

# Evaluating potential biodegradable twines for use in the tropical tuna fishery

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## Abstract

Tens of thousands of man-made drifting FADs are estimated to be in use by industrial purse seiners worldwide. Although FAD fishing is considered a successful and efficient method to catch tropical tuna, it accounts for several ecological and environmental drawbacks, such as producing larger amount of by-catch compared to free school fishing, potentially increasing the amount of marine debris, or unintentionally entangling individuals of some vulnerable species, like sharks or turtles. Indeed, the latest is considered an important concern by RFMOs and fleets have already started to regularly deploy non-entangling DFADs during their commercial trips. However, the use of new materials to construct the underwater part of the DFAD has not been explored in detail so far. In order to face this situation, scientists, industry, and twine manufacturers have worked in collaboration to test and evaluate different potential biodegradable materials that can be used in the FAD fishery. This paper presents first results of a recent research conducted in the Atlantic Ocean dealing with new materials and designs of twines for use in the DFAD construction to prevent the entanglement of sea turtles and sharks, being as much as biodegradable as possible and as efficient in aggregating fouling as the traditional one. Results show that different materials and designs degrade differently over the study period and that material specific characteristics play an important role in the lifetime of the twines. The use of new and promising materials and designs are discussed, as well as its implications for conservation and relevant future lines of investigation.

## Resumen

Se estima que decenas de miles de FADs de origen antropogénico son usados regularmente por la flota industrial de cerco de atún tropical que opera por todo el mundo. A pesar de que la pesca con FADs se considera un método eficiente para pescar atún, esta forma de pesca también tiene ciertas desventajas ecológicas y medioambientales, tales como una mayor captura accesoria en comparación con la pesca de banco libre, el aumento potencial de la basura marina, o la captura involuntaria por enmallamiento de algunas especies vulnerables como tortugas o tiburones. De hecho, este último inconveniente asociado a los FADs es una de las principales preocupaciones de las OROPs y las flotas pesqueras ya están empezando a plantar y usar regularmente objetos no enmallantes en su estrategia de pesca. Sin embargo, el uso de nuevos materiales para construir la parte sumergida de los objetos no ha sido evaluado en detalle hasta ahora. A fin de hacer frente a esta necesidad, científicos, industria pesquera y fabricantes de cordeles han colaborado recientemente en un proyecto para testear y evaluar

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el potencial de diferentes materiales biodegradables que puedan ser usados en la construcción de los FADs. Este documento muestra los primeros resultados de esta investigación, llevada a cabo en el océano Atlántico y en la que se han valorado diferentes diseños y materiales, con la idea de que sean lo más biodegradable posible, lo más eficiente posible en términos de captación de biofouling y que a su vez posibiliten crear FADs que eviten el enmallamiento de tiburones y tortugas. Los resultados de este experimento muestran que los diferentes materiales y diseños tienen un rol importante en el propio deterioro del prototipo, así como en la capacidad de captación de organismos. Este trabajo discute el uso potencial de nuevos materiales y diseños para la creación de FADs y reflexiona sobre las implicaciones que podrían tener en la conservación y las futuras líneas de investigación en el campo.

## Introduction

Industrial purse seiners have historically been looking for natural objects floating in the surface of the tropical and subtropical oceans to facilitate their catch of skipjack, (*Katsuwonus pelamis*) yellowfin (*Thunnus albacares*), and bigeye tuna (*Thunnus obesus*). However, in the last two decades, the effort towards this fishing mode has sharply increased and fishers are now regularly constructing and deploying a significant number of man-made floating objects in the ocean (also called fish aggregating devices, FADs) to increase their fishing efficiency (Dagorn et al., 2012; Fonteneau et al., 2000). Indeed, about 100,000 FADs are estimated to be annually deployed worldwide by the industrial tropical tuna purse seine fishery (Baske et al., 2012; Scott and Lopez, 2014; Ushioda, 2015). According to the ISSF (2016) the tropical tuna purse seine fishery landed around 4.5 million tons in 2014, from which nearly half of them are caught fishing on FADs (Fonteneau et al., 2013). Although FAD fishing is considered a successful and efficient method to catch tropical tuna, it accounts for several ecological and environmental drawbacks, such as producing larger amount of by-catch compared to free school fishing (Hall and Roman, 2013), potentially increasing the amount of marine debris (Maufroy et al., 2015), or unintentionally entangling individuals of some vulnerable species, like sharks or turtles (Filmlalter et al., 2013). While ratings of by-catch impacts of sea turtles and sharks for purse seine are low compared with other fishing gears, accurate estimates of the number of FADs lost or abandoned causing ghost-fishing of these species or reaching to coastal areas each year are unknown. Due to these concerns, regional fisheries management organizations (RFMOs) have recently started to monitor and encourage the use of alternative FADs. As an example, the Working Party on Ecosystems and By-catch of the Indian Ocean Tuna Commission recommended in 2009 the “complete conversion to the use of ecological FADs (i.e., non-entangling FADs) as soon as possible and that these FADs are made of biodegradable materials”. Because FAD structure is of concern, some efforts have already been made to develop an alternative FAD, in the Pacific (Armstrong and Oliver, 1996), in the Indian (Delgado de Molina et al., 2005), and in the Atlantic Ocean (Franco et al., 2009; Franco et al., 2012), and fleets have already started to regularly deploy non-entangling FADs during their commercial trips (Goñi et al., 2015; Goujon et al., 2012). However, the use of new materials to construct the underwater part of the DFAD has not been explored in detail so far. In order to face this situation, scientists, industry, and twine manufacturers have worked in collaboration to test and evaluate different potential biodegradable twines that can be used in the FAD fishery. This paper presents first results of a recent research conducted in the Atlantic Ocean dealing with

new materials and designs of twines for use in the DFAD construction to prevent some of the most significant drawbacks of the FAD fishing, being as much as biodegradable as possible and as efficient in aggregating fouling as the traditional one.

## Material and Methods

Five twine types were selected for use in this study on the basis of their potential biodegradation, resistance, reproducibility, and availability in the market. In general, biodegradable twines are limited to those of vegetable fibre construction where the rate of decay is a function of the kind of fibre, water temperature, rotting power of the water, and the duration of immersion (Klust, 1982). These included: (a) twisted cotton, (b) twisted regenerated cotton and sisal, (c) plaited and bulked regenerated cotton and linen, (d) plaited and bulked cotton, regenerated cotton and linen, and (e) plaited and bulked regenerated cotton, sisal and hemp twines. All twines were designed, manufactured and distributed by Itsaskorda Cordage Building Supplies (Markina, Spain).

The twines were assessed for their initial breaking strength, diameter, weight, and Rtex. For the aim of this specific study, we defined breaking strength (kgf) as the point at which the twines breaks/ruptures when placed under stress, and Rtex as the linear density or mass per unit length (1 tex = 1 g/1 m). The twines were deployed at sea for a duration of 161 days to measure degradation in breaking strength (kgf) over time. The study site was located in the inshore aquaculture grounds in Mutriku, Spain (43.311 N, -2.377 W) (Figure 1). Although the first idea was to subject the twine samples to similar underwater conditions (i.e., depth, temperature, water chemistry) as would be experienced during normal tropical fishing conditions, several logistic constrains make us to revise and change the location of the experiment. The duration of the experiment was comparable to the mean operative days a FAD is available for the fleet (150–180 days). Potential sea surface temperature at the study site was monitored using high resolution satellite data from the GODAS service of the NOAA (<http://www.esrl.noaa.gov/psd/data/gridded/data.godas.html>). Over the period study, surface temperature varied between 12.3 and 19.6°C.

Experimental aquaculture cages were used as an anchoring system to deploy the twine samples near the ocean surface. To reduce the possibility of sample loss, twines were attached to the main emerged structure of the cage by a set of protected nylon twines. Five complete set of samples of the different twines were deployed. Distance between samples was around 30 cm while the distance between the sets was approximately 3 m. Each set of samples contained five 4 m long samples of each of the five twine types, for a total number of 25 samples (Figure 2). Thus, samples were deployed at a water depth of 0-4 m. Maximum water depth at the study site was approximately 15 m.

Samples were first deployed in October 2015 and the sampling crew returned to the study site five times over a period of 161 days (i.e. first retrieval November 2015, last retrieval March 2016). Duration between visits ranged between 28 and 35 days (mean = 32.2) and depended on sea conditions. During each visit, one set of samples was hauled to the surface and twines were collected. When hauled, samples were drained and weighted, and the most visible microorganisms were collected, along with a number of small sub-samples of each of the

twines (Figure 3), for a subsequent dedicated biological sorting and analysis of them in the AZTI laboratories. The retrieved twine samples were transported to the Itsaskorda laboratory for immediate evaluation of breaking strength while in its wet condition.

Breaking strength tests were conducted using a constant rate of traverse model 855-I test machine, manufactured by J. Bot Instruments Ltd. (Barcelona, Spain) and had a capacity of 5098 kgf. Twine samples were held between two grips; a lower stationary grip and a hydraulically driven upper grip which moved at a constant rate of speed (500 mm/min). Load data was logged and collected using Conus software for windows developed by J. Bot Instruments Ltd. (Barcelona, Spain). All samples were tested in a wet condition. Values for Day 0 were derived by storing new samples in saltwater under laboratory conditions and then testing for breaking strength.

## Results and discussion

Results from the pre-testing trials are shown in Table 1. Prior to deployment, breaking strength was lowest for the plaited and bulked cotton, regenerated cotton, and linen twine (Twine 4: 189 kgf) and highest for the twisted cotton twine (Twine 1: 1645 kgf). The linear density or mass per unit length (referred to as Rtex) ranged from 202.7 to 234 tex.

Results from the sea trials revealed noticeable differences in degradation rates over the period of study, characterized as different slopes and intercept in Figure 4. Twisted twines (two of the five twines) demonstrated the expected drop in breaking strength, however plaited and bulked twines (three of the five twines) showed little change in breaking strength over the period of study. The relationship between breaking strength (kgf) and soak time (days) was statistically significant ( $p < 0.05$ ) for three of the five twine types, which can be expressed by the following linear equations:

$$\text{Break strength (Twine 1)} = 1517.16 - 3.638 * \text{soak time} \quad (p = 0.01 ; R2 = 0.77)$$

$$\text{Break strength (Twine 2)} = 1028.51 - 5.310 * \text{soak time} \quad (p = 0.02 ; R2 = 0.71)$$

$$\text{Break strength (Twine 3)} = 223.68 - 0.457 * \text{soak time} \quad (p = 0.17 ; R2 = 0.26)$$

$$\text{Break strength (Twine 4)} = 213.11 - 0.382 * \text{soak time} \quad (p = 0.04 ; R2 = 0.58)$$

$$\text{Break strength (Twine 5)} = 261.69 - 0.558 * \text{soak time} \quad (p = 0.10 ; R2 = 0.51)$$

Analysis of covariance (ANCOVA) revealed significant differences in both slope and elevation among the twine types ( $p < 0.001$ ). Extrapolating the x-intercept for each of the twines for which the linear equation was statistically significant predicts a time to failure (i.e., when breaking strength reaches 0 kgf) of 193 d for twine 2, followed by 417 d for twine 1, and 557 d for twine 4. These results offer first insights into the potential use of these materials to be employed in the FAD fishery, in relation to the average time requirements (i.e., the time a FAD

needs to be operative at sea) demanded by the fleet. Although Maufroy et al. (2015) demonstrated that FADs drift at sea on average for periods over one or two months depending on the ocean for the French fleet, previous experimental projects in the field as well as personal interviews with Spanish skippers suggest that this time may be significantly greater for the Spanish fleet [3-6 months (90-180 d), reaching sporadically to 1 year (365 d)]. In consequence, and as variability of fishing strategy may be large between fleets, the designs and materials used to construct FADs should be adaptable and flexible to the specific characteristics of each fleet.

It is interesting to note that our initial descriptors (Table 1) were not an appropriate indicator of degradation rate at sea. While twines showed the expected pattern in initial breaking strength (i.e., low, high), they did not share similar degradation rates when placed at sea. We attribute this difference to the fact that we evaluated twines with variable construction design and materials. The results illustrate that material type, construction design, and Rtex are not sufficient predictors of degradation rate observed at sea when such twines are constructed with both different designs and materials. We suggest that the use of a specific material twine in regulations, either voluntary or mandatory, appears to hold little value if is not accompanied with specific construction designs and candidate twines are not evaluated by subsequent experiments at sea. Indeed, variations in manufacturing processes (i.e., construction designs, materials, etc.) appear to have a significant effect on degradation rate and thus, twines used in non-entangling fishing devices should be scientifically evaluated to ensure that material and design analysis is continued.

Analysis of the biological samples collected during the study period showed that all twines had good probability of colonization. Both field and laboratory analysis identified a range of marine organisms in the samples: green, brown and red micro and macro-algae, and small invertebrates, including bivalve molluscs, amphipods, and some polychaete annelids. A key observation was that plaited and bulked twines experienced a faster and relatively more complex colonization than twisted twines. In general, plaited and bulked twines had complex biological organisms since the beginning, while twisted twines only presented algae during the first two or three months of the experiment. We attribute this variance to differences in the design, as bulked structures can provide better access and shelter to certain marine fauna. Similarly, linear equations reflecting weight differences over the study period were of positive trend in general (Figure 5). This complementary source of information may hardly be seen as an accurate index of colonization but could certainly provide indicative information on the general colonization process of the biomass. In that sense, results at fine scale with no consideration of the general trend showed a notable increase after the first month at sea, attributable not only to the colonization of marine organisms but also to the saturation of sea water, followed by a second increase and a posterior stabilization (Figure 5). Further investigations should consider specific analysis to study biomass fluctuation at FADs in relation not only to biodegradable materials but also FAD community, either by conducting specific laboratory analysis of the samples or using echo-sounder buys to monitor biomass at FADs systematically over a particular time period.

Assessment of alternative unevaluated twines may provide interesting insights in the field of FAD fishing conservation and should be highly encouraged. In the light of the results, we

recommend further experiments in which a new specific twine should be developed and tested (e.g., a twisted and bulked cotton, sisal and linen twine). However, not only vegetal fibres are being considered for FAD fishery. Some private initiatives lead by tuna fishing technology companies are also investigating the use of new biodegradable plastic materials to construct the floating part of the FAD, which can be programmed to be rotted in a specific period of time (<http://satlink.es/producto/satlink-biodegradable-fad/>). Ideally, experiments should be extended to representative tropical grounds where little interaction exists with fishery. Besides, and because FAD fishery is world widely spread, sources from multiple manufacturers should be compared to account for manufacturer variability in breaking strength and degradation at sea. This information could be used to orient industry, management organizations and scientific community in general on the use of new biodegradable materials in the FAD fishery. If possible, different initiatives around the world leading with biodegradability of FADs should be coordinated, and their potential outputs and results compiled and further discussed with skippers of the different fleets to better understand the feasibility and likelihood of implementation of the new materials in each ocean and fleet.

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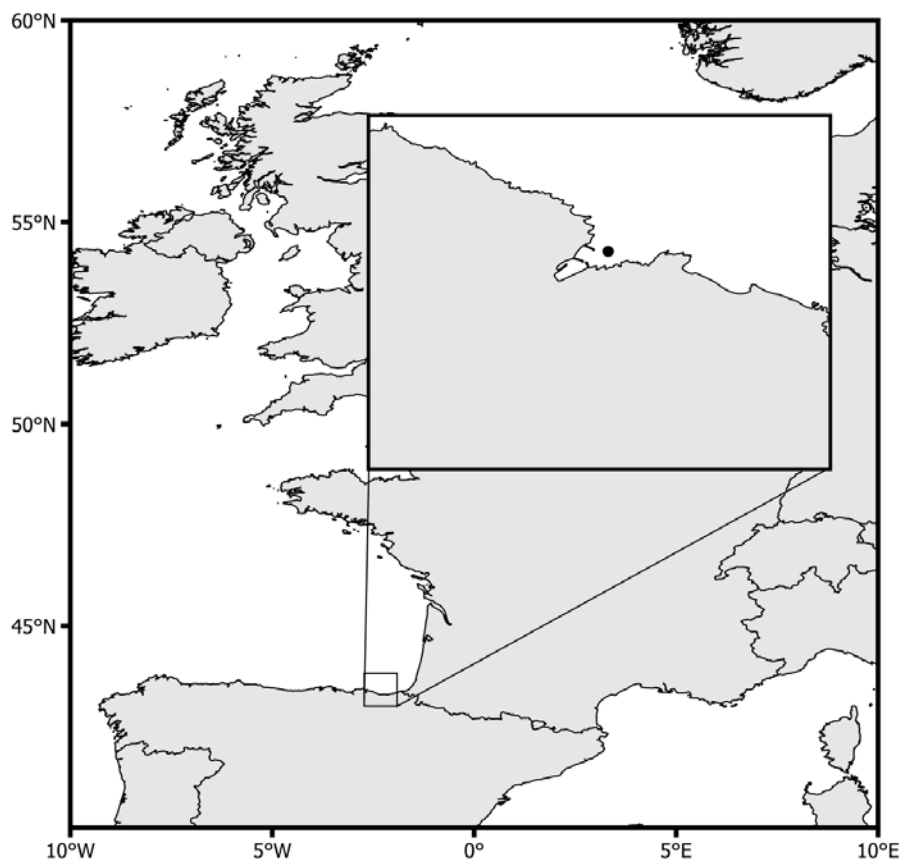
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## Tables and Figures

**Table 1.** Characteristics of five twine types evaluated in this study. Values shown were collected during pre-testing under laboratory conditions using dry (new) samples, prior to sea trials.

Twine	Twine type	Construction	Breaking strength (kgf)	Diameter (mm)	Rtex (gr/m)
1	Cotton	Twisted	1645	20	202.7
2	Regenerated cotton + sisal	Twisted	1144	20.62	210.93
3	Regenerated cotton + Linen	Plaited + bulked	194	16.7	221.16
4	Cotton + Regenerated cotton + Linen	Plaited + bulked	189	16.4	234
5	Regenerated cotton + Sisal + Hemp	Plaited + bulked	288	12.2	212.87



**Figure 1.** Map showing the study area. Twines were deployed in the aquaculture inshore grounds of Mutriku, Spain (43.311 N, -2.377 W).

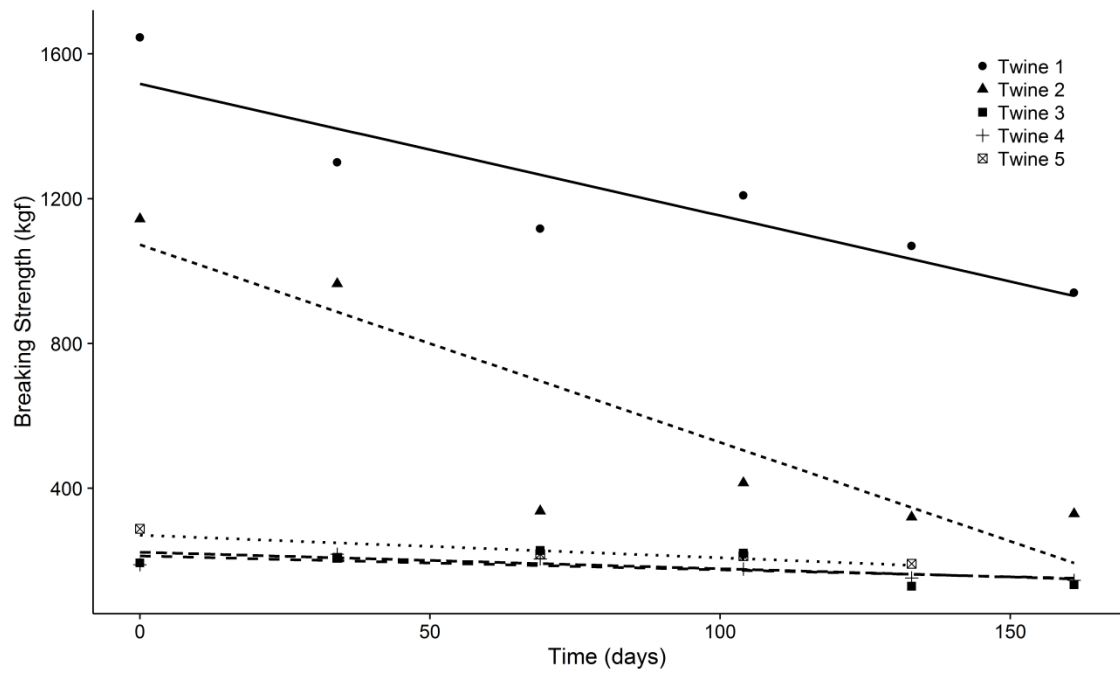




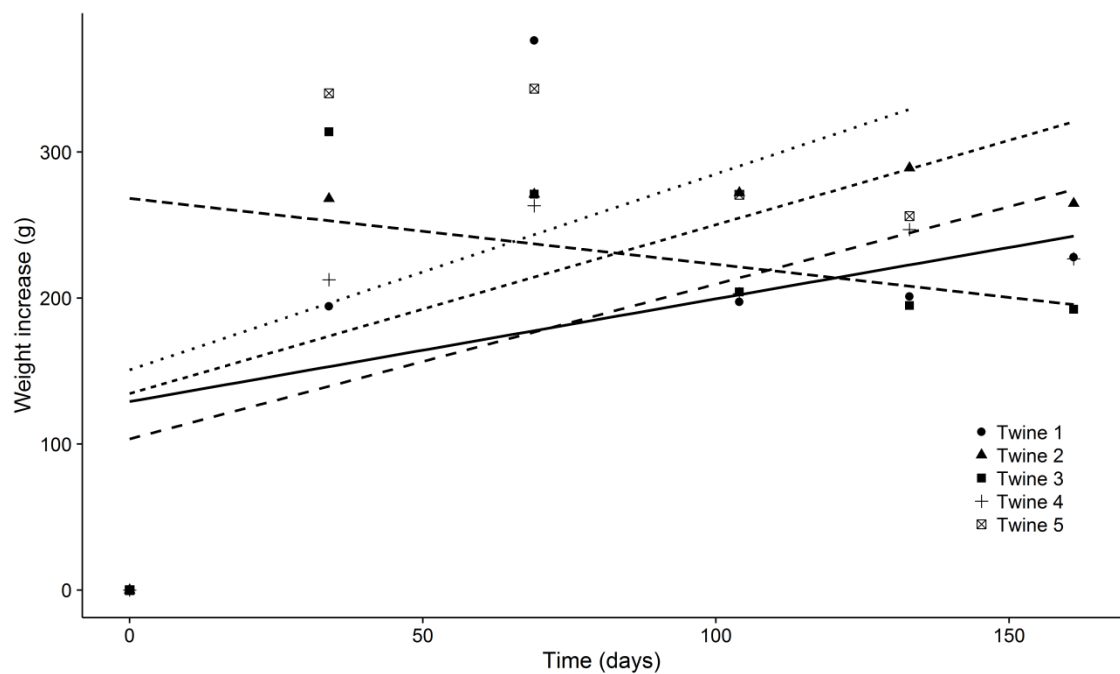
**Figure 2.** Samples of the 5 different twines used in the present study.



**Figure 3.** Pictures illustrating the biological sampling of the twines. Twines are first sampled in the field (top) and a small sample is kept in jars for subsequent analysis in the AZTI laboratories.



**Figure 4.** Relationship between breaking strength (kgf) and soak time (days) for five twine types deployed at sea for a period of 161 days.



**Figure 5.** Relationship between weight (g) and soak time (days) for five twine types deployed at sea for a period of 161 days.