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COLONIZATION OF DRIFTING FISH AGGREGATING DEVICES (DFADs) IN THE WESTERN INDIAN OCEAN, ASSESED BY FISHERS' ECHO-SOUNDER BUOYS

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SUMMARY

Floating objects drifting in the surface of tropical waters attract hundreds of marine species including tuna and other species. Taking advantage of this associative behavior, industrial tropical tuna purse seiners have been increasingly deploying artificial man-made DFAD. Yet, the reasons driving this associative behavior are not fully understood. Currently, most of the DFADs are equipped with satellite linked echo-sounder buoys, which provide information on the accurate geo-location and rough estimates of the aggregated fish biomass underneath along the trajectory of the DFAD. This study investigates the colonization process of DFADs in different periods in the Western Indian Ocean, using information from 962 echo sounder buoys of DFADs deployed between 2012 and 2015 by the Spanish fleet (67716 day observations). It was found that tuna species arrived at DFAD before non-tuna species (13.49±8.35 and 21.69±15.06 days, respectively). Results provided evidences on the relation between object depth and colonization process, finding that tunas arrive earlier to deeper objects. The analysis revealed period and species-specific colonization patterns, suggesting that both non-tuna species and tuna may have different behaviors depending on the period. This study will contribute to the understanding of the ecology and behavior of target and non-target species which are necessary to assure the sustainability of tuna resources.

Keywords

Echo-sounder, buoys, DFAD, colonization

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INTRODUCTION

Drifting fish aggregating devices (DFADs) tend to aggregate pelagic fishes including the main commercial tuna species such as skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*) and bigeye (*Thunnus obesus*). The reasons of this associative behavior are not fully understood, although several hypotheses have been proposed to explain the attraction and retention of pelagic species to and around floating objects. The two most accepted scenarios are “indicator-log” (Hall et al., 1992) and “meeting point” hypothesis (Dagorn and Freon, 1999). The first one is based on the fact that tunas could use floating objects to find or remain in rich waters, as a result from an evolutionary process. This is due to natural objects could be an indicator of productive water mass because they aggregate in rich frontal zones or they originate in rich areas. The second one relies on social reasons and considers that floating objects could act as meeting point to re-form schools, providing advantages to their members.

The use of DFADs in industrial tropical tuna fisheries has been steadily rising since the 90s to facilitate the catch of target species (Fonteneau et al., 2013), representing around 50% of total tuna catches, exceeding 70% in some years in the Indian Ocean (Dagorn et al., 2012b). The success rate of the purse-seine on DFADs is much higher than in unassociated schools (also called free-swimming schools, FSC) (90% against 50%, Fonteneau et al. (2000)). The use of DFADs also carry another advantages for fishers, for example, the travel distance and time dedicated to search tuna schools are greatly reduced, and therefore the fuel consumption.

It was roughly estimated that around 100,000DFADs were deployed annually worldwide (Baske et al., 2012; Scott and Lopez, 2014b; Ushioda, 2015). The increasing number of DFAD deployments could affect the pelagic ecosystem (Fonteneau et al., 2000; Marsac et al., 2000; Essington et al., 2002) due to the increase catch of juvenile and under-sized individuals (Leroy et al., 2012) and several non-target species. Moreover, it has been suggested that extensive deployment DFADs could alter the natural movements of the species associated modifying their behavior and biology (Marsac et al., 2000; Hallier and Gaertner, 2008; Dagorn et al., 2012b). Increase knowledge about the processes that operate in the attraction and aggregation of tropical tuna is very important for scientific advice to regional fisheries management organizations (RFMOs) to manage the resource properly. Although several attempts have been made by scientific community in order to better understand tuna behavior under the DFADs (Dagorn et al., 2000b; Le Gall et al., 2000; Moreno et al., 2007a; Leroy et al., 2009; Lopez et al., 2017), to date there has been limited agreement in which is the aggregation mechanism of tuna.

Currently, the vast majority of DFADs used in European fleets are equipped with satellite linked echo-sounder buoys (Lopez et al., 2014), which remotely provide fishers a rough estimate of fish abundance under the object in near real-time and the geolocation of the DFAD. In recent years the role of these objects as scientific platforms has been highlighted (Dagorn et al., 2006; Moreno et al., 2015; Santiago et al., 2015; Lopez et al., 2016). The echo-sounder buoys may represent a powerful tool for the study of several issues of scientific relevance; such as colonization/aggregation processes, biomass estimations to understand population dynamic or ecological investigations. This paper will focus on investigating the aggregation mechanism of tuna and non-tuna species using the acoustic records provided by fishers' echo sounder buoys.

Thus, the aim of this study was to investigate the colonization process of virgin DFADs in Western Indian Ocean. For this purpose, we want to determine the arrival day of tuna and non-tuna species at DFAD, as well as ascertain the possible differences in the aggregation mechanism according to the depth of the DFAD net. We examine the colonization process by season in order to understand the temporal and spatial processes and patterns of the aggregation which could contribute to any management measures directed to mitigate, for example, the amount of bycatch aggregated under the DFADs.

MATERIALS AND METHODS

1. Data collection

The study was conducted using data from Satlink buoys (SATLINK, Madrid, Spain, www.satlink.es), provided to AZTI by a Spanish purse seine vessel company. The buoy contained a Simrad ES12 scientific echo-sounder which transmits the amount of biomass found under each object by Inmarsat satellite. The depth observation range extended from 3 to 115 m, with a blanking zone between 0 and 3 m, and it was composed of ten homogeneous layers with a resolution of 11.2 m. Based on experimental evidences from tagging and acoustic surveys (Matsumoto et al., 2006; Dagorn et al., 2007; Moreno et al., 2007a; Moreno et al., 2007b; Taquet et al., 2007; Leroy et al., 2009; Govinden et al., 2010; Filmalter et al., 2011; Mitsunaga et al., 2012; Govinden et al., 2013; Schaefer and Fuller, 2013; Matsumoto et al., 2014; Forget et al., 2015), we establish a vertical depth limit in 25 meters, as the potential boundary between tuna and non-tuna species **(Figure 1)**.

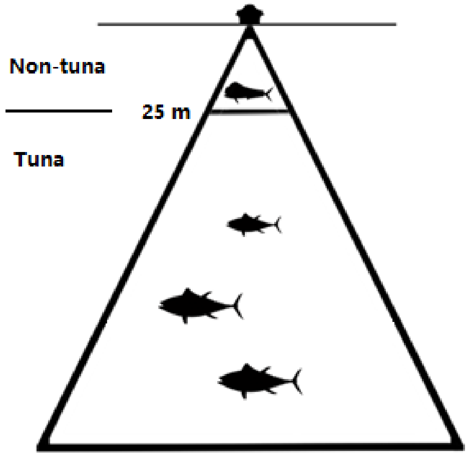

Figure 1. Depth limit between non-tuna and tuna species

The dataset contains information about vessel, buoy (code and type), position (latitude and longitude), date and GMT hour, and biomass estimation of 7514 buoys from January 2012 to May 2015 in the Indian Ocean. Data cleaning was done following the protocol proposed by Orue et al. (In prep) using RStudio (R Core Team, 2016). The number of acoustic records available after the cleaning process was 522,964. FAD and fishing logbooks were collected for the periods considered in the present study. These logbooks provided information on the activity associated to the DFAD (i.e. deployment, fishing, etc.), the object characteristics, as well as buoy code and location.

2. Identification of virgin DFADs

In order to obtain the first day in the water as well as the posterior trajectory of the DFAD, we match 1622 deployments obtained from the FAD logbooks with the acoustic record dataset using buoy code and date. If more than one acoustic record was available for the same day, we selected the maximum value for both tuna and non-tuna species.

Deployments of natural objects were excluded from the study on the basis of these objects being previously in the water and therefore they could not be classified as virgin objects. Subsequently, in order to identify possible sets made during the DFADs trajectory, we crossed DFAD trajectories with the FAD and fishing logbooks and fishing sets were identified on the logbooks based on the information of buoy code and position. If a fishing set based on logbook information was identified in the DFAD trajectories, the trajectories after these sets were eliminated from the analysis because they cannot considered virgin colonized DFADs. There is the possibility of DFADs being fished by vessels of another companies and, therefore, without information of FAD logbooks of those sets. However, in most cases, if this happens the vessel fishing on another company DFAD changes the buoy attached to the DFAD for its own buoy. Therefore, we assume that if DFADs are fished by another company the original buoy will stop emitting signal and, thus, it is not included in our analysis as these data will be missing from our database.

We have identified 962 deployments of virgin objects with their posterior trajectories. First, to study the colonization process a maximum limit of 180 days for the trajectory was established due to DFADs lifespan are generally lower than 6 months (Moreno et al., 2007a). Nevertheless, when we analyzed the number of information available from objects in 180 days, we realized that after two months we had loss information of 50% of the objects **(Figure 2)**. Therefore, we decided to study the colonization process of the first 60 days of object trajectory.

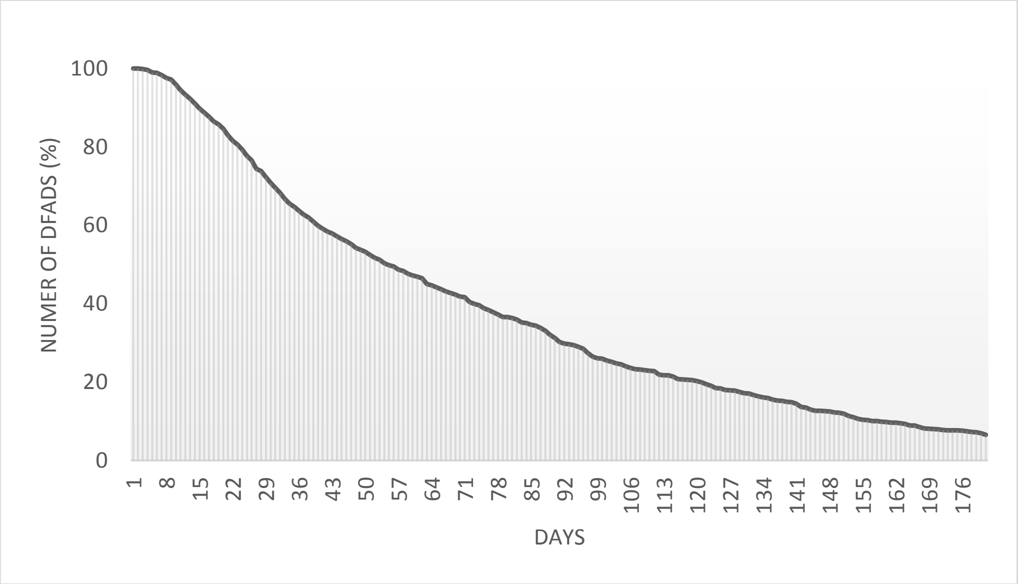

Figure 2. Percentage of DFADs available over 180 days

3. Data analysis

Generally, DFADs deployed throughout all oceans have an underwater part suspended below the floating object. The FAD logbooks allowed us to identify the depth and material of the underwater part from 776 DFADs. In all cases, the material used was net and the depths ranged between 10 and 60 meters. To study if the structure of the object has any influence on the aggregation mechanism of tuna and non-tuna species, we use the depth of the net hanging down from the DFADs to group the deployments in two categories: (i) DFADs with the net shallower than 20 meters and (ii) DFADs with the net deeper than 20 meters.

To analyze possible spatio-temporal differences in the colonization process, the deployments were grouped. Although the French fleet show a strong seasonal pattern on deployment areas (Maufroy et al., 2015), this was not observed in the Spanish fleet case. Therefore, and due to the marked Indian Ocean monsoon system, the deployments were grouped according to these regimes that greatly affect the oceanography and production in the Indian Ocean. Based on the monsoon pattern we group the deployments in four different seasons: (i) Winter Monsoon from December to March, (ii) Spring intermonsoon from April and May, (iii) Summer Monsoon from June to September and (iv) Autumn intermonsoon from October to November (Schott and McCreary, 2001). Furthermore, the DFAD deployed south of 10°S were grouped separately because this region does not show much seasonal variability as the Southeast Trades persist throughout the year (Swallow, 1984; Schott and McCreary, 2001).

Multiple comparison test (U Mann-Whitney and Kruskal-Wallis test) was used to examine significant differences in the arrival day of tuna and non-tuna species depending on the deployment period and the object depth.

Generalized additive mixed models (GAMM) (Wood, 2006) with a Gaussian error distribution and identity link function, were generated to analyze the trend of biomass over 60 days in virgin DFADs. DFAD identification was included as random-effect because there is a dependency structure in the data, as biomass abundance is collected repeatedly for each DFAD. In order to avoid model overfitting, maximum degree of freedom (k) was limited by k=4. All the GAMM models were fitted using gamm4 package (Wood and Scheipl, 2013) in RStudio (R Core Team, 2016). The mathematical notation for the fitted GAMM was:

DFAD Biomass ~ s (Day, k=4) + random= ~ (1 | ID_DFad)

Where DFAD Biomass is the maximum biomass signal received in a day by a particular buoy

RESULTS

1. Identification of virgin DFADs

From 1622 deployments available in FAD logbooks, we have identified 962 deployments of virgin objects with their corresponding trajectories **(Figure 3).**

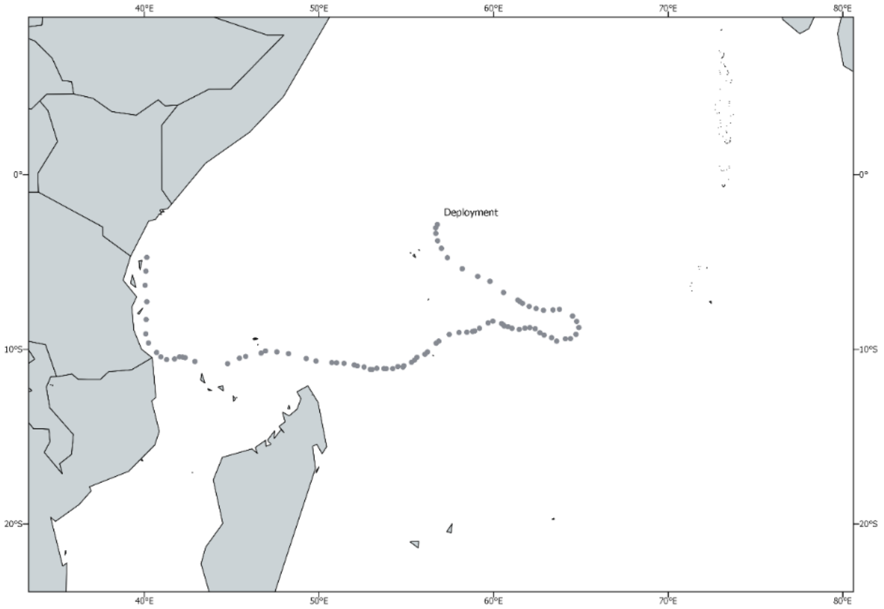

Figure 3. Example of deployment and trajectory of one DFAD in the Indian Ocean

2. Arrival day

The average time for biomass colonization of the DFADs (i.e. first day that the echo-sounder detects biomass) was 12.19 ± 7.74 days. We found that tuna arrived before non-tuna species at DFAD, founding significant differences between them (Wilcoxon Mann Whitney, $p < 0.001$) (**Figure 4**). The average arrival day was 13.49±8.35 days for tuna and 21.69±15.06 for non-tuna species.

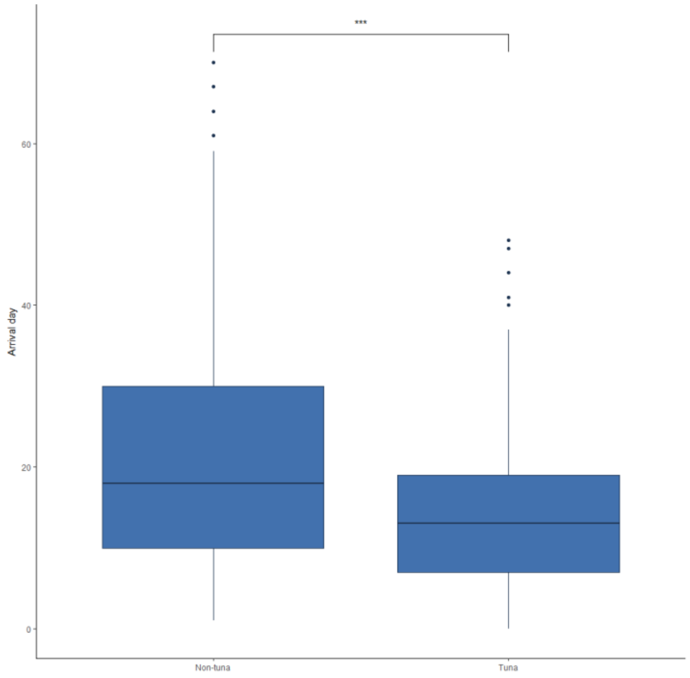

Figure 4. Boxplot of arrival day of tuna and non-tuna species to the object. Asterisks indicate the significance levels of differences following Mann-Whitney U test (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS not significant).

Although the results showed that both tuna and non-tuna species arrive earlier when the net is deeper than 20 m; tuna arrived significantly sooner at DFADs with deeper net while there was no significant difference between arrival day of non-tuna species according to the object depth (**Figure 5**).

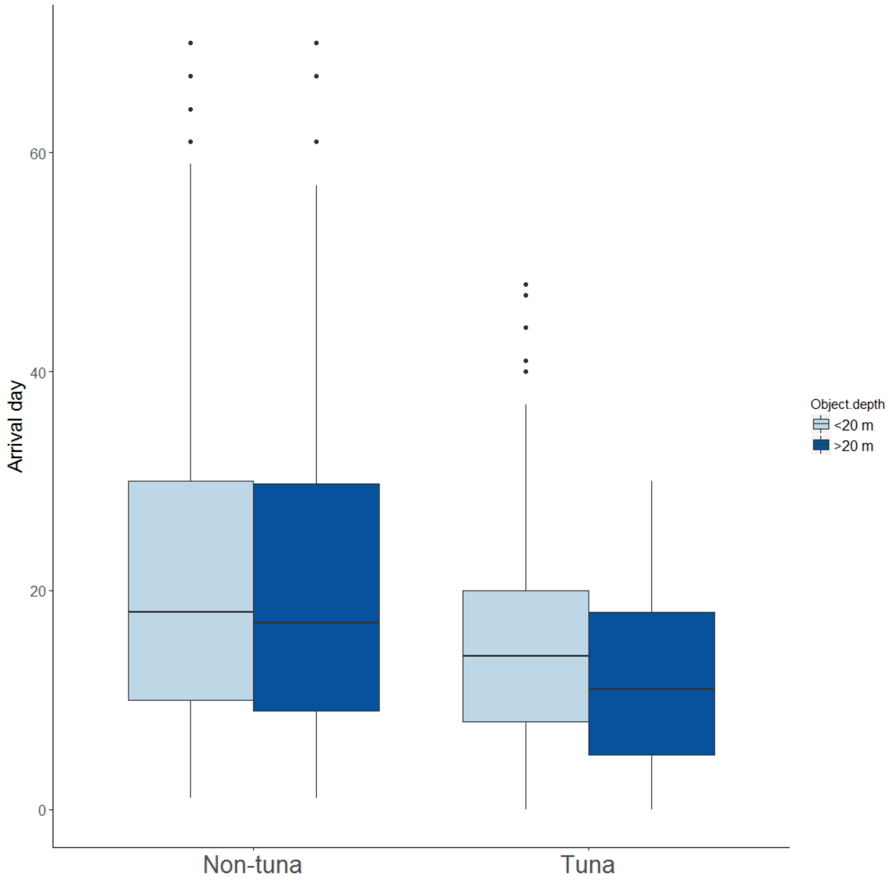

Figure 5. Boxplot of arrival day to the object of tuna and non-tuna species according to object depth

The arrival day were also compared by monsoon period. Significant differences were found in the arrival day for both tuna and non-tuna species according to the period of deployment (Kruskal Wallis, $p<0.05$). We observed that tuna arrived before non-tuna species in all cases, finding significant difference in all periods (**Figure 6**).

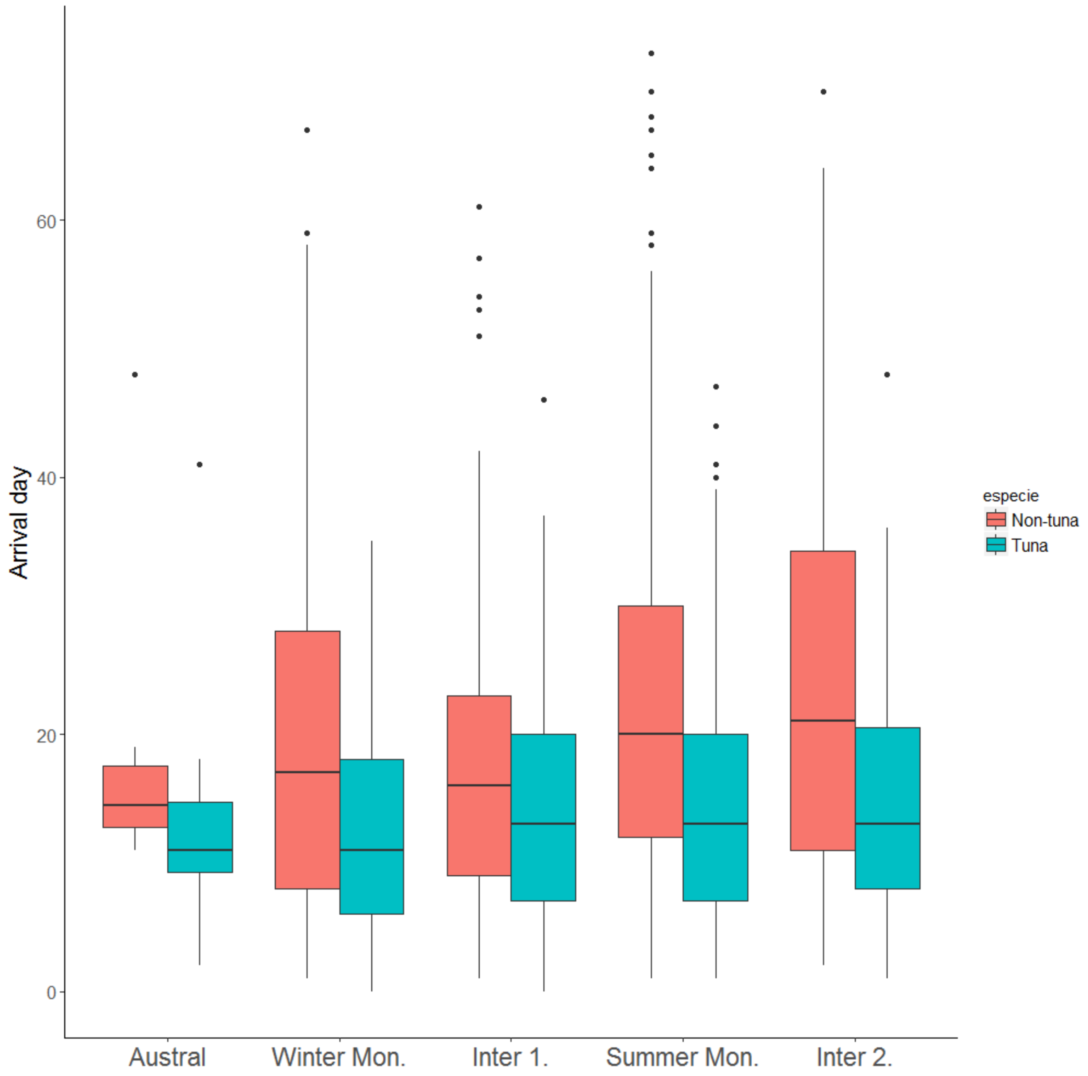

Figure 6. Boxplot of arrival day to the object of tuna and non-tuna species by monsoon period (Winter Mon.=winter monsoon, Inter 1. = spring intermonsoon, Summer Mon.= summer monsoon, Inter 2. = autumn intermonsoon)

3. Colonization process

We ran GAMMS to detect possible differences in the colonization and biomass aggregation trends between species groups considering the monsoon period. The models showed the aggregation mechanism of biomass across sixty days of tuna (**Figure 7**) and non-tuna species (**Figure 8**) in different periods. In Fig. 7 a clear trend of tuna biomass increase in both monsoon and autumn intermonsoon period and a subsequent stabilization between 30 and 40 days in monsoon periods and a decrease in autumn intermonsoon period is observed. A greater fluctuation is observed during the spring intermonsoon. In the case of Austral zone, we found an increasing smoother trend. For non-tuna species, Fig.8 shows that biomass increased steadily in both monsoon and autumn intermonsoon, peaking around one month. From one month onwards to the second month, the biomass decreased in winter monsoon and autumn intermonsoon, while in summer monsoon the biomass was maintained at the same level. Similarly for tuna-biomass, a greater fluctuation is observed during the spring intermonsoon and a liner increase over the 60 days in the Austral zone for non-tuna group.

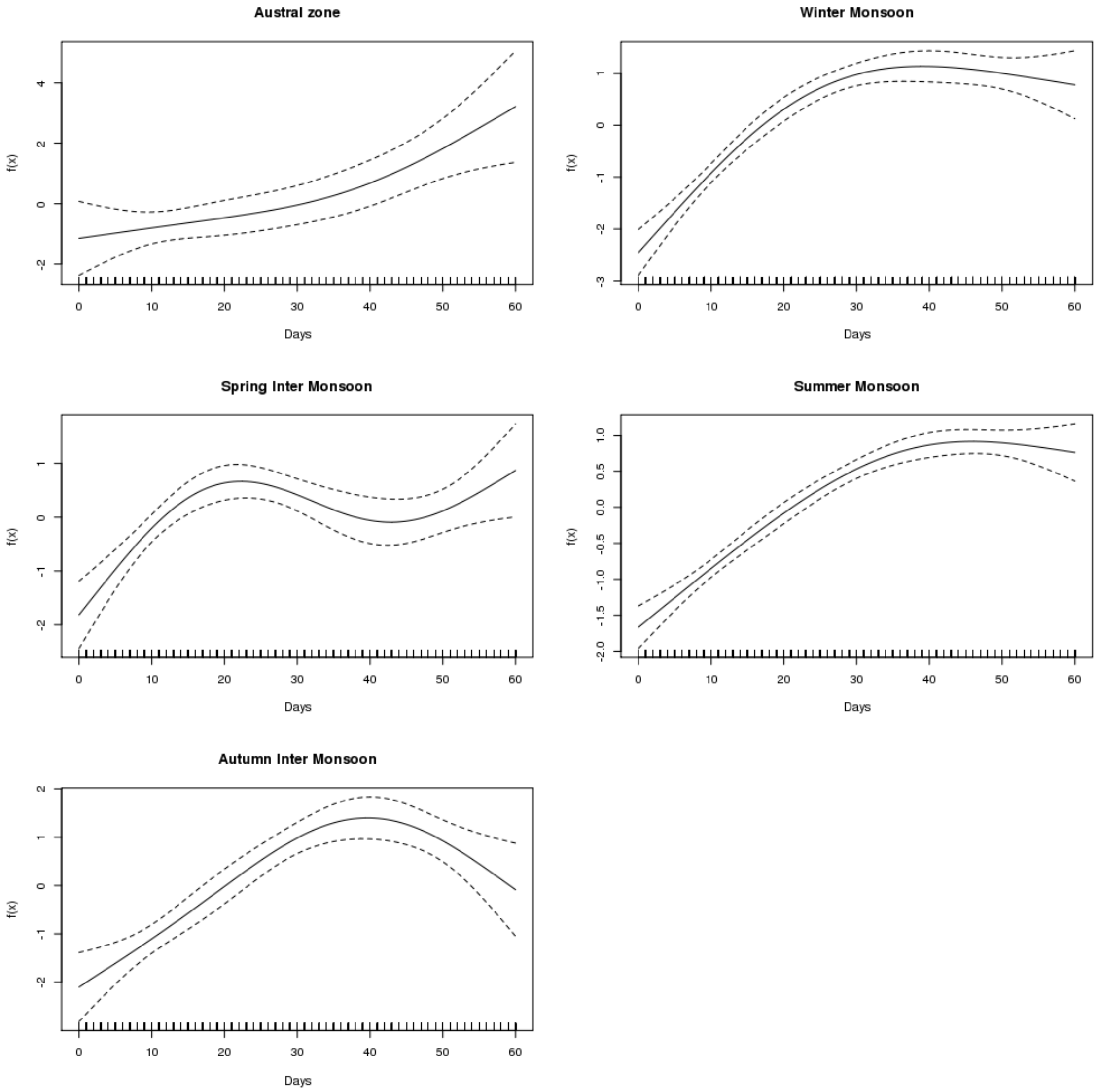

Figure 7. GAMM analyses showing the non-parametric relationship between tuna biomass and days with 95% confidence intervals (dashed lines), for each period

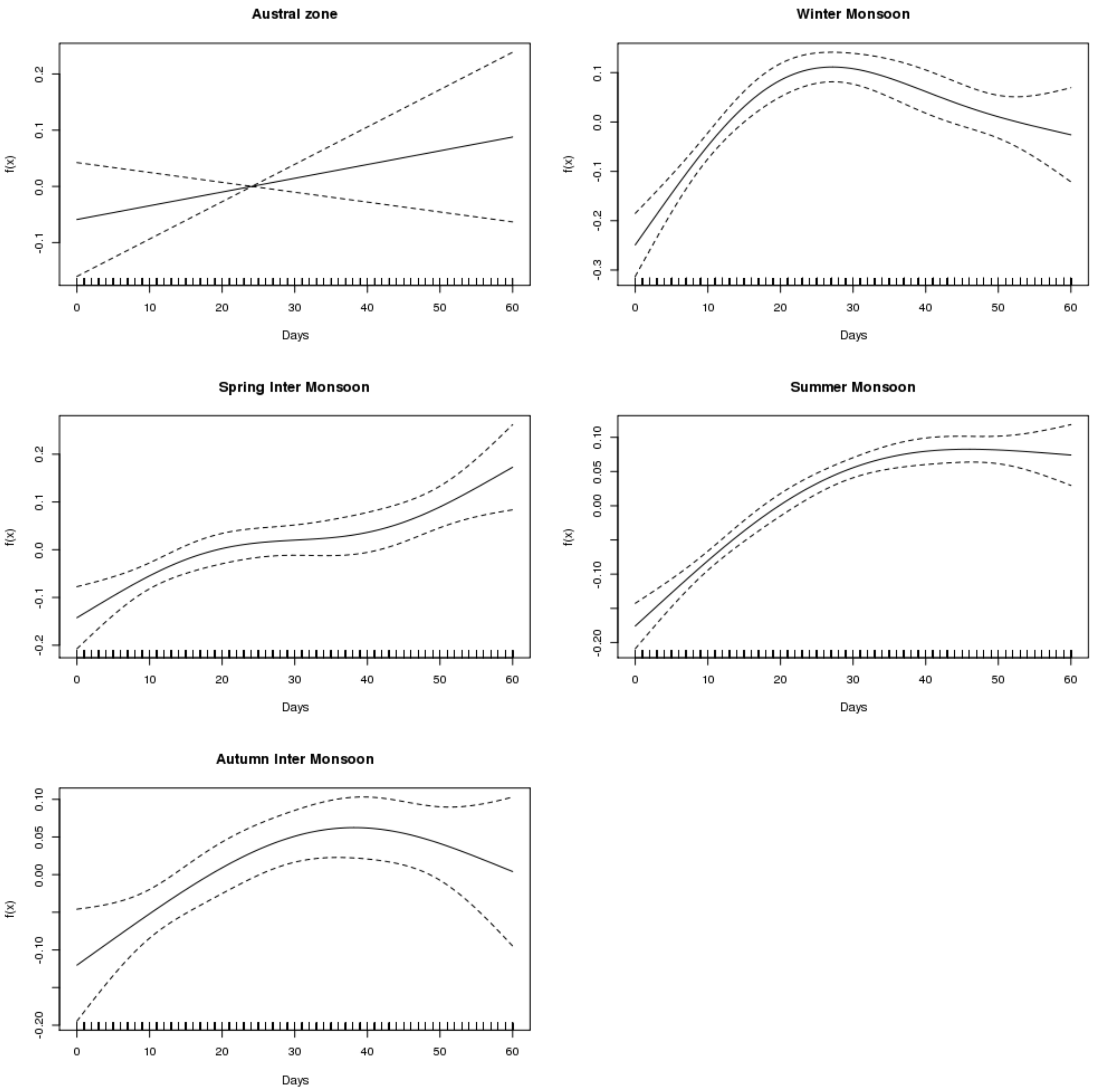

Figure 8. GAMM analyses showing the non-parametric relationship between non-tuna biomass and days with 95% confidence intervals (dashed lines), for each period.

DISCUSSION

Colonization

This is the first time that fishers´ echo-sounder buoy data has been used to explore DFADs colonization and the results provides the first fine-scale information on colonization process of tuna and non-tuna species around DFADs. So far, few studies have been conducted on aggregation mechanism of species in DFADs (Hunter and Mitchell, 1967; Bard et al., 1985; Yu, 1992). Our investigation shows that the average arrival date of fish to DFADs is around 2 weeks.

Previous studies observed a faster colonization of DFADs, generally less than one week (Bard et al., 1985; Yu, 1992). Fishers working with anchored FADs (AFADs) in Philippines wait 11 days after the first deployment before checking for biomass aggregation (Macusi et al., 2017) , which shows a faster colonization of these objects than in our case. AFADs may be easier to colonize because these objects are a fixed reference point and are located in a more coastal zone.

Although some authors, based on fishers knowledge and empirical studies, have stated that non-tuna species arrive first to DFADs (Hunter and Mitchell, 1967; Castro et al., 2002; Moreno et al., 2007a), our results show that tuna arrive at DFAD before non-tuna species. Moreno et al. (2007a) conducted interviews with fishing masters of the purse-seine fleets working in the Western Indian Ocean. In response to the question about how much time is necessary to colonize a virgin DFAD, the fishing masters considered that it takes 1-3 weeks for non-tuna species and at least one month for tuna. A possible explanation for the response of fishers is that they had recently started working extensively with FADs equipped with echo-sounders and thus by the time of the interview (2007), they were not able to see how the colonization process of fish occur, since they deployed the DFAD and let it drift for a month until they visited them. Another possible explanation for the fishers response is that non-tuna species may be easier to observe than tuna by fishers, because non-tuna species are associated most of the time with DFADs (Moreno et al., 2007a; Dagorn et al., 2012a; Forget et al., 2015; Lopez et al., 2017). On the contrary, tuna species do not show as strong association as non-tuna species, showing variable daily behavior patterns (Lopez et al., 2017). On the other hand, it is necessary to take into account the limitations of the echo-sounders, such as the range of vision, due the diameter becomes larger with depth and, hence, the biomass information of superficial waters (< 25 m) could be underestimated affecting our understanding of the colonization process.

Our observations were consistent for all the periods (i.e., tuna always arrived earlier than non-tuna species to DFADs). The arrival day of tuna species at DFADs were similar for the different deployment seasons, despite being statistically significant different, with a maximum difference between deployment season of 2.5 days. This could mean that in addition of environmental features other factors could also affect the arrival of tuna species at DFADs, such as the density and abundance of the population. On the other hand, there are greater differences in the arrival of non-tuna species between periods, reaching a difference of one week.

Influence of object structure on colonization process

The characteristics of the DFADs can vary between fleets but, generally, they are composed of a raft and an underwater part hanging below the object (Itano, 2003; Murua et al., 2016). The depth reached by the structure ranges from 15 to 80-100 meters, and is ocean-specific (15-20m in the Indian Ocean, 80-100m in the Atlantic Ocean and around 30m in the Eastern Pacific Ocean) (Scott and Lopez, 2014a), although in recent years a trend towards the deeper objects in all the oceans is being accentuated (Hall and Roman, 2016). The study has shown the relation of the object depth in the colonization process, finding that the structure of the object has influence on the arrival date in tuna species. In regard to non-tuna species, the observed difference between the arrival day according to the depth of the net was no significant. One possible explanation could be related to the vertical distribution of the different species under the DFADs. Non-tuna species occupy shallower waters (Forget et al., 2015), so that the tail depth would not affect their aggregation process. By contrast, tunas are found in deeper waters (Dagorn et al., 2000a; Schaefer et al., 2009; Forget et al., 2015), so the depth of the object may influence its aggregation, since it may be easier for tunas to find objects with deeper tail.

To our knowledge, this is the first time that the depth of the net hanging down is related with the colonization process. Until now, this depth had been linked to the tuna capture. Lennert-Cody and Hall (2000) and Lennert-Cody et al. (2008) saw that capture varied with the deep of the net hanging down, finding more successful sets for bigeye and yellowfin on objects with deeper net. On the other hand, Satoh et al. (2008) did not find higher bigeye captures with deeper FADs. Related with these investigations Inter-American Tropical Tuna Commission (IATTC) considered the possibility of shortening the depth of the underwater part hanging below the FAD (IATTC, 2008) in order to reduce bigeye bycatch, although the measure was not finally adopted.

The structures hanging under the object may be made of different materials (e.g. nylon, piece of net, ropes or palm leaves). In this case, the tail of all identified DFADs were composed of net, so it has not been possible to analyze differences in the aggregation according to the material of the tail. Further research is needed to investigate the influence of the material in the aggregation of tuna and non-tuna species to DFADs. Currently, one of the concerns of RMFOs is the use of biodegradable materials to construct DFADs. However, the use of these materials to construct the underwater part of the DFAD has not been explored in detail so far. Further investigations should consider specific analysis to study the aggregation mechanism in relation to biodegradable materials.

Colonization by periods

The large number of data available for this work (67716 daily biomass observations) provides high spatio-temporal resolution, which is very useful to study the colonization processes during different seasons. The Indian Ocean is characterized by experiencing strong environmental fluctuations associated to monsoon regimes that affect ocean circulation and biological production (Schott and McCreary, 2001). Changes in biophysical factors associated with seasonality (i.e. chlorophyll, temperature, salinity, dissolved oxygen) may play an important role in aggregation mechanism of tuna and non-tuna species. An upwelling occurs in the Western Indian Ocean in the summer monsoon season (Schott et al., 2009) producing an increase of phytoplankton blooms along the coast of Somalia (Veldhuis et al., 1997; Hitchcock et al., 2000) which can spread more than 500 km offshore (Wiggert et al., 2006). In this period both tuna and non-tunas aggregated to the objects later than in the other seasons studied. Similarly, is when DFADs are deployed in this season when the maximum biomass is reached later in comparison to other seasons. It may be that this increase in productivity during the summer monsoon makes floating objects less attractive as there are enough productivity in the environment. On the other hand, productivity is significantly lower during the winter monsoon in the western Indian Ocean (Wiebinga et al., 1997), when we found that both tuna and non-tuna species arrive before and the biomass peaked earliest compared to the summer monsoon. The distribution of large predators, like tunas, are affected by productivity (Longhurst and Pauly, 1987). Jury et al. (2010) also suggested that this marked seasonality affects the presence and relative species composition in an area. These changes in marine ecology can be reflected in the way different species are aggregated to DFADs. Understanding how the seasonal variation affects colonization process of tuna and non-tuna species is an essential step towards ecosystem-based management of fisheries.

Increase knowledge of the ecology and behavior of tuna and non-tuna species associated with DFADs is extremely important for a correct management of DFAD fishery. The generation of more data by the fisheries, such as more detailed FAD and fishing logbooks, is providing important tools for this purpose. With this study, we have taken the first step to understand the DFADs colonization mechanism in relation to DFAD deployment sites and seasons.

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