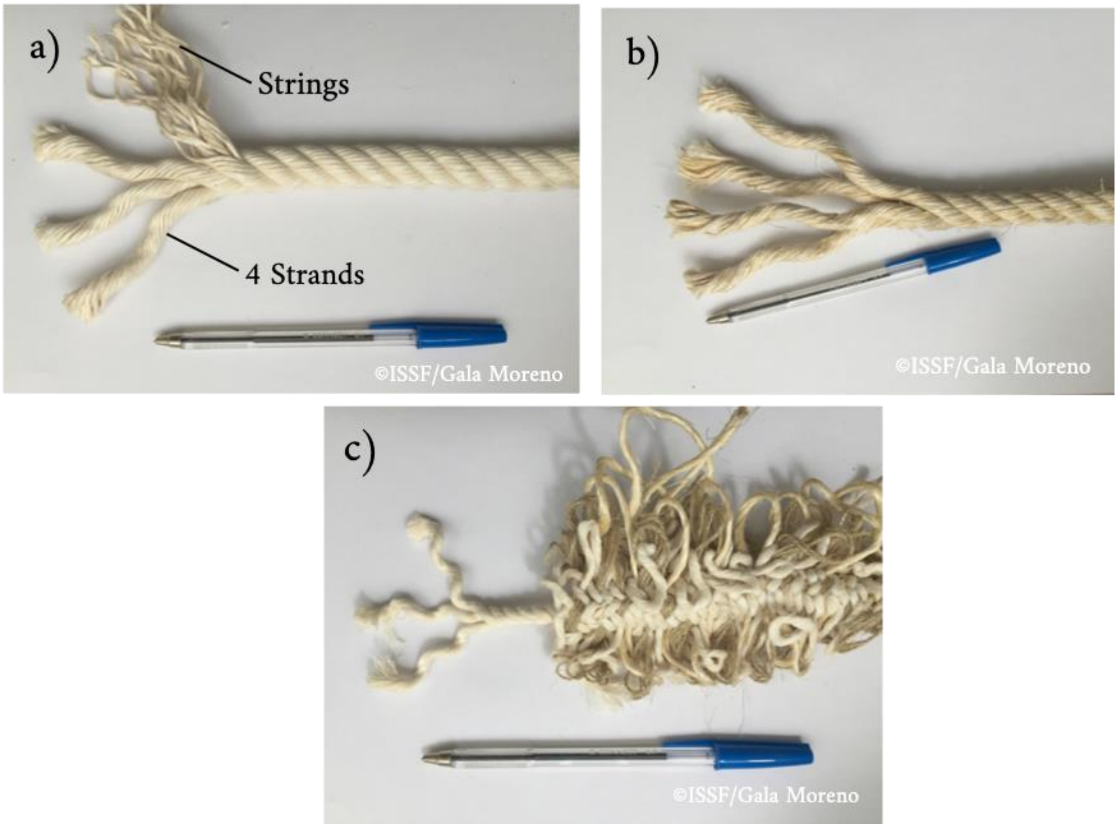


Figure 3. Selected ropes to be tested in controlled conditions

The rope with loops (Figure 3c) was chosen by fishers due to the surface provided for fouling organisms, such as barnacles. Some fishers consider FADs that allow bio-fouling as having greater fish aggregating potential.

1.2 Study site and data collection

Maldivian waters were selected to monitor the evolution of biodegradable ropes in controlled conditions, on one hand, because light and water characteristics were similar to those of tropical tuna purse seine fishing grounds found in the western Indian Ocean and on the other, the facilities of Maldives Marine Research Center allowed for close monitoring of the ropes.

Samples were deployed in June 2016 in 2 different sites simultaneously (Figure 4), (i) in offshore waters attached to a mooring rope, experiencing similar conditions as tropical pelagic environment and (ii) in a shallow lagoon close to the reef in Maniyafushi island, simulating the arrival of a FAD to the coast. These 2 different environments allowed monitoring the behavior of the ropes simulating a FAD while in oceanic waters as well as when a beaching event occurs, monitoring the time that the rope remains in the reef.

The three ropes were monitored at sea for one year to measure degradation with time. In total 6 bags made of netting were deployed in each site containing 3 samples of each rope type. Two extra bags were also deployed in each site, in case one of the bags was lost or to avoid any unforeseen event that could jeopardize the completion of the experiment. Once every 2 months, samples were retrieved from the 2 sites by a diver and the breaking strength in Kg (defined as the weight at which the strings break) for the 3 samples of each rope type was measured using a dynamometer.

Measurements were taken on set of strings (cf. Figure 3a), at least three, but sometime 4 or 5 strings. However, strings became too degraded at the end of the sixth month for rope type 3, becoming impossible to use the dynamometer. From the 6th month onwards measurements were taken both on strings and strands for ropes types 1 and 2. It should be noted that cotton strings in type 2 were so degraded by the end of the second month that only sisal strings were considered for data analyses throughout the study period.

The amount of biofouling accumulated was also assessed and the weight of the ropes with time at sea measured.

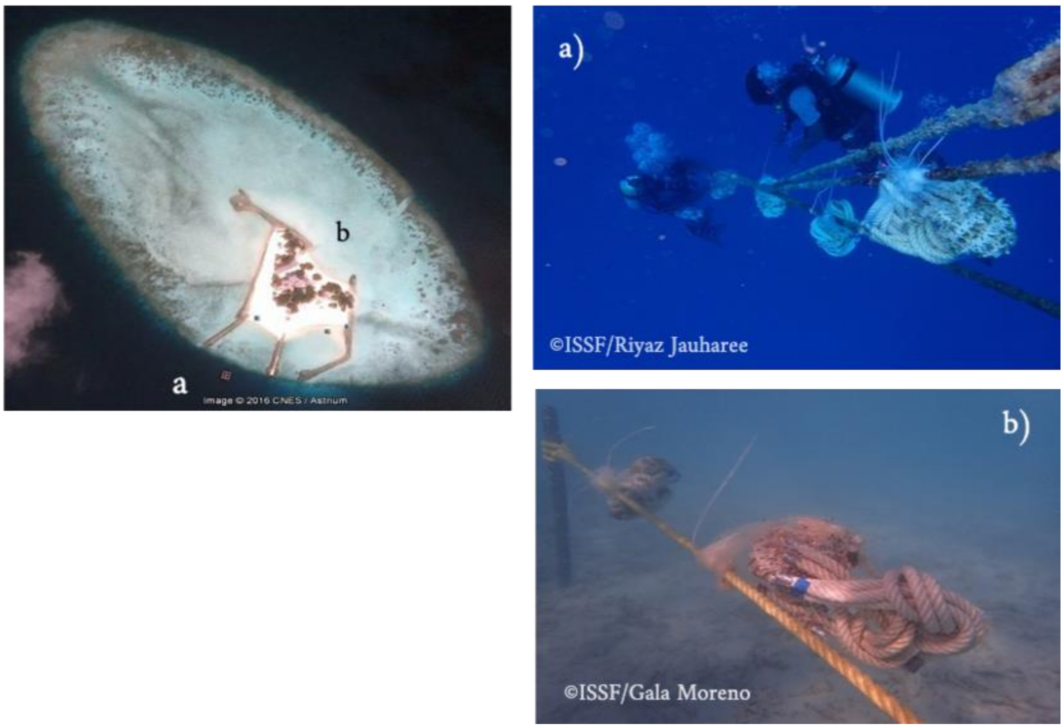


Figure. 4. Biodegradable ropes deployment sites in Maniyafushi island (Maldives) a) anchored in offshore waters (© ISSF/ Riyaz Jauharee), b) within the lagoon

4. Results

Results on the breaking strength of the strings clearly showed that the most resistant rope in terms of breaking strength was the cotton and sisal twisted rope followed by the 100% cotton rope that had similar degradation pattern in time (Figure 5). The weaker rope appeared to be the looped rope, as it suffered a steep drop in the breaking strength over time, presenting after 6 month at sea a poor performance.

From month 6 onwards measurements of the breaking strength of the strands were conducted for ropes type 1 and 2 (Figure 6). Measurements with the strands for cotton rope and mixed, cotton and sisal ropes, showed that the sisal and cotton rope was stronger compared to the one made of 100% cotton.

The breaking strength curve related to the time at sea for both, samples in the lagoon as well as for samples anchored offshore showed similar behavior, although degradation occurred slightly faster in the lagoon (Figure 5 and 6).

The rope Type 3 with the loops allowed biofouling faster than the other 2 rope types in both sites. However, the 3 types of ropes where colonized by barnacles, shrimps, algae and small fish during the experiment. The ropes tested in offshore waters allowed more biofouling compared to those in the lagoon, probably due to the accumulation of sediments in the ropes at the lagoon.

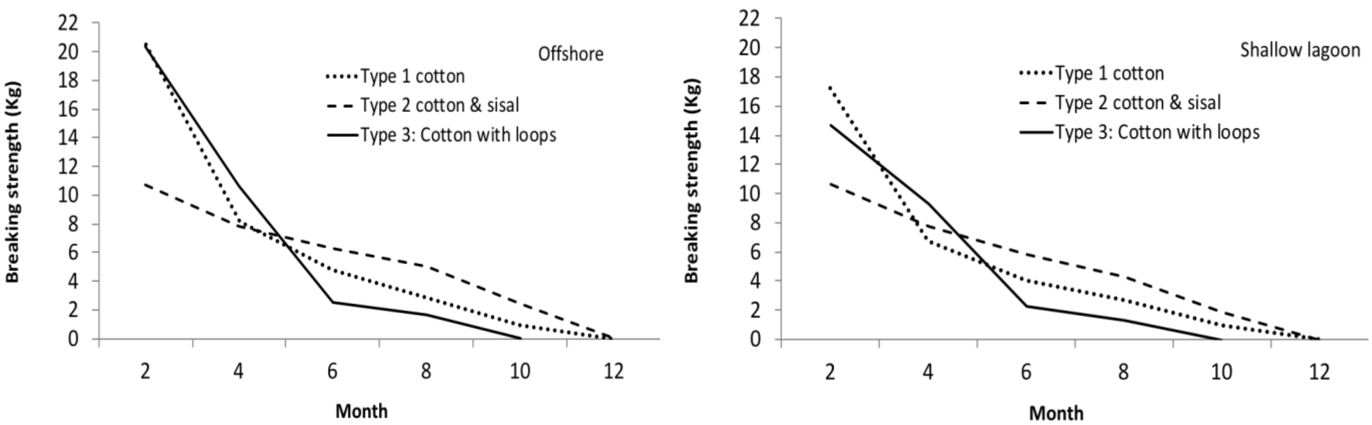
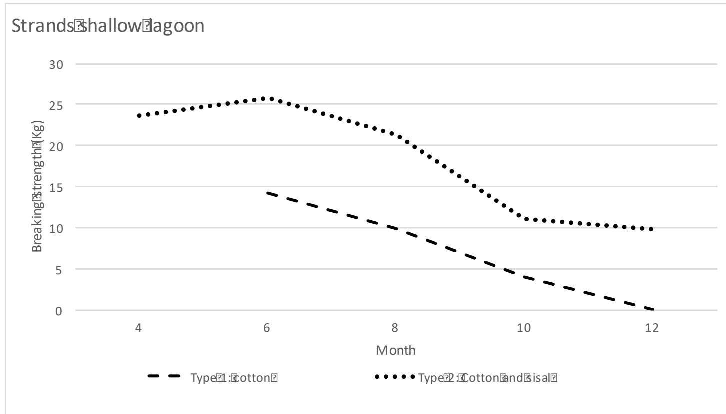


Figure 5. Biodegradable ropes' strings degradation with time at sea. For ropes anchored in offshore waters (a) and within the lagoon (b).



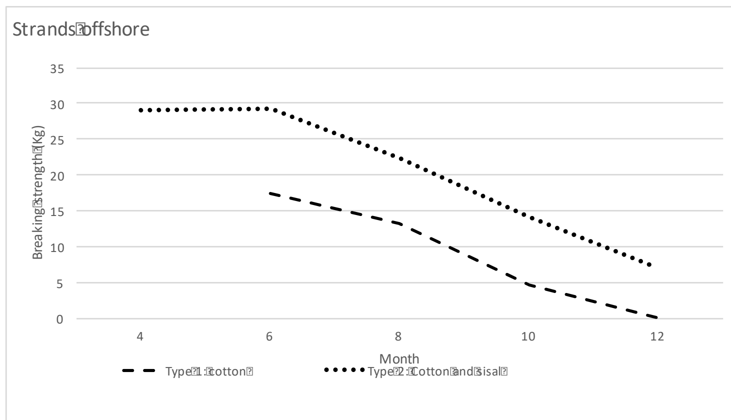


Figure 6. Biodegradable ropes strands degradation with time. For those anchored in the lagoon (top) and in offshore waters (bottom).

5. Discussion

Breaking strength measurements showed that mixed cotton and sisal rope of 20 mm diameter (Figure 6) was the strongest rope after one year at sea. However, in order to select the most appropriate rope to be used on FADs, not only robustness and resistance to degradability is important. Following the criteria set for the selection of natural fibers, being easy to handle, cost, availability close to fishing grounds and degradation after one year need to be taken into account.

Fishers found 100% cotton rope were easier to handle compared with the cotton and sisal rope. In addition, from the results of this experiment on breaking strength as well as the criteria mentioned above, the 100% cotton rope seems to better fulfil the characteristics needed to be used on FADs. The cotton rope´s breaking strength is not as strong as the mixed sisal and cotton rope. However, its useful lifetime matches that desired by fishers for FADs i.e. around one year. Our results suggest that the mixed sisal and cotton rope would remain strong after 1 year, which is more than the time needed.

The rope with the loops was the weakest in our experiments as it was found to be not strong enough to last for a year at sea. The initial breaking strength of this rope was 194 Kg which is an order of magnitude lower than the other 2 ropes (cotton rope and cotton and sisal rope). The results obtained support the need for ropes that have an initial breaking strength above 200 Kg. We did not test the performance of ropes that are between 200 Kg and 1000 Kg of breaking strength. However, it should be noted that the breaking strength is not the only feature determining the degradability of the ropes at sea; torsion and abrasion suffered as well as capacity to stretch are important features that determine the lifetime of a rope. For instance, the cotton rope (type 1), which initially had the higher breaking strength (1645 Kg) performed worse compared to type 2 which had a lower breaking strength (1144 Kg).

The looped rope (type 3) would allow biofouling (as used in mussels farming). The fact that biofouling has the capacity of aggregating non-tuna species that may, at the same time attract tuna species, has not been scientifically proven. While some fishers support this hypothesis, others do not support it and think that biofouling makes the FAD weaker due to accumulation of weight, eventually making the FAD sink or the ropes unravel and break. However, experts on physical oceanography suggest that the weight acquired by the structure due to biofouling is insignificant in terms of the need of extra floatation and increasing stress to the structure from physical forces.

Some components of the FAD need to support the weight of the structure, as it is the case of the ropes that link the raft on the surface with the weight usually added by the hanging components at the end of the submerged section of the FAD. Those components need to be strong enough for the FAD to be useful for a year. Other components do not necessarily need to be strong, as they are used just to provide more volume (or presence) of the FAD structure which is believed by fishers, in general, make the FAD more attractive to non-tuna and tuna species. For example, palm leaves and empty gunny bags are commonly used for hanging from the main structure of the FAD to provide shadow for fish.

In the case of biodegradable ropes tested in this study, a good compromise could be using the 100% cotton rope to support the main structure of the FAD, due to its robustness, and using the rope with the loops just to provide volume to the FAD, hanging them from the raft in small pieces. In this way, the degradation of these ropes would not severely affect the integrity of the main structure and thus the potential sinking of the FAD.

Other projects working with biodegradable twines have shown that variations in manufacturing processes, or possibly variations in cotton blends, appear to have a significant effect on degradation rate (Winger et al. 2015). This shows that, not all cotton ropes with the same specifications (diameter, twisted, number of strings, strands and yarns etc.) are expected to behave and degrade the same way. Research on biodegradable twines made of cotton, in other fisheries, show the strength of the rope is dependent on the manufacturing process and the quality of the cotton. Therefore, it is likely that the results of this experiment may be different if ropes were of a different manufacture. The quality of the material, its configuration, including unique manufacturing process are key to the finding of the most suitable material to be used on FADs.

One example of the importance of this quality is that of bamboo canes and FADs floatation. Not every bamboo cane works the same on FADs. Fishers clearly stated that green bamboo cane's performance at sea is better than those canes that have dried. Also, different species of bamboo behave differently. Green bamboo canes allow FADs to float for longer, which is key for a robust lifetime of a FAD. Fishers have learnt that it is the quality that is required for a given material, in this case bamboo, to be useful at FADs. The same learning process it is expected to happen for new biodegradable materials used for the hanging structure of FADs.

In addition, not only the configuration of the material and its quality will be important for the degradation of the biodegradable material but also the surrounding environmental conditions influence strongly. In the case of the ropes tested in this experiment, the behavior with time in both sites, i.e. lagoon and offshore sites, was similar for the 3 different ropes tested. We expected having much greater degradation within the lagoon due to abrasion with the seabed, but this was not the case. However, sea temperature, light exposure and levels of oxygen might be very similar in both sites and thus degradation was similar.

Finally, it should be noted that the ropes in this experiment were not used in real drifting FADs, thus breaking strength and lifetime of the ropes could be different in real fishing conditions. However, our results provide a reference for comparing the robustness and degradability of 3 types of ropes that fulfill the criteria set by scientists and fishers to be successful to replace current plastic components at FADs.

6. Conclusion

One of the main difficulties encountered when testing materials on drifting FADs is the lack of sufficient observations during the life of experimental biodegradable FADs because it is difficult to revisit them. The experiment conducted in Maldives to test different biodegradable rope types to be used on FADs shows the usefulness of these experiments under controlled conditions to analyze the behavior of different biodegradable materials. The study allowed comparing different ropes and assigning different uses to these ropes to be used on FADs. In our case, the strongest rope in terms of breaking strength, type 2 cotton and sisal rope, was discarded because measurements suggested that it would sufficiently have not degraded after one year at sea. The idea is to use material that makes the FAD not useful after its lifetime for fishing, estimated to be around one year (Moreno et al. 2016). Also, fishers considered that type 2 was difficult to handle due to the mix of cotton and sisal. Type 3 rope although being weak was considered to be value to be used as an attractor to provide shadow and volume to the structure (first steps of FAD colonization could be favored - thanks to this type of rope) and type 2 was considered the best to assemble the main structure of the FAD.

In conclusion, this experiment allowed selecting the appropriate biodegradable material to be used on FADs, which allows moving towards the next step on the use of biodegradable FADs; testing them at sea in real fishing conditions. This preselection decreases the failure of trials at sea, which in many cases have failed due to lack of knowledge of the behavior and characteristics of the materials under test.

7. Recommendations

Recommendation 1:

- Biodegradable materials to be used at FADs should be made of 100% vegetal fibers that are sustainably harvested

Recommendation 2:

- Biodegradable materials to be used at FADs should be sourced from areas close to the fishing ground

Recommendation 3:

- Biodegradable materials should allow a maximum lifetime of FADs of one year and then degrade as fast as possible.

Recommendation 4:

- Tests in controlled conditions are necessary to better understand the behavior of different vegetal fibers. Those experiments should be region specific.

Recommendation 5:

- The quality of the vegetal fibers, its configuration and manufacturing process as well as the surrounding environmental conditions will determine the degradation of FADs.

Recommendation 6:

- From the present experiment results, 100% cotton ropes (20 mm diameter, 4 strands in torsion Z) fulfil all the criteria to be used at FADs as an alternative to the submerged nets currently used at FADs.

8. Acknowledgments

ISSF would like to thank IPNLF and the staff at Maniyafushi Island, Marine Research Centre in Maldives who did all the work to successfully test biodegradable ropes in Maldivian waters. This study was co-funded by FAO Common Oceans ABNJ Program.

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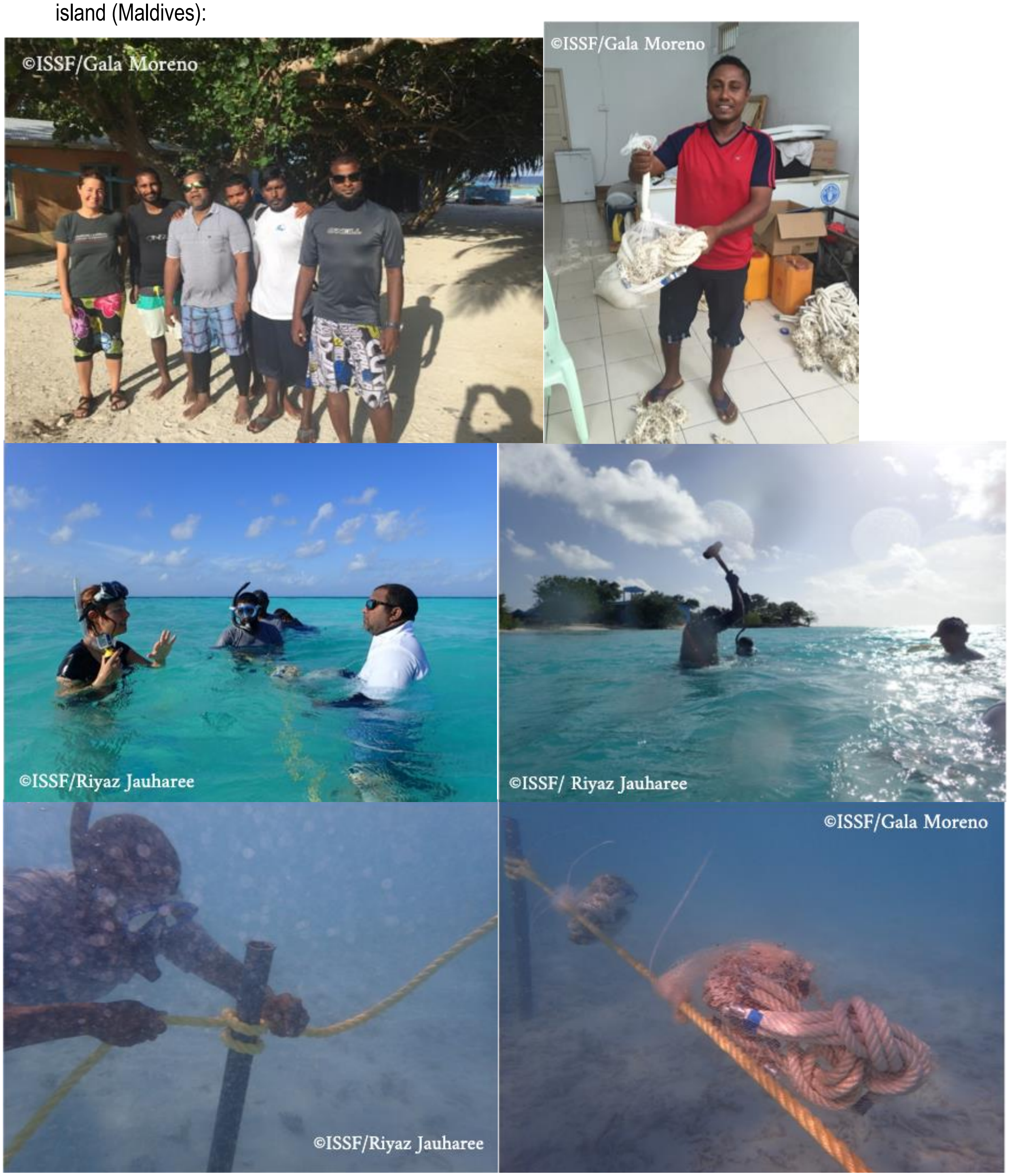
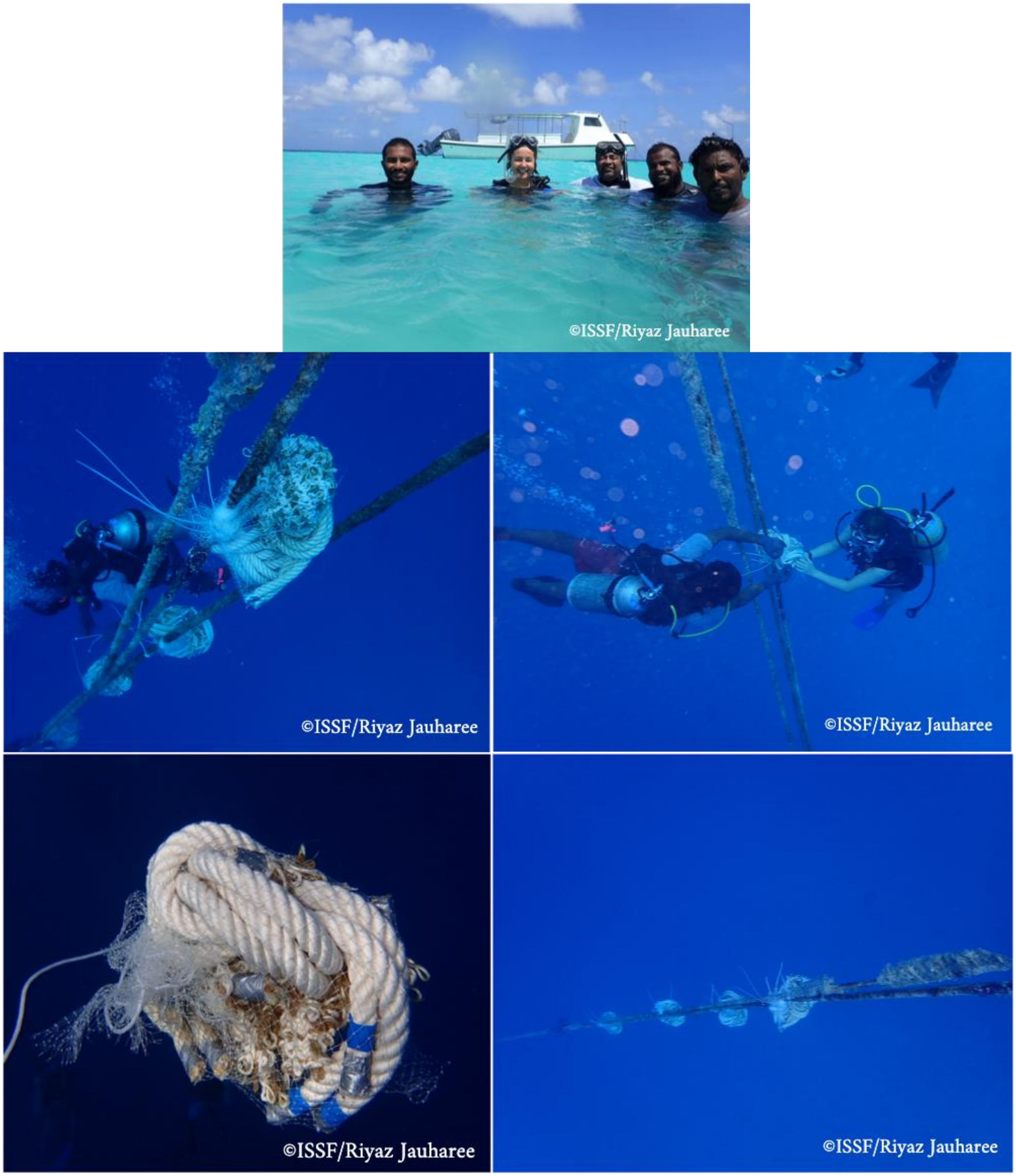
Zudaire et al. 2018. Which is the best definition for the biodegradable FADs? Indian Ocean tuna commission, IOTC-2017-SC20-INF07.

Appendix: Images

1. Deployment of biodegradable ropes in the lagoon, ISSF with the staff of the Marine Research Centre in Maniyafuhi island (Maldives):



2. Deployment of biodegradable ropes offshore, ISSF with the staff of the Marine Research Centre in Maniyafuhi island (Maldives):



3. Biodegradable ropes after 2 months at sea

4. Biodegradable ropes after 12 months at sea

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