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OCEAN AND COASTAL RESEARCH

Aggregative capacity of experimental anchored Fish Aggregating Devices (aFADs) in Northeastern Brazil revealed through electronic tagging data

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ABSTRACT

Catches of pelagic fish associated to anchored Fish Aggregating Devices have been responsible for increases in income, fish consumption, and even cultural identity of artisanal fishing communities in many developing countries worldwide. Nonetheless, in Brazil, aFAD fishing is still poorly developed and studied. In this experiment, FADs were anchored offshore the city of Recife (Northeastern Brazil) to investigate the potential of moored buoys in the aggregation of commercially important pelagic species near the coast, as an alternative fishing site for artisanal fishers. The behavior of acoustically tagged fish was investigated to assess whether they were attracted to the FADs and how long they remained associated to them. The results indicated that, although economically important species were found near the FADs, they did not remain associated for long periods. From the four species tagged, *Acanthocybium solandri, Coryphaena hippurus, Thunnus atlanticus*, and *Caranx crysos*, only the two latter were detected at the FADs. Both species presented a preference for a specific FAD, with stronger site fidelity being recorded for *C. crysos*. This species presented Total Resident Times (TRTs) of more than a month and continuous residence times of more than 14 consecutive days. *T. atlanticus*, on the other hand, remained around the buoys for short time intervals, with a maximum TRT of only two days. Short diurnal excursions far from the FADs and few longer excursions during nighttime were recorded for *C. crysos*. These results do not support the possible use of moored FADs near the coast of Recife as an alternative fishing site for artisanal fisheries. It is possible that the geomorphological characteristics of the experimental area did not favor the aggregative behavior of large pelagic fish species, such as tunas, around FADs.

Descriptors: Associative behavior, Acoustic tagging, Moored FADs, Pelagic fish, Artisanal fishing.

INTRODUCTION

Fish Aggregating Devices (FADs) have been used by fishers since ancient times to increase their catches due to many pelagic fish species' natural behavior to aggregate around floating objects (Morales-Nin et al., 2000). At first, FADs consisted just of floating debris such as trunks and palm leaves, naturally found in the ocean (Jones, 1772). Besides using these natural FADs, fishers also started to construct them, primarily of bamboos and palm leaves (Morales-Nin et al., 2000). Since the 1960s, however, modern FADs, produced with man-made materials, like plastic buoys and metal rafts, have been deployed in

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oceanic and coastal regions (Taquet, 2013), reaching, nowadays, tens of thousands of FADs disseminated across all five oceans (Baske et al., 2012).

Coastal and oceanic anchored FADs (aFADs) are mainly used by small-scale and sport fishing, targeting tunas, and other pelagic species (Taquet, 2013). However, in some coastal countries like the Maldives, the pole and line tuna fisheries around aFADs have attained a semi-industrial level (Adam et al., 2015). Oceanic drifting FADs are primarily used by industrial purse seiners, having tunas as their target species (Taquet, 2013). Purse seine fishing around FADs is currently responsible for more than half of the tuna catches worldwide (Parker et al., 2014). Due to the great economic importance and environmental impacts of these activities, most of the studies dedicated to the behavior of FAD-associated species, and the relationship between the fish and the FAD, have focused on tunas (Dahlet et al., 2019; Moreno et al., 2019; Oshima et al., 2019).

Catches of pelagic fish associated to FADs, including non-tuna species, have also been discussed, particularly concerning their value to sport fishing and food security in coastal communities (Bell et al., 2015; Campbell et al., 2016; Holland et al., 2000). Besides the increase in fishers income, fish consumption, and even cultural identity (Albert et al., 2014; Montes et al., 2019), shifts in fishing effort from demersal species with slow growth and high longevity to fast-growing pelagic fishes may benefit demersal fish (Mbaru et al., 2018). Despite the environmental, economic, and social importance of these pelagic species, however, limited research has focused on their associative behavior (Capello et al., 2012; Forget et al., 2015; Rodriguez-Tress et al., 2017; Soria et al., 2009; Taquet et al., 2007), leaving, still, a remarkable lack of information on their ecology, fishing potential and, consequently, on the status of their populations (Gaertner et al., 2008; Moreno et al., 2016).

In Brazil, the fishing for various tuna (*Thunnus obesus, Thunnus albacares, Thunus alalunga, Thunnus atlanticus,* and *Katsuwonus pelamis*) and non-tuna species (*Coryphaena hippurus, Elagatis bipinnulata,* and *Acanthocybium solandri*) associated with oil rigs, or even with anchored oceanographic buoys, have already demonstrated their use for artisanal fisheries (Carvalho et al., 2015; Silva et al., 2018, 2013), although no study has been so far conducted on the associative behavior of pelagic fish species around these anchored structures.

The use of aFADs in Brazil was first registered in 1984, with the deployment of anchored devices in the Continental shelf break in the Southwest region, located far from the coast, aiming to reestablish and develop commercial skipjack fishing (*Katsuwonus pelamis*) (Scott, 1985). Even though the results were promising, the floating structures did not resist the harsh oceanic conditions (Silva et al., 2013). In 1998, due to an agreement signed between the Brazilian government and fishing companies, six aFADs were also deployed on the Southwest coast (Lima et al., 2000). Despite the increased tuna and non-tuna catches around them (around 700 tons), financial resources were discontinued (Lima et al., 2000). On the Northeast coast, increased catches of tuna and non-tuna species have been registered around an oceanographic buoy from the Pilot Moored Array in the Tropical Atlantic (PIRATA) (Silva et al., 2013). The buoys are moored in open waters, in depths exceeding 4,000m (Silveira, 2014). The high aggregation potential of deep anchored FADs has been well studied and established worldwide (Adam et al., 2015; Bell et al., 2015; Whitney et al., 2016), including the PIRATA buoy (Silva et al., 2013), but no information is available regarding the aggregative potential of shallow aFADs in Brazil.

In this study, Fish Aggregating Devices were anchored off the city of Recife, Pernambuco (Brazil), with the objectives to investigate if the buoys aggregate economically important pelagic species near the coast and evaluate how long they would retain the fish. Aiming these objectives, the associative behavior of acoustically tagged fish nearby the coastal aFAD array was investigated using passive acoustic telemetry, to evaluate the temporal persistence of commercially important fish around the FADs. This is the first study on the associative behavior of pelagic species associated with FADs in Brazil.

MATERIALS AND METHODS

Study site and FAD array instrumentation

FADs were anchored at 50 m and 200 m depth (Table 1), 20 miles off the Port of Recife, Brazil (Figure 1). Both FADs consisted of a single float of equal size, a monitoring buoy, a stainless-steel chain, a positively buoyant rope, and four concrete block anchors (Figure 2). A third buoy from the "Programa Nacional de Boias" (G), anchored by the Brazilian Navy and The Global Ocean Observing System-Brasil (GOOS-Brasil) to collect oceanographic data, was located in the study area during the time of the experiment. Each FAD was equipped with a Vemco VR2W acoustic receiver (VEMCO, INNOVASEA, Canada). The receivers were attached at 15 m depth, from 3 November 2015 to 29 February 2016. Due to financial and logistical difficulties, a detection range test with the transmitters was not performed, but using the range calculator from Vemco´s website (www.vemco.com), it was possible to estimate the ranges for the V13 tags from 410 m to 550 m (for winds from 11 to 16 knots) and the V9 tags from 360 m to 500 m (for winds from 11 to 16 knots).

Tagging procedures

Two cruises were conducted to tag fish aboard the research boat Sinuelo (13 m length wood vessel), on 3 and 6 November 2015. The fish were captured using different techniques, including trolling, rod and reel, and handline, using circle hooks without barbs to minimize fish injuries. To capture large pelagic predator fish associated to the FADs, trolling was carried out with the boat navigating from one FAD to the other. To catch smaller fish, which are usually closely associated to the FADs, the boat was positioned right next to the buoy, and trolling was switched to

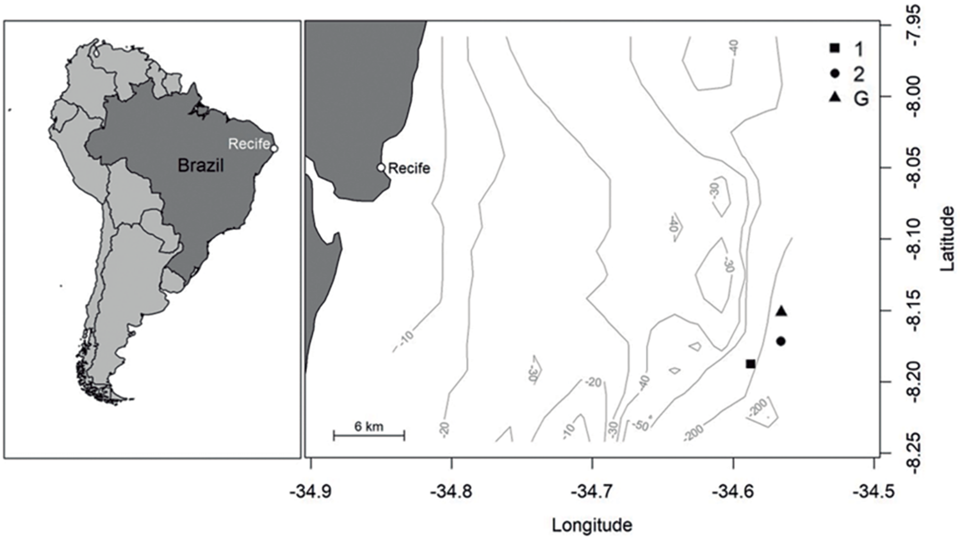

Figure 1. Study area showing the departure port (Port of Recife), and the corresponding FAD locations: FAD1 (1), FAD2 (2) and PNBOIA (G). Black dots indicate FAD positions and gray lines depict the isobaths.

Table 1. Position and description of the 2 Fish Aggregating Devices deployed in the study area (1 and 2) and the oceanographic buoy (PNBOIA) (G). FADs 1 and 2 were instrumented with acoustic receivers.

FAD #	Position	Depth ~ (m)	Deployment date
1	**Lat 8.18 S Lon 34.59 W**	**50**	**07/07/2015**
2	**Lat 8.17 S Lon 34.56 W**	**200**	**05/11/2015**
G	Lat 8.15 S Lon 34.56 W	200	07/11/2012

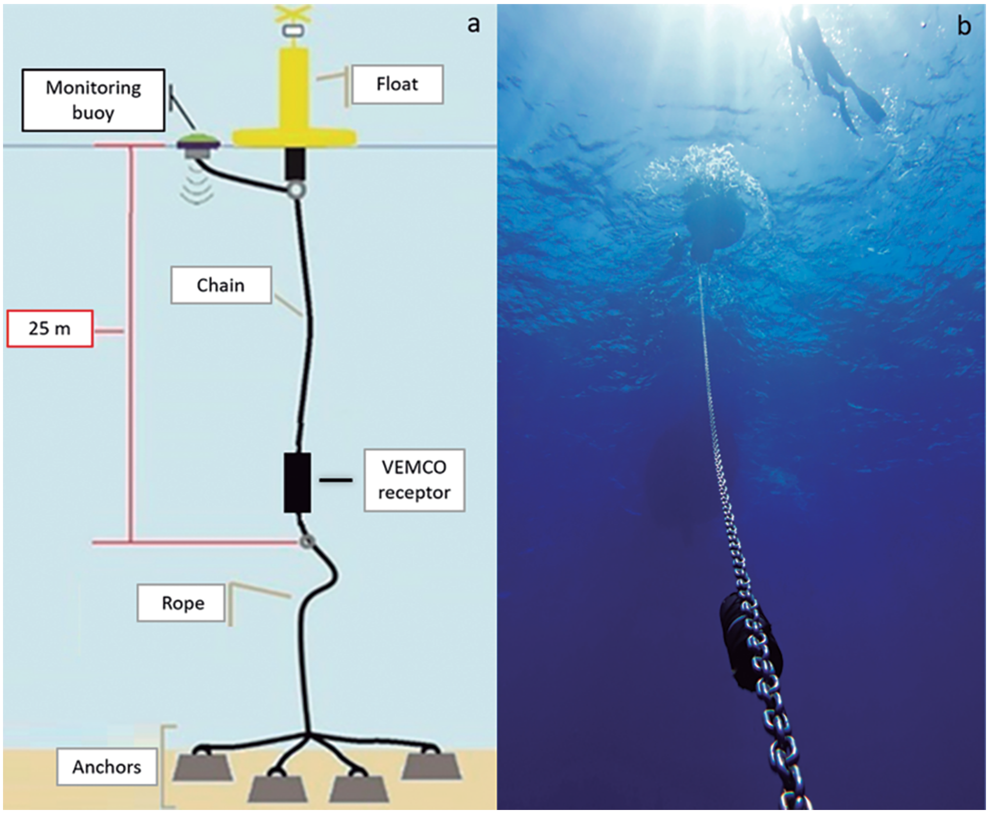

Figure 2. a) Schematic figure and b) underwater picture of the Fishing Aggregation Devices deployed off Recife, Pernambuco, Brazil. Both FADs were instrumented with Vemco VR2W acoustic receivers.

rod and reel and handline fishing. When hooked, fish were carefully transferred to a V-shaped table, where its eyes were covered with a wet cloth, and a hose was placed in its mouth to ensure the supply of oxygen. Only apparently healthy fish were measured (Fork Length- FL) and then tagged with coded Vemco V9 and V13-69kHz acoustic transmitters. The tags were surgically implanted in the fish's peritoneal cavity (Govinden et al., 2013; Meyer et al., 2000). After tagging, the fish was immediately released back to the water, and the GPS position was registered. The total duration of the tagging procedure did not exceed 2 minutes. All tagging procedures occurred during daytime hours (8:00 to 15:00).

A total of 13 fish of four different species were tagged (Table 2): four *Thunnus atlanticus*, two *Acanthocybium solandri*, one *Coryphaena hippurus,* and six *Caranx crysos*. All tagged fish were captured and released closer to FAD2 than FAD1 (Figure 3).

DATA ANALYSIS

To investigate the site fidelity and behavior of the tagged fish, the time spent by the fish around the FADs was characterized using (i) Total Residence Times (TRTs), defined as the total time spent by the fish in the FAD array, as detected by the acoustic receivers (Dagorn et al., 2007; Robert et al., 2012), and (ii) Continuous Residence Times (CRTs), defined as the total detection time of a tagged fish by an acoustic receiver without absences of predetermined time intervals, known as Maximum Blanking Periods (MBP) (Capello et al., 2015). Two distinct CRTs were considered: (i) large-timescale (CRT), corresponding to continuous presences at the FADs without day-scale absences (MBP= 24 h), usually applied in studies on tunas and other large pelagic fish (Dagorn et al., 2007; Girard et al., 2007; Govinden et al., 2013), and (ii) small-timescale (fCRT), used to analyze the fine-scale behavior of tagged fish (Capello et al., 2013a, 2012;

Table 2. Fish species, fish ID, date of capture, fish size (fork length), type of tag, distance of release position to FAD1 and distance of release position to FAD2.

Species	ID	Date	FL (cm)	Tag type	Distance to FAD1 (km)	Distance to FAD2 (km)
T. atlanticus	TATL1	03/11/15	43	V13	1.89	0.85
	TATL2	03/11/15	42	V13	1.58	1.17
	TATL3	03/11/15	39	V13	1.72	1.04
	TATL4	06/11/15	40	V13	1.85	0.90
A. solandri	ASOL1	03/11/15	95	V13	2.07	0.71
	ASOL2	06/11/15	100	V13	2.18	0.63
C. hippurus	CHIP1	06/11/15	70	V13	2.86	0.12
C. crysos	CCRY1	06/11/15	29	V9	2.63	0.27
	CCRY2	06/11/15	30	V13	2.74	0.10
	CCRY3	06/11/15	28	V13	2.64	0.10
	CCRY4	06/11/15	32	V13	2.71	0.10
	CCRY5	06/11/15	33	V13	2.81	0.06
	CCRY6	06/11/15	31	V13	2.61	0.14

fish species, fish ID, date of capture, fish size (fork length), type of tag, distance of release position to FAD1 and distance of release position to FAD2.

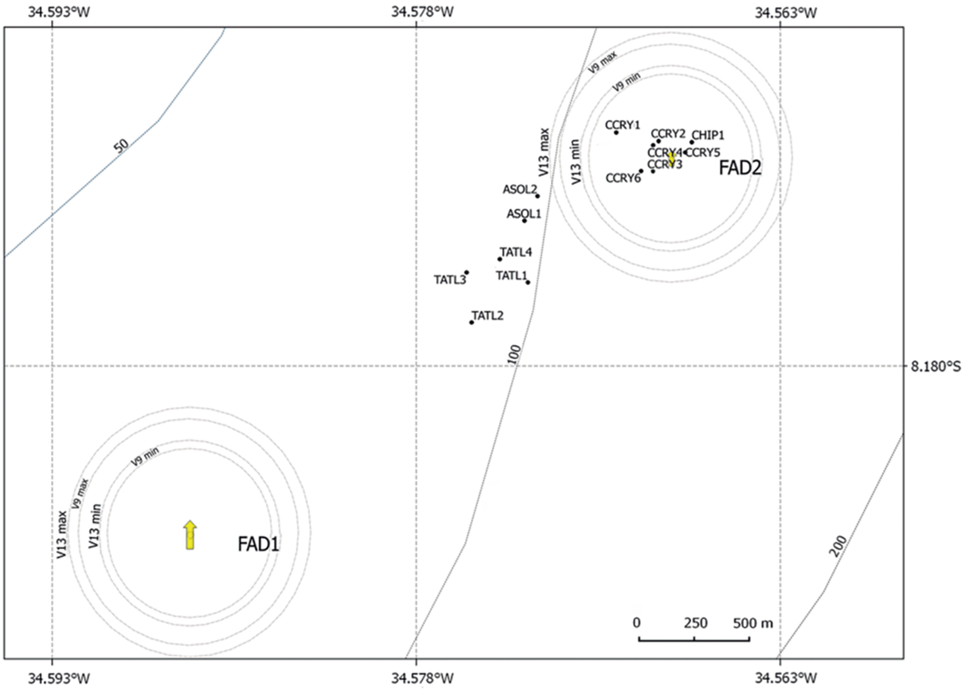

Figure 3. Release position of the 13 acoustically tagged fish. Yellow arrows represent FAD positions. Black dots indicate the release position of the fish. Open circles represent the maximum and minimum detection range of the receivers for V9 and V13 tags. Gray lines represent the isobaths.

Soria et al., 2009). fCRTs were obtained considering an MBP of 20 min, following the procedure described by Capello et al. (2015). Daytime was considered from 5:00 to 16:59 and nighttime from 17:00 to 4:59, based on sunrise and sunset times in Recife during summer-time. The departure times of *C. crysos* were also analyzed from fCRTs, to investigate day-night departure differences and determine if some fish could have left the FAD simultaneously, i.e., within a 20 min interval. This choice, which corresponded to the small-timescale MBP, minimized the effects of noise and collisions in the analysis (Capello et al., 2015).

The total duration of excursions out of the hydrophone's detection range, also called Continuous Absence Time (CAT and fCAT) (Govinden et al., 2013), was obtained considering the time intervals between consecutive CRTs and consecutive fCRTs. Additionally, the maximum diel excursion distance (MED) traveled by a fish which departed and returned to the same FAD within less than 24 h was calculated considering a linear movement at a mean speed (one body length per second) (Capello et al., 2012). The maximum diel excursion distance (MED) was defined as follows:

$$MED = \frac{fCAT}{2} v_{BL}$$

where v_{BL} is the mean fish speed (units: m/min^{-1}) and f_{CAT} is the absence time of the fish out of the aFAD (units: min). Individual fork lengths reported in Table 2 were used to calculate the speed.

Current velocity and direction measurements were obtained from the G buoy, for the total experiment period, from 1 November 2015 to 10 December 2015. Current values were plotted against small-scale residence times (fCRTs) and absence times (fCATs) to check for current intensity and direction influences. Wind roses were plotted for the tagging experiment period (6 November 2015 and 7 December 2015) for each one of the current direction categories (North, Northeast, East, Southeast, South, Southwest, West, and Northwest). All analyses were conducted using the R statistical package (R Core Team, 2019).

RESULTS

Acoustic tagging

Only seven fish were detected from the 13 tagged fish: two *T. atlanticus* (TATL1, TATL2) and five *C. crysos* (CCRY1, CCRY2, CCRY3, CCRY4, CCRY5). Except for one of the *C. crysos* (CCRY3), which visited both FADs, the other six fish were only detected at the FAD closer to their release position, FAD 2 (Table 2). One individual of *C. crysos* (CCRY6) was detected only twice and, thus, excluded from the analysis.

Total residence times (TRT)

Clear differences in the Total Residence Times were observed between the two detected species (Welch t-test; t=3.07; $p < 0.05$) (Table 3). The *T. atlanticus* were only detected during the first two days after the tagging. The *C. crysos* presented, in general, longer TRTs, close to or higher than 15 days, with a mean of 16.83 d (±11.70 S.D.). The interval between the release and first detection time was also different between the two species, mainly because the two *T. atlanticus* were released out of the receiver's detection range, while all *C. crysos* were released inside the detection range. The intervals for *T. atlanticus* were 1.05 and 17.83 h, while for *C. crysos,* they did not exceed 0.2 h.

Long-scale residence and absence times (CRTs and CATs)

Ten CRTs were obtained, with a maximum of two CRTs per fish (Table 4 and Figure 4). All seven detected specimens showed CRTs at FAD2 (the FAD closer to the tagging locations, see Figure 3), whereas only one individual was detected at the two FADs (CCRY3) (Figure 4). The *T. atlanticus* presented residence times of less than one day. TATL1 presented two CRTs, both at FAD2, one on the same day of the tagging, and the second one on the next day. Both CRTs were of short duration with a maximum of 16.32 min. TATL2 presented one CRT, also at FAD2, with a duration of 7.93 h. *C. crysos*, in general, were detected for much longer periods than *T. atlanticus* (Welch t-test; t=3.06; $p < 0.05$). Apart from CCRY1, detected only in the first day after tagging, with a residence time of 7.8 h, the remainder four detected *C. crysos* individuals remained associated to the FAD of tagging for around 15 consecutive days. CCRY5 returned to FAD2 almost seven days after departure and remained associated to the FAD for 7.09 h. CCRY3 was the only fish to make an excursion between both FADs, being detected at FAD1 15 days after its last detection at FAD2, with a residence time of 10.17 h.

Short-scale residence and absence times (fCRTs and fCATs)

The pattern of short-scale residence times was close to the long-term residence times. However, fCATs allowed characterizing more refined scale movements of the fish. Excursions shorter than 24

Table 3. Fish ID, FADs visited during the TRT, release time after the tagging, total number of detections at the two FADs, start date (year 2015) and time, end date (year 2015) and time, total TRT duration in days and interval between release and detection time in hours, of Thunnus atlanticus (TATL) and Caranx crysos (CCRY).

	Fish ID	FADs Visited	Release time	Total # of Detections	Start	End	Total TRT (days)
1	TATL1	FAD2	13:25	8	03/11 14:28	04/11 16:32	1.09
2	TATL2	FAD2	13:50	38	04/11 07:40	04/11 15:35	0.33
3	CCRY1	FAD2	08:20	167	06/11 08:31	06/11 16:19	0.32
4	CCRY2	FAD2	09:00	10358	06/11 09:08	21/11 02:30	14.72
5	CCRY3	FAD1&2	14:23	9706	06/11 14:32	07/12 16:22	32.08
6	CCRY4	FAD2	14:50	10423	06/11 15:01	21/11 02:26	14.48
7	CCRY5	FAD2	15:00	9916	06/11 15:12	29/11 04:38	22.56

Table 4. Fish ID, FAD visited during the CRT, CRT number, total number of detections, start date (year 2015) and time, end date (year 2015) and time, total CRT duration in days, CAT duration in hours.

	Fish ID	FADs Visited	CRT #	Total # of Detections	Start	End	Total CRT (days)	CAT (days)
1	TATL1	FAD2	1	5	03/11 14:28	03/11 14:35	0.005	
2	TATL2	FAD2	1	38	04/11 07:40	04/11 15:35	0.33	
3	TATL1	FAD2	2	3	04/11 16:16	04/11 16:32	0.01	1.07
4	CCRY1	FAD2	1	167	06/11 08:31	06/11 16:19	0.32	
5	CCRY2	FAD2	1	10358	06/11 09:08	21/11 02:30	14.72	
6	CCRY3	FAD2	1	9700	06/11 14:32	22/11 01:05	15.44	
7	CCRY4	FAD2	1	10423	06/11 15:01	21/11 02:26	14.48	
8	CCRY5	FAD2	1	9911	06/11 15:12	22/11 02:15	15.46	
9	CCRY5	FAD2	2	5	28/11 21:33	29/11 04:38	0.29	6.80
10	CCRY3	FAD1	2	6	07/12 12:20	07/12 16:22	0.17	15.47

h were recorded for both species (Table 5). TATL2 presented two excursions out of the FAD, totalizing 0.24 days (5.88 h). Those excursions were responsible for most of its TRT (0.33 days), meaning TATL2 was only closely associated to the buoy for a few minutes at a time. During the longest excursion, (3.37 h), the estimated maximum excursion distance was 2.55 km. CCRY3 and CCRY5 were observed to leave FAD2 simultaneously with CCRY2 and CCRY4, both returning on the next day. The *C. crysos* showed similar behavior of fCATs of less than an hour (0.5 h ± 0.1 S.D.) during the day, and longer nocturnal fCATs, varying from 6.8 to 24 h. The maximum distances that could have been traveled out of the detection range during the diurnal excursions had a mean of 267.2 m ± 68.3 S.D., while the nocturnal excursions had a mean of 10.3 km ± 5.5 S.D.

CURRENT MEASUREMENTS

There was a clear increase in current velocity throughout the experiment, with the lowest mean current strength being registered on the first day (8 cm s^{-1} ± 5 SD) and the highest mean value on the last day (48 cm s^{-1} ± 8 SD) (Figure 4). Three wind directions were most frequent and presented the highest values, North (N), Northeast (NE), and Southwest (SW) (Figure 5). Three current intensity peaks were registered, but, in general, the mean current strength increased continuously (Figure 4). During this period, no predominant current direction was observed when current speeds were below 20 cm s^{-1}. However, at current intensities higher than 20 cm s^{-1}, they were exclusively from North and Northeast direction until the 30th day of the experiment (3 December) and from Southeast direction from day 31 until the end

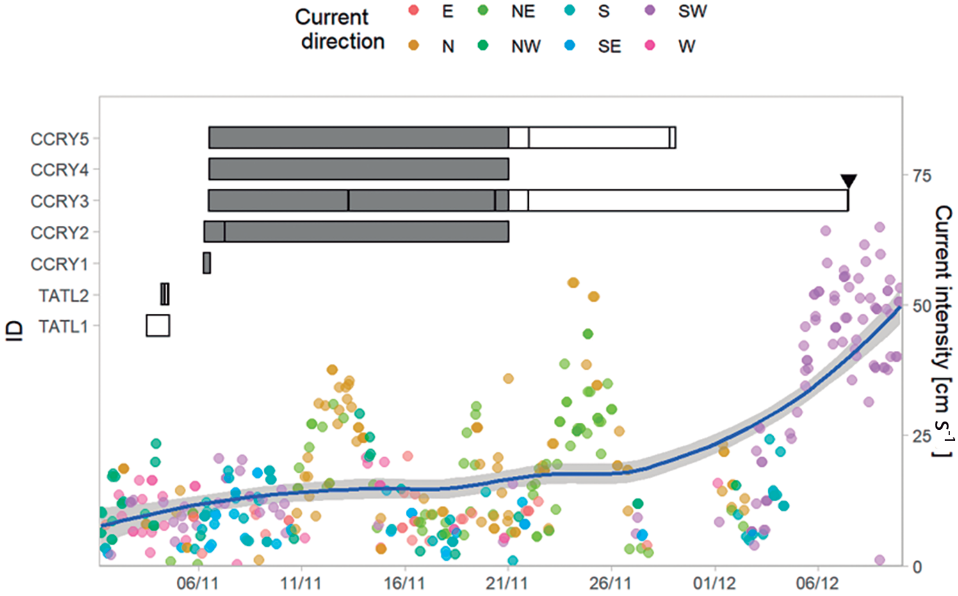

Figure 4. Short-scale continuous residence times (fCRTs) per individual (gray bars), and current intensity (cm s^{-1}) and direction (North-N, Northeast-NE, East-E, Southeast-SE, South-S, Southwest-SW, West-W and Northwest-NW). White bars represent the Continuous Absence Times (fCATs). Black arrow indicates detections at FAD1. Colored points represent current intensities. The blue line is the current velocity smooth conditional mean and the gray shaded area around it, the standard error bounds.

Table 5. Short excursions description (fCAT < 24h): Fish ID, Fish Aggregating Device number, excursion number, excursion start date (year 2015) and time, excursion end date (year 2015) and time, Continuous Absence Time duration in hours, and maximum excursion distance in meters.

	Fish ID	FADs Visited	Excursion #	Start	End	fCAT (h)	Maximum Excursion distance (m)
1	TATL2	FAD2	1	04/11 08:09	04/11 10:40	2.51	1901
2	TATL2	FAD2	2	04/11 11:28	04/11 14:50	3.37	2550
3	CCRY2	FAD2	1	07/11 08:42	07/11 09:05	0.38	208
4	CCRY3	FAD2	1	13/11 08:11	13/11 08:38	0.45	252
5	CCRY3	FAD2	2	20/11 10:55	20/11 11:32	0.61	342
6	CCRY3	FAD2	3	21/11 02:20	22/11 01:01	22.68	12657
7	CCRY5	FAD2	1	21/11 02:04	22/11 02:04	24	14256
8	CCRY5	FAD2	2	28/11 21:35	29/11 04:25	6.84	4064

of the experiment (Figures 4 and 5). Also, all *C. crysos* left FAD2 when the mean current intensity started to increase strongly, with some fish being detected later, but for a couple of minutes only (Figure 4). CCRY3 showed up at FAD1 on the 34th day of the experiment (7 December), when the Southwest current, present since day 30, was predominant and had the highest strength recorded for the whole tagging period (Figure 4). However, possibly due to the small dataset, no clear correlation could be found between fish departure and current intensity.

DISCUSSION

Fish Associative Behavior

From the 13 tagged fish, two blackfin tunas (*T. atlanticus*), two wahoos (*A. solandri*), and one dolphinfish (*C. hippurus*) were never detected. Up to date, there is few available information on the behavior of these species around FADs (Addis et al., 2006; Dempster, 2004; Dempster and Taquet, 2004; Girard et al., 2007; Sepulveda et al., 2011; Silva et al.,

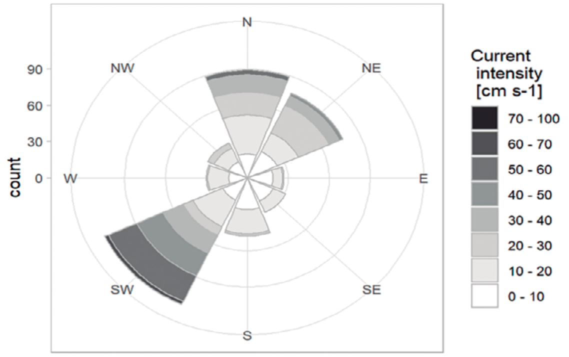

Figure 5. Current intensities (cm s-1) from 11 to 13.5 m depth, at each of the eight current direction categories: North (N), Northeast (NE), East (E), Southeast (SE), South (S), Southwest (SW), West (W) and Northwest (NW), during the tagging experiment.

2019). Studies with ultrasonic transmitters have shown that fish return to the FAD vicinity after swimming longer distances than the receiver's detection range (Holland et al., 1990; Matsumoto et al., 2013; Weng et al., 2013). A detection range test was not performed in the present study, so it was not possible to determine the maximum detection distance of the fish from the FAD (Kessel et al., 2014); nonetheless, the VEMCO calculator presented a conservative detection interval of almost 150 m (410-550 m for V13 and 360-500 m for V9). Therefore, the likelihood of distant associations for these species remains low, suggesting they probably left the area right after the release, due to tagging stress (Taquet et al., 2007), natural displacement and/or migrating behavior (Maguire et al., 2006) or because they had a higher attraction to the shelf break (Dubroca et al., 2013; Holland and Grubbs, 2007).

A preference for the deeper FAD (FAD2, 200 m depth) was registered for all species. This could be explained by the proximity to the tagging location (since the fish were released closer to FAD2 than FAD1). However, the tagging locations already suggested that fish were more abundant near the buoy deployed in deeper areas. Another possible explanation of the higher number of fish present at one of the two FADs relies on the competition among the two FADs, which were close to each other (distance less than three km). Previous studies demonstrated that tuna could detect a FAD up to distances of ten km (Girard et al., 2004; Holland et al., 1990; Marsac and Cayré, 1998). In the presence of social interactions (Capello et al., 2011; Sempo et al., 2013), even if the two FADs can be considered equivalent, one of the two FADs could present higher fish biomass than the other. This scenario would imply alternating associated biomass between the two FADs over time.

Both *T. atlanticus* individuals that were tagged and detected stayed around the FADs for short time intervals (maximum of 48 min), and a maximum Total Resident Time of only two days. Studies on the associative behavior of this species are not yet available, but residence times of tunas around FADs have been extensively studied, varying significantly among study sites, tuna species, and size classes (Capello et al., 2016; Govinden et al., 2013; Rodriguez-Tress et al., 2017). Robert et al. (2013) categorized tuna behavior around FADs in three groups, briefly passing near a FAD, short association, or long association. The former is generally an association of a couple of minutes, as observed in the present study, suggesting they did not show associative behavior to the experimental FADs. Even with decades of scientific efforts to understand how tuna species behave around floating objects, the reasons why the fish are attracted or aggregate around these devices are still not well understood (Girard et al., 2004; Rodriguez-Tress et al., 2017). Several hypotheses are proposed to explain association periods (Fréon and Dagorn, 2000), but based on the short-term visits recorded in the present study, four main reasons were considered as most plausible. By the indicator-log hypothesis, fish would explore floating objects to assess information on the species present in the area, such as possible preys or predators. In the comfortability stipulation hypothesis, if local conditions are favorable at the time, fish could use the FADs as quick resting areas. Moreover, a floating device could equally be used as a meeting point to form larger fish schools. It should also be considered that, since both tunas presented the same behavioral pattern, they possibly did not associate to the buoys due to a combination of non-favorable local abiotic and biotic factors, such as water temperature (Robert et al., 2013), prey availability (Graham et al., 2007), and the presence of congeners associated with the FAD (Capello et al., 2011). The current velocities registered when the tunas visited the FAD were low, ruling out their influence in the short visits observed. However, since only two individuals were detected, further studies should be conducted to confirm the short association times found here.

The residence times obtained for *C. crysos,* with TRTs of more than a month and fCRTs of more than 14 consecutive days, suggested a strong site fidelity to the FADs. *C. crysos* probably explored the FADs in search for food supply and protection (Gooding and Magnuson, 1967; Hunter and Mitchell, 1968; Rountree, 1989). This species has a preference for coastal waters, but is also naturally found inhabiting areas near open-ocean features, including floating or fixed objects, due to the increased food availability around them (Brown et al., 2010; Castro et al., 2002; Holland and Grubbs, 2007). Sinopoli et al. (2019) have demonstrated a strong correlation between the extensive use of FADs and the expansion of *C. crysos* geographical distribution in the Mediterranean Sea, where the FAD network is probably facilitating the species' retention in coastal waters, providing food availability and protection against predators.

Faster excursions far from the FADs during the day and smaller number of longer excursions during the night were recorded for *C. crysos*. The daily excursions may be used to explore and feed, with the FAD acting as a reference point (Gooding and Magnuson, 1967). The maximum diurnal excursion distances found for *C. crysos* (267.2 m ± 68.3 S.D.) suggest that they did not move far from the FAD area and could not have visited the other FADs during these excursions. Nocturnal excursions were less common, with fish staying closer to the FADs. When the nocturnal excursion occurred, nonetheless, the maximum calculated excursion distances were higher (10.3 km ± 5.5 S.D.), and fish could have swum to much farther areas, not returning to the FAD.

The observed general pattern of independent *C. crysos* departures, plus the observation of certain synchronicity in departure events of some individuals, suggest the existence of small fish schools rather than a large one, with small groups leaving the buoy within short time intervals and others remaining associated to the FAD (Dagorn et al., 2007). However, the only simultaneous departure event does not guarantee that individuals have physically exited the FAD together. Similar synchronous patterns of small fish schools around FADs have also been observed for other small pelagics (Soria et al., 2009).

Although the departure of all *C. crysos* coincided with an increase in current intensity, the available data do not show a clear correlation between *C. crysos* departures and current speed. Capello et al. (2013) studied aggregations of a small Carangidae species, *Selar crumenophthalmus,* using acoustic tagging and found aggregations' position to be shifted upstream, with increasing distances from a moored FAD with increasing current intensity. As observed by Capello et al. (2013), *C. crysos*, which is also a Carangidae species, could have changed its distribution around the FAD in stronger currents, moving further from the FAD or upcurrent. The data indicate that fish left the FAD mostly when mean current values were between 18 and 20 cm s^{-1} (Figure 5). However, the available data do not allow us to assess the tagged fish's position at a fine spatial scale. Remarkably, CCRY3 was observed to depart from FAD2 during a strong southwest current, occurring at FAD1 (located southwest of FAD2) 15 days later. The current direction could have influenced this fish after leaving FAD2 because the shallower FAD1 was located in the current path. However, other factors, such as the arrival of predators or changes in food availability, may explain the departure of *C. crysos*.

INSIGHTS FOR THE DEVELOPMENT OF FAD FISHERIES IN COASTAL WATERS IN NORTHEAST BRAZIL

This study assessed for the first time the potential use of shallow aFADs off the Northeast coast of Brazil. Even though the overall number of tagged individuals was low (N=13), half of the dataset was constituted by large pelagic fish species of commercial interest. The large tagged fish were either never detected or showed short residence times at the experimental FADs. Even though passive acoustic studies on pelagic fish of commercial interest around FADs usually consider a higher number of tagged individuals (Forget et al., 2015; Govinden et al., 2013; Stehfest et al., 2013; Taquet et al., 2007), the proportion of detected fish was considerably higher (>70%) than in the present study (<30%). Such discrepancy corroborates the hypothesis that these species may not have had aggregative behavior around the studied FADs. Few studies have also obtained information regarding pelagic fish associative behavior, such as tunas and the dolphinfish, with few individuals tagged (N=5 and 13) (Muir et al., 2012; Whitney et al., 2016). Telemetry studies with pelagic fish other than elasmobranchs in Brazil have only been published for *Thunnus albacares* with three tagged individuals (Travassos et al., 2009), and for *Istiophorus platypterus* with four fish (Mourato et al., 2014), highlighting the importance of the present results. The acoustic telemetry articles published with sharks and rays (Bezerra et al., 2019; Branco-Nunes et al., 2016; Ferreira et al., 2013; Niella et al., 2017) also dealt with similar or lower number of tagged fish compared to this study.

From the four tagged species (*T. atlanticus, A. solandri, C. hippurus* and, *C. crysos*), only *C. crysos* had a strong site fidelity to the buoys; nonetheless, all individuals left the study area within a month. Despite this species being frequently captured by recreational and artisanal fishing in Brazil (mostly line and trap fishing), and one of the main Carangidae species captured in the Northeast region, its commercial value is much lower than the other tagged species (Haimovici et al., 2014; Lessa and Nóbrega, 2000; Lima et al., 2018).

Dolphinfish and tunas are commonly found associated to other coastal aFADs around the world and have been responsible for increases in income, food security and livelihoods of local artisanal fishers in different regions (Albert et al., 2014; Bell et al., 2015; Montes et al., 2019). Such aggregating devices were deployed in oceanic islands, where insular shelves are relatively narrower than continental ones (Quartau et al., 2014). In these regions, despite aFADs being deployed only a few miles from the islands, they were located in open waters, where the surface buoy was probably the only reference point used by the fish in search of food supply, protection against predators (Hunter and Mitchell, 1968; Rountree, 1989), cleaning stations (Gooding and Magnuson, 1967), or meeting points (Dagorn et al., 1997; Fréon and Dagorn, 2000). Therefore, the geomorphological characteristics of our study area might not have favored the aggregative behavior of large pelagic fish around the aFADs.

Small-scale artisanal fishing boats, mainly from Northeastern Brazil, are currently targeting yellowfin, *T. albacares,* and bigeye tunas, *Thunnus obesus* (Lowe, 1839), close to the open-ocean buoys from the Pilot Moored Array in the Tropical Atlantic (PIRATA) (Silva et al., 2013). The buoys are moored in open waters more than 300 nm from the nearest port (Areia Branca-RN) (Silveira, 2014). Thus, an anchored FAD's deployment close to the shore was considered an alternative to aggregate tunas in a more accessible site to local fishers. However, the present results may indicate that the location the FADs were moored did not favor fish aggregation because of its proximity to the coast. Eighani et al. (2019) conducted experiments with shallow coastal FADs in the Persian Gulf and reported similar results due to the short distance to shore. Nearshore aFADs, thus, may not be an effective alternative strategy to artisanal fishers from Brazilian Northeast coast. Notwithstanding, further studies, based on larger numbers of individuals, should be conducted to confirm these findings.

CONCLUSIONS

From the four pelagic species (*T. atlanticus, C. hippurus, A. solandri* and *C. crysos*) tagged around the experimental aFADs, only *C. crysos* demonstrated site fidelity behavior, possibly using the FADs for food supply and protection. The possible non-aggregative behavior observed for the other species may be due to a combination of non-favorable local conditions, such as depth, prey availability, water temperature, and the presence of congeners associated with the aFADs.

This work offers a first assessment of the potential use of nearshore anchored FADs as a possible fishing alternative, in a region where the artisanal fisheries sector is in a difficult situation due to overfishing, consequently facing declining productivity of most exploited stocks, such as lobsters and demersal fish species (Silva et al., 2018). However, the results suggested that the studied aFADs may not be effective in aggregating pelagic fish of commercial importance, such as tunas and the dolphinfish.

For future work on this field, we suggest telemetry experiments with an increased number of tagged species and specimens. Long-term monitoring periods, as well as using complementary techniques, such as active telemetry and acoustics, would also contribute to a better understanding of fish behavior, fish spatial distribution and movement patterns around FADs. Proper monitoring of the fishing activities and research on fish composition, reproduction, behavior, and stock status will also be essential to ensure the aggregative potential and sustainability of such a new fishing alternative.

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AUTHOR CONTRIBUTIONS

LQV - Conceptualization, Formal Analysis, Investigation, Writing - original draft, Writing - review & editing,
MC - Conceptualization, Formal Analysis, Investigation, Writing - review & editing
FF - Investigation, Writing - review & editing
MTT - Investigation, Writing - review & editing
DPV - Investigation, Writing - review & editing
LD - Resources, Writing - review & editing
FHH - Conceptualization, Funding acquisition, Writing - review & editing

REFERENCES

ADAM, M. S., JAUHAREE, A. R. & MILLER, K. I. 2015. Review of yellowfin tuna fisheries in the Maldives. In: *Working Party on Tropical Tunas*. Victoria: Indian Ocean Tuna Commission, 19, pp. 1-15.

ADDIS, P., CAU, A., MASSUTÍ, E., MERELLA, P., SINOPOLI, M. & ANDALORO, F. 2006. Spatial and temporal changes in the assemblage structure of fishes associated to fish aggregation devices in the Western Mediterranean. *Aquatic Living Resources*, 19(2), 149-160.

ALBERT, J. A., BEARE, D., SCHWARZ, A. M., ALBERT, S., WARREN, R., TERI, J., SIOTA, F. & ANDREW, N. L. 2014. The contribution of nearshore fish aggregating devices (FADs) to food security and livelihoods in Solomon Islands. *PLoS One*, 9(12), e115386.

BASKE, A., GIBBON, J., BENN, J. & NICKSON, A. 2012. *Estimating the use of drifting fish aggregation devices (FADs) around the globe*. Washington: The Pew Environment Group - Discussion Paper, pp. 1-8.

BELL, J. D., ALBERT, J., ANDRÉFOUËT, S., ANDREW, N. L., BLANC, M., BRIGHT, P., BROGAN, D., CAMPBELL, B., GOVAN, H., HAMPTON, J., HANICH, Q., HARLEY, S., JORARI, A., SMITH, M. L., PONTIFEX, S., SHARP, M. K., SOKIMI, W. & WEBB, A. 2015. Optimising the use of nearshore fish aggregating devices for food security in the Pacific Islands. *Marine Policy*, 56, 98-105.

BEZERRA, N. A., MACENA, B., TRAVASSOS, P., AFONSO, P. & HAZIN, F. H. V. 2019. Evidence of site fidelity and deep diving behaviour of scalloped hammerhead shark (*Sphyrna lewini*) around the Saint Peter and Saint Paul Archipelago, in the equatorial Mid-Atlantic ridge. *Marine and Freshwater Research*, 71(6), 653-661.

BRANCO-NUNES, I. S. L., VERAS, D. P., OLIVEIRA, P. & HAZIN, F. 2016. Vertical movements of the southern stingray, *Dasyatis americana* (Hildebrand & Schroeder, 1928) in the biological reserve of the Rocas Atoll, Brazil. *Latin American Journal of Aquatic Research*, 44(2), 216-227.

BROWN, H., BENFIELD, M. C., KEENAN, S. F. & POWERS, S. P. 2010. Movement patterns and home ranges of a pelagic carangid fish, *Caranx crysos*, around a petroleum platform complex. *Marine Ecology Progress Series*, 403, 205-218.

CAMPBELL, B., HANICH, Q. & DELISLE, A. 2016. Not just a passing FAD: insights from the use of artisanal fish aggregating devices for food security in Kiribati. *Ocean and Coastal Management*, 119, 38-44.

CAPELLO, M., BACH, P. & ROMANOV, E. 2013a. Fine-scale catch data reveal clusters of large predators in the pelagic realm. *Canadian Journal of Fisheries and Aquatic Sciences,* 70(12), 1785-1791.

CAPELLO, M., DENEUBOURG, J. L., ROBERT, M., HOLLAND, K. N., SCHAEFER, K. M. & DAGORN, L. 2016. Population assessment of tropical tuna based on their associative behavior around floating objects. *Scientific Reports*, 6(1), 1-14.

CAPELLO, M., ROBERT, M., SORIA, M., POTIN, G., ITANO, D., HOLLAND, K., DENEUBOURG, J. L. & DAGORN, L. 2015. A methodological framework to estimate the site fidelity of tagged animals using passive acoustic telemetry. *PLoS One*, 10(8), e0134002.

CAPELLO, M., SORIA, M., COTEL, P., DENEUBOURG, J. L. & DAGORN, L. 2011. Quantifying the interplay between environmental and social effects on aggregated-fish dynamics. *PLoS One*, 6(12), e28109.

CAPELLO, M., SORIA, M., COTEL, P., POTIN, G., DAGORN, L. & FRÉON, P. 2012. The heterogeneous spatial and temporal patterns of behavior of small pelagic fish in an array of Fish Aggregating Devices (FADs). *Journal of Experimental Marine Biology and Ecology,* 430-431, 56-62.

CAPELLO, M., SORIA, M., POTIN, G., COTEL, P. & DAGORN, L. 2013b. Effect of current and daylight variations on small-pelagic fish aggregations (*Selar crumenophthalmus*) around a coastal fish aggregating device studied by fine-scale acoustic tracking. *Aquatic Living Resources*, 26, 63-68.

CARVALHO, M. F., BARBOSA, J. M., ARAÚJO, A. R. R. & SOUZA, J. M. 2015. Cadeia de comercialização de tunídeos no Estado de Sergipe, Brasil. *Acta of Fisheries and Aquatic Research*, 3(1), 1-12.

CASTRO, J. J., SANTIAGO, J. A. & SANTANA-ORTEGA, A. T. 2002. A general theory on fish aggregation to floating objects: an alternative to the meeting point hypothesis. *Reviews in Fish Biology and Fisheries,* 11(3), 255-277.

DAGORN, L., HOLLAND, K. N. & ITANO, D. G. 2007. Behavior of yellowfin (*Thunnus albacares*) and bigeye (T. obesus) tuna in a network of fish aggregating devices (FADs). *Marine Biology,* 151, 595-606.

DAGORN, L., PETIT, M. & STRETTA, J. M. 1997. Simulation of large-scale tropical tuna movements in relation with daily remote sensing data: the artificial life approach. *BioSystems*, 44(3), 167-180.

DAHLET, L. I., DOWNEY-BREEDT, N., ARCE, G., SAUER, W. H. H. & GASALLA, M. A. 2019. Comparative study of skipjack tuna *Katsuwonus pelamis* (Scombridae) fishery stocks from the South Atlantic and western Indian oceans. *Scientia Marina,* 83(1), 19-30.

DEMPSTER, T. 2004. Biology of fish associated with moored fish aggregation devices (FADs): implications for the development of a FAD fishery in New South Wales, Australia. *Fisheries Research,* 68(1-3), 189-201.

DEMPSTER, T. & TAQUET, M. 2004. Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies. *Reviews in Fish Biology and Fisheries,* 14(1), 21-42.

DUBROCA, L., CHASSOT, E., FLOCH, L., DEMARCQ, H., ASSAN, C. & MOLINA, A. D. 2013. Seamounts and tuna fisheries: tuna hotspots or fisherman habits?. *Scientific Papers of The International Commission for the Conservation of Atlantic Tunas,* 69(5), 2087-2102.

EIGHANI, M., PAIGHAMBARI, S. Y., TAQUET, M. & GAERTNER, J. C. 2019. Introducing nearshore fish aggregation devices (FAD) to artisanal Persian Gulf fisheries: a preliminary study. *Fisheries Research*, 212, 35-39.

FERREIRA, L. C., AFONSO, A. S., CASTILHO, P. C. & HAZIN, F. H. V. 2013. Habitat use of the nurse shark, *Ginglymostoma cirratum*, off Recife, Northeast Brazil: a combined survey with longline and acoustic telemetry. *Environ. Biol. Fishes,* 96(6), 735-745.

FORGET, F. G., CAPELLO, M., FILMALTER, J. D., GOVINDEN, R., SORIA, M., COWLEY, P. D. & DAGORN, L. 2015. Behaviour and vulnerability of target and non-target species at drifting fish aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic telemetry. *Canadian Journal of Fisheries and Aquatic Sciences*, 72(9), 1398-1405.

FRÉON, P. & DAGORN, L. 2000. Review of fish associative behaviour: toward a generalisation of the meeting point hypothesis. *Reviews in Fish Biology and Fisheries,* 10, 183-207.

GAERTNER, J. C., TAQUET, M., DAGORN, L., MÉRIGOT, B., AUMEERUDDY, R., SANCHO, G. & ITANO, D. 2008. Visual censuses around drifting fish aggregating devices (FADs): a new approach for assessing the diversity of fish in open-ocean waters. *Marine Ecology Progress Series*, 366, 175-186.

GIRARD, C., BENHAMOU, S. & DAGORN, L. 2004. FAD: fish aggregating device or fish attracting device? A new analysis of yellowfin tuna movements around floating objects. *Animal Behaviour,* 67, 319-326.

GIRARD, C., DAGORN, L., TAQUET, M., AUMEERUDDY, R., PEIGNON, C. & BENHAMOU, S. 2007. Homing abilities of dolphinfish (*Coryphaena hippurus*) displaced from fish aggregating devices (FADs) determined using ultrasonic telemetry. *Aquatic Living Resources,* 20(4), 313-321.

GOODING, R. M. & MAGNUSON, J. J. 1967. Ecological significance of a drifting object to pelagic fishes. *Pacific Science,* 21(4), 486-497.

GOVINDEN, R., JAUHARY, R., FILMALTER, J., FORGET, F., SORIA, M., ADAM, S. & DAGORN, L. 2013. Movement behaviour of skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*) tuna at anchored fish aggregating devices (FADs) in the Maldives, investigated by acoustic telemetry. *Aquatic Living Resources*, 26, 69-77.

GRAHAM, B. S., GRUBBS, D., HOLLAND, K. & POPP, B. N. 2007. A rapid ontogenetic shift in the diet of juvenile yellowfin tuna from Hawaii. *Marine Biology*, 150(4), 647-658.

HAIMOVICI, M., ANDRIGUETTO, F. J. M. & SUNYE, P. S. 2014. *A pesca marinha e estuarina no Brasil - estudos de caso multidisciplinares*. Rio Grande: Editora da FURG.

HOLLAND, K., BRILL, R. & CHANG, R. K. C. 1990. Horizontal and vertical movements of Pacific blue marlin captured and released using sportfishing gear. *Fishery Bulletin,* 88(2), 397-402.

HOLLAND, K. N. & GRUBBS, R.D. 2007. Fish visitors to seamounts: tunas and bill fish at seamounts. In: PITCHER, T. J., MORATO, T., HART, P. J. B., CLARK, M. R., HAGGAN N. & SANTOS, R. S. (eds.). *Seamounts: ecology, fisheries & conservation*. Oxford: Blackwell Publishing, pp. 189-201.

HOLLAND, K. N., JAFFE, A. & CORTEZ, W. 2000. The fish aggregating device (FAD) system of Hawaii. In: *Pêche thonière et dispositifs de concentration de poissons*. Caribbean-Martinique, pp. 55-62.

HUNTER, J. R. & MITCHELL, C. T. 1968. Field experiments on the attraction of pelagic fish to floating objects. *ICES Journal of Marine Science,* 31(3), 427-434.

JONES, J. 1772. Oppian's Halieuticks of the nature of fishes and fishing of the ancients. In: BOOKS, V. (ed.). *Oppians's life and writings, and a catalogue of his fishes.* Oxford: Theater.

KESSEL, S. T., COOKE, S. J., HEUPEL, M. R., HUSSEY, N. E., SIMPFENDORFER, C. A., VAGLE, S. & FISK, A. T. 2014. A review of detection range testing in aquatic passive acoustic telemetry studies. *Reviews in Fish Biology and Fisheries*, 24(1), 199-218.

LESSA, R. & NÓBREGA, M. 2000. *Guia de identificação de peixes marinhos da região Nordeste*. Recife: Programa REVIZEE/SCORE-NE.

LIMA, J. H. M., LIN, C. F., DIAS NETO, J. & MENEZES, A. A. S. 2000. Sobre o uso da rede de cerco na pesca de atuns no Brasil. *Boletim* Técnico-*Científico do CEPNOR,* 11(1), 81-115.

LIMA, J. S., ZAPPES, C. A., DI BENEDITTO, A. P. M. & ZALMON, I. R. 2018. Artisanal fisheries and artificial reefs on the southeast coast of Brazil: contributions to research and management. *Ocean and Coastal Management,* 163, 372-382.

MAGUIRE, J. J., SISSENWINE, M., CSIRKE, J., GRAINGER, R. & GARCIA, S. 2006. *The state of world highly migratory, straddling and other high seas fishery resources and associated species.* Rome: FAO Fisheries Technical Paper.

MARSAC, F. & CAYRÉ, P. 1998. Telemetry applied to behaviour analysis of yellowfin tuna (Thunnus albacares, Bonnaterre, 1788) movements in a network of fish aggregating devices. *Hydrobiologia*, 371-372, 155-171.

MATSUMOTO, T., KITAGAWA, T. & KIMURA, S. 2013. VERTICAL Behavior of bigeye tuna (*Thunnus obesus*) in the northwestern Pacific Ocean based on archival tag data. *Fisheries Oceanography,* 22(3), 234-246.

MBARU, E. K., SIGANA, D., RUWA, R. K., MUENI, E. M., NDORO, C. K., KIMANI, E. N. & KAUNDA-ARARA, B. 2018. Experimental evaluation of influence of FADs on community structure and fisheries in coastal Kenya. *Aquatic Living Resources,* 31(6), 1-12.

MEYER, C. G., HOLLAND, K. N., WETHERBEE, B. M. & LOWE, C. G. 2000. Movement patterns, habitat utilization, home range size and site fidelity of whitesaddle goatfish, *Parupeneus porphyreus*, in a marine reserve. *Environmental Biology of Fishes*, 59(3), 235-242.

MONTES, N., SIDMAN, C., LORENZEN, K., TAMURA, M. & ISHIDA, M. 2019. Influence of fish aggregating devices on the livelihood assets of artisanal fishers in the Caribbean. *Ocean and Coastal Management*, 179, e104872.

MORALES-NIN, B., CANNIZZARO, L., MASSUTI, E., POTOSCHI, A. & ANDALORO, F. 2000. An overview of the FADs fishery in the Mediterranean Sea. *Fish Aggregating Devices Symposium*, 184-207.

MORENO, G., BOYRA, G., SANCRISTOBAL, I., ITANO, D. & RESTREPO, V. 2019. Towards acoustic discrimination of tropical tuna associated with fish aggregating devices. *PLoS One*, 14(6), e0216353.

MORENO, G., DAGORN, L., CAPELLO, M., LOPEZ, J., FILMALTER, J., FORGET, F., SANCRISTOBAL, I. & HOLLAND, K. 2016. Fish aggregating devices (FADs) as scientific platforms. *Fisheries Research*, 178, 122-129.

MOURATO, B. L., CARVALHO, F., MUSYL, M., AMORIM, A., PACHECO, J. C., HAZIN, H. & HAZIN, F. 2014. Short-term movements and habitat preferences of sailfish, *Istiophorus platypterus* (Istiophoridae), along the southeast coast of Brazil. *Neotropical Ichthyology,* 12(4), 861-870.

MUIR, J., ITANO, D., HUTCHINSON, M., LEROY, B. & HOLLAND, K. 2012. Behavior of target and non-target species on drifting FADs and when encircled by purse seine gear. *Western and Central Pacific Fisheries Commission,* 8, 1-8.

NIELLA, Y. V, AFONSO, A. S. & HAZIN, F. H. V. 2017. Bioecology and movements of bull sharks, *Carcharhinus leucas*, caught in a long-term longline survey off northeastern Brazil. *Neotropical Ichthyology*, 15(3), e170106.

OSHIMA, T., TAKAO, Y., HASEGAWA, S., KIMURA, T., UEHARA, T. & FUSEJIMA, I. 2019. Differences in reaction of bigeye tuna (*Thunnus obesus*) and skipjack tuna (*Katsuwonus pelamis*) to intermittent light. *Fisheries Research*, 214, 148-156.

PARKER, R. W. R., VÁZQUEZ-ROWE, L. & TYEDMERS, P. H. 2014. Fuel performance and carbon footprint of the global purse seine tuna fleet. *Journal of Cleaner Production*, 103, 517-524.

QUARTAU, R., HIPÓLITO, A., ROMAGNOLI, C., CASALBORE, D., MADEIRA, J., TEMPERA, F., ROQUE, C. & CHIOCCI, F. L. 2014. The morphology of insular shelves as a key for understanding the geological evolution of volcanic islands: Insights from Terceira Island (Azores). *Geochemistry, Geophysics, Geosystems*, 15, 1801-1826.

R CORE TEAM, 2019. *R: a language and environment for statistical computing*. Vienna: R Foundation for Statistical Computing.

ROBERT, M., DAGORN, L., DENEUBOURG, J. L., ITANO, D. & HOLLAND, K. N. 2012. Size-dependent behavior of tuna in an array of fish aggregating devices (FADs). *Marine Biology*, 159(4), 907-914.

ROBERT, M., DAGORN, L., FILMALTER, J. D., DENEUBOURG, J. L., ITANO, D. & HOLLAND, K. 2013. Intra-individual behavioral variability displayed by tuna at fish aggregating devices (FADs). *Marine Ecology Progress Series,* 484, 239-247.

RODRIGUEZ-TRESS, P., CAPELLO, M., FORGET, F., SORIA, M., BEEHARRY, S. P., DUSSOOA, N. & DAGORN, L. 2017. Associative behavior of yellowfin *Thunnus albacares*, skipjack *Katsuwonus pelamis*, and bigeye tuna *Thunnus obesus* at anchored fish aggregating devices (FADs) off the coast of Mauritius. *Marine Ecology Progress Series*, 570, 213-222.

ROUNTREE, R. A. 1989. Association of fishes with fish aggregation devices: effects of structure size on fish abundance. *Bulletin of Marine Science,* 44(2), 960-972.

SCOTT, P. C. 1985. Fish aggregating buoys in Brazil. *ICLARM Newsletter*, 11, 1.

SEMPO, G., DAGORN, L., ROBERT, M. & DENEUBOURG, J. L. 2013. Archimer spatial distribution of social fish species. *Journal of Applied Ecology*, 50(5), 1081-1092.

SEPULVEDA, C. A., AALBERS, S. A., ORTEGA-GARCIA, S., WEGNER, N. C. & BERNAL, D. 2011. Depth distribution and temperature preferences of wahoo (*Acanthocybium solandri*) off Baja California Sur, Mexico. *Marine Biology*, 158(4), 917-926.

SILVA, G. B., CHAVES, D. C. B. & FONTELES-FILHO, A. A. 2013. Aspectos econômicos da pesca de atuns e afins associada a uma boia oceânica no atlântico oeste equatorial. *Boletim do Instituto de Pesca*, 39(1), 85-91.

SILVA, G. B., HAZIN, H. G., HAZIN, F. H. V. & TRAVASSOS, P. 2019. The tuna fisheries on "associated school" in Brazil: description and trends. *Collective Volume of Scientific Papers*, 75(7), 1924-1934.

SILVA, G. B., HAZIN, H. G. & NASCIMENTO, P. V. A. 2018. Fishing operations to catch tuna on aggregated schools at the vicinity of a data buoy in the Western Equatorial Atlantic. *Brazilian Journal of Oceanography*, 66(4), 335-338.

SILVEIRA, C. M. V. A. 2014. Relatório Final LH-010/2014 - Comissão Pirata BR-XV.

SINOPOLI, M., LAURIA, V., GAROFALO, G., MAGGIO, T. & CILLARI, T. 2019. Extensive use of fish aggregating devices together with environmental change influenced the spatial distribution of a tropical affinity fish. *Scientific Reports*, 9(1), 1-12.

SORIA, M., DAGORN, L., POTIN, G. & FRÉON, P. 2009. First field-based experiment supporting the meeting point hypothesis for schooling in pelagic fish. *Animal Behaviour*, 78(6), 1441-1446.

STEHFEST, K. M., PATTERSON, T. A., DAGORN, L., HOLLAND, K. N., ITANO, D. & SEMMENS, J. M. 2013. Network analysis of acoustic tracking data reveals the structure and stability of fish aggregatios in the ocean. *Animal Behaviour*, 85(4), 839-848.

TAQUET, M. 2013. Fish aggregating devices (FADs): Good or bad fishing tools? A question of scale and knowledge: FOREWORD: Tahiti International Conference "tuna Fisheries and FADs", November 2011. *Aquatic Living Resources*, 26(1), 25-35.

TAQUET, M., DAGORN, L., GAERTNER, J. C., GIRARD, C., AUMERRUDDY, R., SANCHO, G. & ITANO, D. 2007. Behavior of dolphinfish (*Coryphaena hippurus*) around drifting FADs as observed from automated acoustic receivers. *Aquatic Living Resources*, 20(4), 323-330.

TRAVASSOS, P. E., PEREIRA, A. A. & TOLOTTI, M. T. 2009. Comportamento da Albacora-laje, *Thunnus albacares* (Bonnaterre, 1788). In: VIANA, D. L., HAZIN, F. H. V., SOUZA, M. A. C. (eds.). *O arquipélago de São Pedro e São Paulo: 10 anos de Estação Científica*. São Paulo: ECIRM - Marinha do Brasil, pp. 348.

WENG, J. S., HUNG, M. K., LAI, C. C., WU, L. J., LEE, M. A. & LIU, K. M. 2013. Fine-scale vertical and horizontal movements of juvenile yellowfin tuna (*Thunnus albacares*) associated with a subsurface fish aggregating device (FAD) off southwestern Taiwan. *Journal of Applied Ichthyology,* 29(5), 990-1000.

WHITNEY, N. M., TAQUET, M., BRILL, R. W., GIRARD, C., SCHWIETERMAN, G. D., DAGORN, L. & HOLLAND, K. N. 2016. Swimming depth of dolphinfish (*Coryphaena hippurus*) associated and unassociated with fish aggregating devices Nicholas. *Fishery Bulletin*, 114(4), 426-434.