In-situ experiment to test a hypothesis on tuna movements within a FAD array in the Maldives

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Abstract

To test the hypothesis on connectivity of anchored FADs in the Maldivian 65 skipjack and 57 yellowfin tuna were tagged with acoustic transmitters. Tagging campaigns were within a subsection of the array consisting of 21 AFADs, equipped with acoustic receivers. Only three yellowfin tuna (5.2%) and one skipjack tuna (1.5%) were observed to move from one FAD to another. These four fish were tagged together at the same AFAD during the same tagging campaign, while no fish tagged at the other AFADs moved between FADs. Despite being tagged together, the fish that moved between the AFADs were detected at different AFADs, suggesting that they did not have a specific preference in the direction of movement. Another important result is that fish departing from the same AFAD is detected at different AFADs, suggesting that tuna left the AFAD in multiple schools. The mean continuous residence time at AFADs recorded for all tagged skipjack and yellowfin tuna were 2.03±2.93 days and 4.42±6.72 days, respectively. The few observed inter-AFAD movements of tuna suggest that the AFAD array in the Maldives, with its large inter-AFAD distances, does not act as a network but rather as individual AFADs that locally attract tuna. In contrast to other denser AFAD arrays in the world, it appears that large distances between AFADs minimize any possible AFAD array-effect on tuna movements.

Key words: acoustic tagging, tuna movement, continuous residence time, anchored FAD, AFAD array

1 Introduction

Large schools of tuna are attracted to various types of floating objects in the marine environment (Castro et, al., 2002; Kingsford, 1993). These floating objects can be natural or artificial such as anchored fish aggregating devices (AFADs). In the Indian Ocean, several countries including the Maldives use AFADs for aggregating tuna for fishing. The Maldives have one of the most extended AFAD arrays in the world (Govinden et al., 2013) stretching over 900 km in the middle of the Indian Ocean. All the AFADs in the Maldives are deployed by the government who takes the full responsibility of maintaining this relatively low-density array of AFADs. Other AFAD arrays are usually characterized by shorter distances between FADs, e.g. 2-14 km in Mauritius (Rodriguez-Tress et al., 2017) or 7-31 km around Oahu, Hawaii (Laurent Dagorn, Holland, & Itano, 2007), while in the Maldives (with all 55 AFADs), distances between neighbouring AFADs range from 25-48 km.

Govinden et al., (2013) investigated the behaviour of tuna at AFADs in the Maldivian array through acoustic telemetry. In their study, skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares)* tuna were tagged at two AFADs in the middle of a set of eight AFADs aligned on a north-south axis, all equipped with acoustic receivers (Figure 1). No inter-AFAD movement was observed within the equipped AFAD array, neither to the north nor to the south of the AFADs of tagging. The authors hypothesized that the absence of observed movements between equipped AFADs could be due to the large inter-FAD distances. Another hypothesis could be that in this region, tuna have a general west-east (or east-west) movement. However, since the AFADs on the west of the study area were not equipped, and no AFADs exist on the east, it was not possible to verify any east-west or west-east movement.

From the acoustic tagging studies conducted in Mauritius it was observed that the average continuous residence time (CRT) for yellowfin tuna was 9.6±11.4 days and for skipjack was 2.5±4.4 days. While the total residence time observed for yellowfin tuna was 30.1±13.2 days and for skipjack tuna was 17.6±14.3 days (Rodriguez-Tress et al. 2017). Similar study conducted in Hawaii showed that the average CRT for yellowfin tuna was 8.0±12.6 days with a TRT of 28.7±36.1 days. Both these AFAD arrays had several FADs that were less than 10 km apart from each other. Girard et al. (2004) studies showed that yellowfin tuna can orient towards a FAD from approximately 10 km.

The AFADs in the Maldives array do not have such short distance between the AFADs. Hence the objectives of this study were to test whether connectivity exists in the Maldives AFAD array (with such large inter-AFAD distances) and estimate the durations of individuals' association with AFADs, with the aim of comparing them with the durations measured in the Maldives previously (Govinden et al., 2013) and also in other AFAD arrays with lower inter-AFAD distances (see (Pérez et al., 2020) for a summary of data from other studies).

2 Materials and methods

2.1 Study site

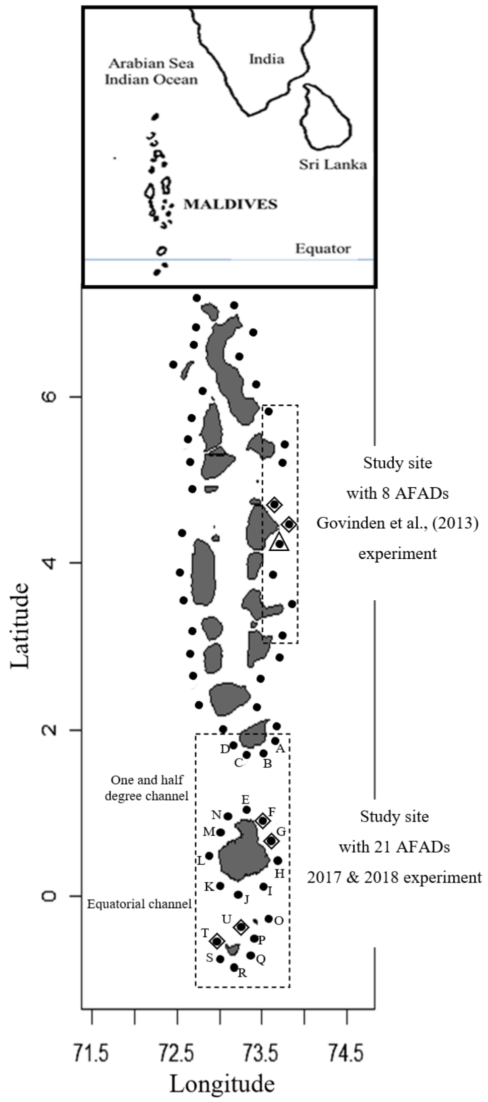

Figure 4.1: Current anchored FAD array in the Maldives with location of this study site and of Govinden et al. (2013) study site. (●AFADs,◇Acoustic tagging AFADs, △AFAD deployed in 2019 that was not present in the site during Govinden et al. 2013 study).

The Maldives extends from 7°N to 1°S in the central Indian Ocean (Figure 1). From about 6°N to 2.5°N, the Maldives atolls are formed in a double chain and below 2°N, the atolls form a single chain and are separated with wide deep channels such as the equatorial channel and the one-and-half degree channel through which pelagic fish such as tuna could easily pass through. Across the Maldives there is an array of 55 AFADs deployed about 20 km from the outer edge of the atolls moored at depths ranging from 1000 m to 2800 m.

Two tagging campaigns were conducted, respectively in 2017 and 2018, in the south of the Maldives, between 2°N and 1°S and 72.5°E and 74.0°E (Figure 1). In this study site there were 21 AFADs with distances between neighbouring AFADs of 27-35 km. In 2017 acoustic tagging was conducted at two AFADs (F and G, see Figure 1) on the east side of the array and in 2018 at four AFADs (F, G, T and U, see Figure 1) both on the east and west side of the array. The distances between the AFADs of tagging and the other instrumented AFADs of the array (Figure 2), demonstrate a denser FAD sub-array as compared to the Govinden et al. (2013) study.

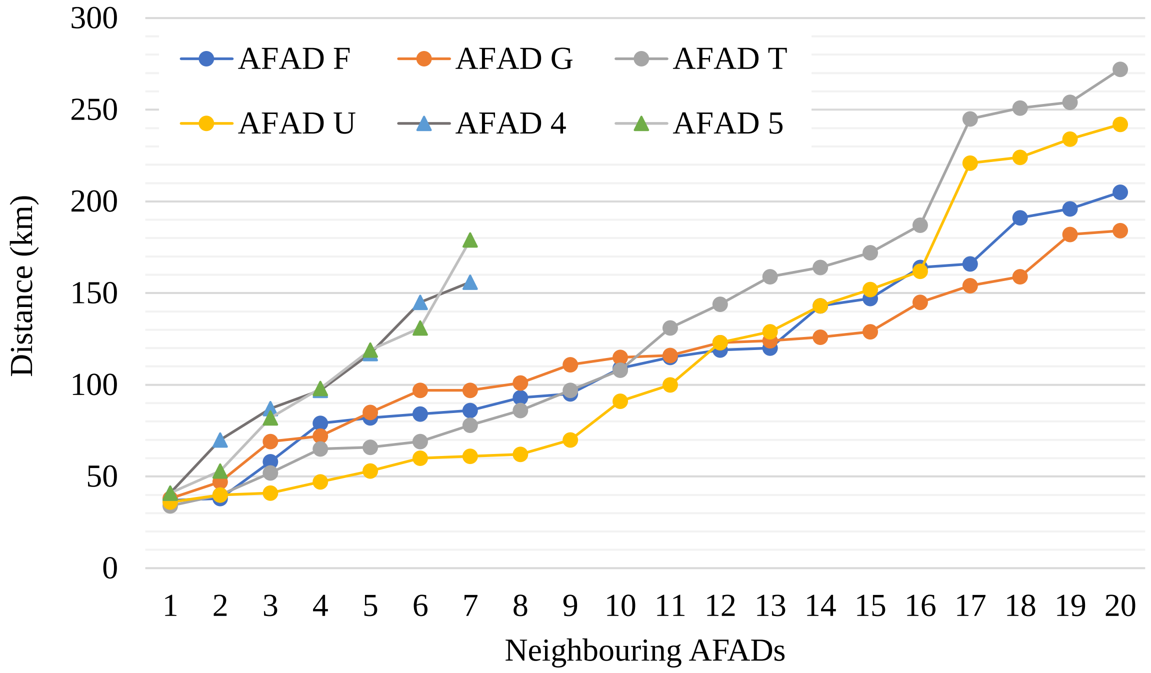

Figure 2: Inter-AFAD distances between the tagging FADs and the other instrumented FADs of the array (in order of neighbourhood) (Present - 2017/2018 study – AFADs F, G, T and U; Govinden et al. 2013 study, AFADs 4 and 5).

All 21 AFADs of our study site were instrumented with acoustic receivers (VR2W, Vemco, Halifax, Canada). The acoustic receivers were fixed (tied) to the main mooring ropes of the AFADs at depths between 12 m and 15 m. Two plastic cable ties helped to position the receiver with the hydrophone pointing downwards. In 2017, all the receivers stayed attached to the FADs from 15 February till 17 May (98 days). In 2018, the receivers were deployed at the AFADs between 15 February and the 30 September (227 days), well into the southwest monsoon.

2.2 Acoustic tagging

This study focused on the two major commercial tuna species (skipjack tuna – *Katsuwonus pelamis*, and yellowfin tuna – *Thunnus albacares*) found at AFADs in the Maldives. Tagging was conducted on a pole and line fishing vessel. Fish caught by fishers were gently placed by scientists on a V-shaped tagging table positioned at the back of the boat. A wet cloth covered the eyes while a hose with flowing saltwater was placed in the mouth of the fish to ensure the gills were ventilated. Fish were equipped with internal acoustic transmitters (Vemco V13-1L-R64K, 69 kHz, 50−130 s delay, estimated battery life 878 days). The transmitter was placed inside the peritoneal cavity of the fish by making an incision using a sharp scalpel in the abdominal musculature about 2 to 3 cm from the anus. The opening was closed by two sutures made using monofilament nylon. The average size of tagged fish was 41.9 ± 6.3 cm and 43.5 ± 7.0 cm for skipjack and yellowfin tuna, respectively. A total of 65 skipjack (SKJ) and 57 yellowfin (YFT) tuna were tagged in through 2017 and 2018 (respectively at 2 and 4 FADs) constituting 6 different replicates. A tagging replicate is defined as fish tagged during the same tagging campaign at the same AFAD (Table 1).

Table 1: Acoustic tagging replicates with number of tagged skipjack and yellowfin tuna.

AFAD – year	Tagging dates	Number of SKJ – YFT tagged
F – 2017 F – 2018	9 Mar – 16 Mar 2017 15 Mar – 17 Mar 2018	5 – 8 8 – 14
G – 2017 G – 2018	11 Mar – 16 Mar 2017 12 Mar 2018	14 – 12 11 – 9
T – 2018	18 Mar – 19 Mar 2018	17 – 4
U – 2018	18 Mar 2018	10 – 10

2.3 Data analysis

The continuous residence time (CRT) of individual tuna at AFADs was calculated based on the definition provided by Ohta and Kakuma (2005), that is “the duration in which a tagged tuna was continuously monitored without day-scale (> 24 hours) absence”. A fish was considered to be present at a FAD if it was detected at least three times at the FAD, in order to avoid any false detection. The continuous absence time (CAT) was calculated as the time between two AFAD associations (Capello et al., 2016; Rodriguez-Tress et al., 2017). The overall directions of movements between AFADs were estimated by calculating the angle (in degrees) relative to the north of the direct line between the AFAD of departure and the AFAD of arrival. Hence if the direction is between >315° and ≤45° it was considered north, >45° and ≤135° it was considered east, >135° and ≤225° it was considered south and >225° and ≤315° it was considered west. The speed of the tuna was calculated by dividing the Euclidean distance between the two AFADs by the time it took to travel from one FAD to the other.

Wilcoxon signed ranked test was used to compare the CRTs of the skipjack and yellowfin tuna tagged at the four FADs during the 6 tagging replicates. The same test was also applied for comparing CRTs recorded within the two tagging campaigns (2017 and 2018) for each species and to run a comparison between species for all CRTs. The null hypothesis was rejected at the 0.05 threshold, and the Bonferroni correction was applied to account for multiple pairwise tests. All statistical analysis were performed using the R software (R Core Team R, 2019)

3 Results

3.1 Tuna movements between AFADs

Only four individuals (3.3% of all tuna tagged) of the 122 tuna tagged were detected at an instrumented AFAD other than where they were released: three yellowfin (5.2% of all tagged yellowfin tuna) and one skipjack tuna (1.5% of all tagged skipjack tuna). In total, these fish exhibited seven movements, whose characteristics are detailed in Table 2.

Table 2: Tuna individual (FL = fork length), **AFADs of departure/arrival, direction of movement, distance, continuous residence time (CAT) and estimated speed for the four tuna that moved between AFADs.**

Tuna	**AFAD**		**Direction**		**Distance (km)**	**CAT (days)**	**Speed (km/h)**
	Left	**Arrived**					
YFT (FL 51 cm)	G	F	345°	North	38	2.3	0.69
	F	E	300°	West	37	2.5	0.62
YFT (FL 52 cm)	G	N	295°	West	85	13	0.27
	N	E	80°	East	27.5	8	0.14
	E	G	138°	South	72	134	0.02
YFT (FL 54 cm)	G	O	188°	South	101	165	0.03
SKJ (FL 38 cm)	G	H	172°	South	47	1.27	1.54

It is noteworthy that these four fish were tagged during the same tagging replicate at AFAD G in 2018, corresponding to 20% of fish (all species considered) tagged during this replicate exhibiting movements between AFADs. No fish from any of the other five tagging replicates was observed at any other AFAD than the tagging AFADs. Considering only the seven observed between-AFAD movements, four corresponded to a north-south axis while three were on a east-west axis (Figure 3 and Table 2). One yellowfin (FL = 51cm) travelled north from G to F and then to west from F to E (Figure 4.3). Another yellowfin (FL = 52cm) travelled west from G to N and then to east from N to E. Then it moved south from E to G. The third yellowfin (FL = 54cm) moved south from G to O. The skipjack swam from AFAD G to AFAD H in the south.

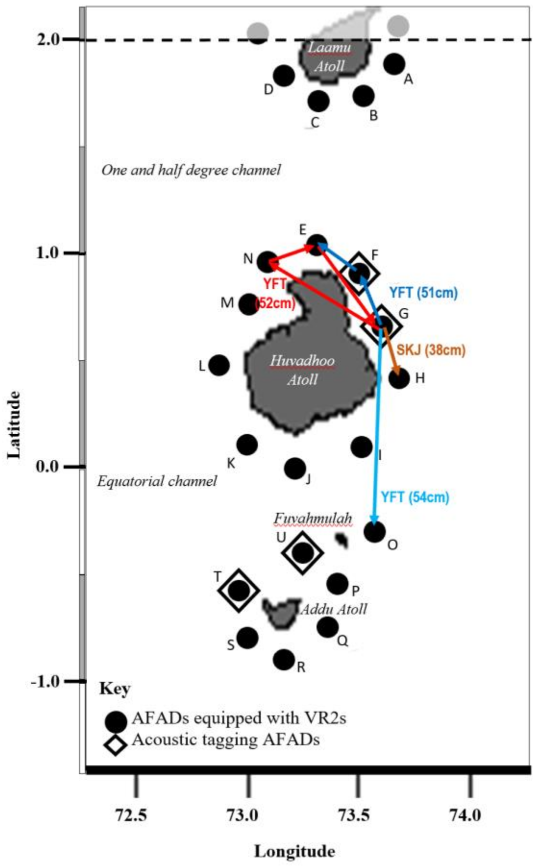

Figure 3: Tuna movements between AFADs in the instrumented array. Solid circles denote FADs, diamonds denote AFADs where tagging was conducted. The arrows denote the movements and direction displayed by tagged individuals which displayed a movement between different AFADs and colors denote individuals. YFT: yellowfin tuna, SKJ: skipjack tuna.

For each of these four fish, Figure 4 details the continuous residence times (CRT) and the absence times (CAT) at FADs between the associations. Two yellowfin tuna (52 cm and 54 cm) showed exceptionally long CATs (133.84 days and 168.28 days respectively).

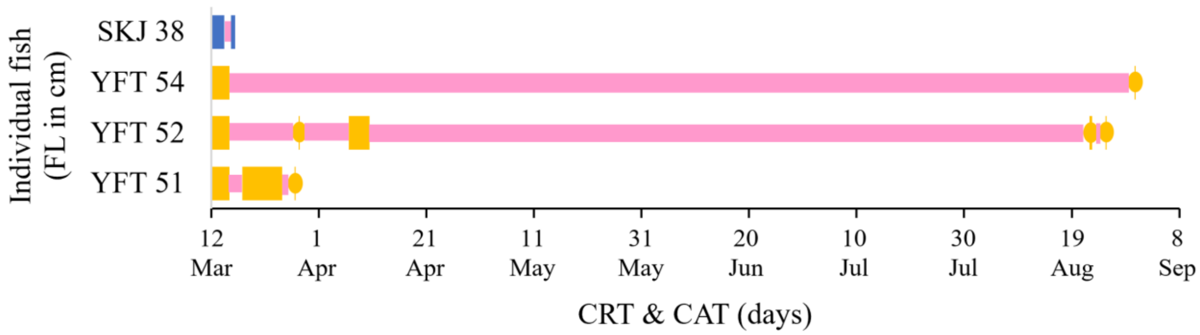

Figure 4: CRTs and CATs at each visited AFAD by the four tuna that were detected at an AFAD other than the one where they were tagged and released.

(CRT < 1 day ⬮, yellowfin tuna ■, skipjack tuna ■, and CAT ■).

3.2 First Continuous residence times

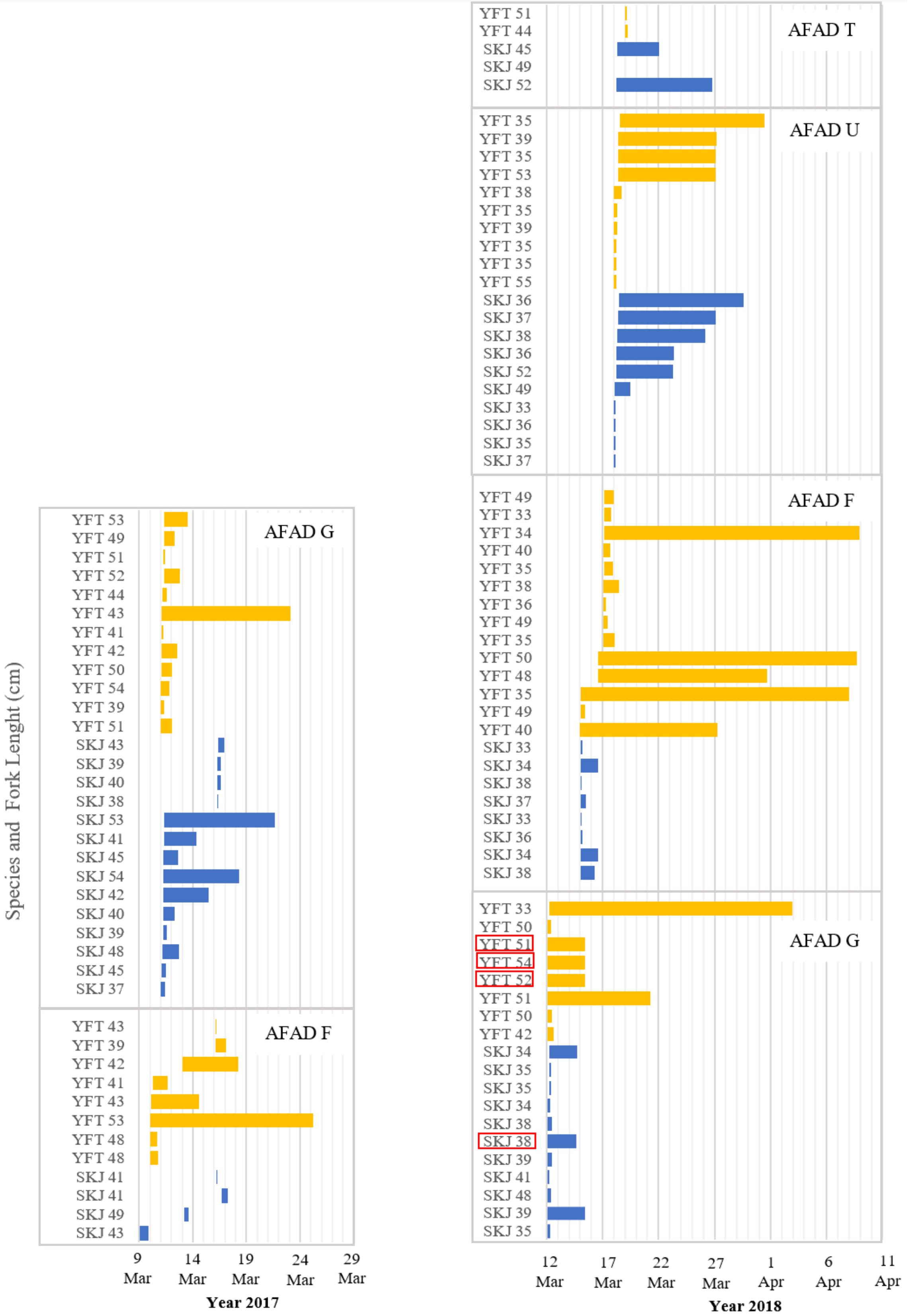

Figure 5: First CRTs at tagging AFADs for each tagging cohort (FADs F, G, T and U. (Yellowfin tuna ■, skipjack tuna■ , that moved between AFADs ▭).

The mean, maximum and the minimum CRTs for skipjack and yellowfin tuna for each replicate are presented in Table 3. The mean CRT for yellowfin tuna was 2.54 days in 2017 and 5.52 days in 2018, and 4.42 days over the entire study period (2017 and 2018 combined). For skipjack tuna the mean CRT was 1.83 days in 2017 and 2.08 days in 2018, and 2.03 days over the study period.

Table 3: The mean, maximum, minimum and standard deviations of the first CRTs, mean fork length and n= number of tunas.

Cohort	Mean CRT (days)	Max CRT (days)	Min CRT (days)	SD CRT	Mean FL (cm)	n
SKJ-AFAD F-2017	0.480	0.88	0.02	0.380	43.50	4
SKJ-AFAD F-2018	0.676	1.57	0.08	0.669	35.37	8
SKJ-AFAD G-2017	2.219	10.34	0.03	3.058	43.14	14
SKJ-AFAD G-2018	0.794	3.44	0.15	1.108	37.82	11
SKJ-AFAD T-2018	4.107	8.50	0.07	4.226	48.67	3
SKJ-AFAD U-2018	4.000	11.11	0.14	4.170	38.90	10
YFT-AFAD F-2017	3.599	15.20	0.04	5.053	44.62	8
YFT-AFAD F-2018	7.396	23.98	0.23	9.806	40.78	14
YFT-AFAD G-2017	1.837	12.01	0.13	3.262	47.42	12
YFT-AFAD G-2018	5.336	21.75	0.34	7.241	47.87	8
YFT-AFAD T-2018	0.215	0.28	0.15	0.092	47.50	2
YFT-AFAD U-2018	4.113	12.94	0.20	5.049	39.90	10
All SKJ 2017	1.83	10.34	0.02	2.779	43.22	18
All SKJ 2018	2.08	11.11	0.07	3.065	38.56	32
All YFT 2017	2.54	15.20	0.04	4.043	46.30	20
All YFT 2018	5.52	23.98	0.15	7.729	42.59	34
All SKJ (2017+2018)	2.03	11.11	0.02	2.93	40.24	50
All YFT (2017+2018)	4.42	23.98	0.04	6.72	43.96	54

The longest recorded CRT were 23.98 days and 11.11 days for yellowfin tuna and skipjack tuna, respectively. The results of the Wilcoxon signed ranked test conducted on CRTs for different cohorts showed no significant differences between different combinations of cohorts except for the comparison of CRTs between skipjack tuna and yellowfin tuna tagged in 2017 and 2018 combined (p-value = 0.03).

4 Discussion

4.1 Experimental approach

In order to test our hypothesis after Govinden et al. (2013), we needed to work (1) in the same geographical area than Govinden et al. (2013) and (2) instrument an array with AFADs located around the ones where tuna are tagged. We decided to conduct an experiment in a sub-section of the Maldivian AFAD array, located in the South (Figure 1 and 3). The main difference from the Govinden et al. (2013) study site is that the instrumented AFADs (attached with VR2s) were not aligned on a single axis but formed a 2-dimensional array, which allowed to better understand the connectivity of the AFAD array, including east-west or west-east tuna movements.

Following the striking result obtained during the first tuna tagging study within the Maldivian AFAD array (Govinden et al. 2013), where no inter-FAD movement was recorded, our study was designed to test the connectivity of the AFAD array in the Maldives and the directionality of movements displayed by tuna in the array. The absence of movements observed in the Govinden et al. 2013 had never been observed in other similar studies, when several surrounding FADs were instrumented (Laurent Dagorn et al., 2007; Robert et al., 2013; Rodriguez-Tress et al., 2017).

4.2 Connectivity of the Maldives AFAD array

In several acoustic tagging experiments conducted at AFADs in other parts of the world, tuna were observed to move between AFADs (Laurent Dagorn et al., 2007; Holland, Brill, & Chang, 1990; Mitsunaga, Endo, Anraku, Selorio Jr, & Babaran, 2012; Ohta & Kakuma, 2005; Robert, Dagorn, Deneubourg, Itano, & Holland, 2012; Rodriguez-Tress et al., 2017). In the Maldives, however, such movements were not apparent. For five tagging events, we did not observe any movement, similar to the four tagging events in Govinden et al. (2013). This result indicates that although some characteristics changed between the two FAD sub-arrays that were investigated, results tend to be comparable with no tuna exhibiting inter-AFAD movements in nine tagging events out of ten.

The general trend of tuna movements in the Maldives is considered to be linked to the monsoon seasons – northeast monsoon and southwest monsoon. Conventional tagging experiments conducted in the past showed that during the northeast monsoon when the currents are from east to west tuna tend to move westward while in the southwest monsoon when the current is in the opposite direction fish tend to move eastward (Anderson, Adam, & Waheed, 1996; Yesaki & Waheed, 1992). Analysis of the conventional tagging data by Yesaki and Waheed (1992) also showed that small skipjack (< 50 cm) are less migratory and tend to stay closer to the Maldives than yellowfin. These tagging experiments also showed that the long-distance migrations were along with the current (westwards during the northeast monsoon and eastwards during southwest monsoon) (Yesaki & Waheed, 1992).

During our study, acoustic tagging was conducted in March (which is towards the end of the northeast monsoon and the beginning of the transition period for the southwest monsoon) and between 2°N and 2°S, where there is less effect from the monsoon currents than in the centre or north of the country (Anderson, 2005). In addition, since the inter-monsoon periods are also characterized by weaker winds and currents it is believed to have less influence on the direction of tuna movements.

Only one tagging event showed some fish visiting other AFADs, with 20% of tagged fish performing inter-AFAD movements. There was no clear directionality in the movements of these individuals as they associated to neighboring AFADs. Hence, these results support the hypothesis of a no directionality in the movements of tuna within the Maldivian FAD array. Rather, it seems that the distances between AFADs can explain the rare observed movements. Our results are consistent with Perez et al. (2020) findings. Given that the sub-array in our experiment is denser than the one of Govinden et al. (2013), this could explain why we could observe more movements than in the Govinden et al. (2013) study. But still, the array is not truly acting as a network since there are very few movements observed. Our interpretation is that the average distances between AFADs in the Maldives do not facilitate movements between AFADs, but that specific local conditions could sometimes lead tuna to move between them, as observed for some fish tagged at G AFAD in March 2018. The tagging data from AFAD G in 2018 tend to show that some fish left the AFAD together e.g. some yellowfin tuna seemed to leave the AFAD in one school but did not appear together at the same AFAD. The school most likely split as they left the AFAD and fish moved in different directions.

The high observed speed in our study between two AFADs (skipjack moving from G to H at 1.57 km/h – Table 2) could suggest a more or less directed movement between the two AFADs. Dagorn et al. (2007), using speeds measured during active tracking, considered that a speed faster than 2.5 km/h could correspond to directed movements. However, they worked with tuna that were mainly 70-75 cm FL (mode of their size distribution), while the tagged skipjack individual moving from FAD G to H was 38 cm FL. When considering body lengths, this skipjack moved at an average speed of 1.15 bl/s, which is higher than the 2.5 km/h threshold from Dagorn et al. (2007), which approximately corresponded to 0.96 bl/s (for a 72.5 cm FL tuna). We could then hypothesize that this skipjack swam directly from FAD G to H, which are 47 km apart. This distance is larger than the longest directed movement observed from the same passive tracking protocol by Dagorn et al. (2007) in Oahu (37 km) and is almost four times longer than the maximum orientation distance (10 km) suggested by Girard et al. (2004) from active tracking studies. Girard et al. (2004) also suggested that tuna may use coastal or bathymetric patterns to swim in a straight line.

After Govinden et al. (2013) and our study, it seems that most of the time, tuna in the Maldives only visit one AFAD, but some particular conditions (e.g. those at AFAD G in March 2018) could lead some tuna to stay longer within the AFAD array and visit more AFADs. This result agrees with Robert et al. (2013) who considered that the behaviour of tuna at AFADs was likely dependent upon local conditions around the AFAD at a given time, either environmental factors or social interactions. More globally, our study strongly suggests that the AFADs in the Maldives do not act as a network but as independent attractors.

4.3 Continuous residence time

The residence times measured in our study for small yellowfin and skipjack tuna are compatible with those observed in previous studies either in the Maldives (Govinden et al. 2013) or in other countries (Ohta and Kakuma 2005; Dagorn et al. 2007; Mitsunaga et al. 2012; Robert et al. 2012, 2013; Matsumoto et al. 2014; Rodriguez-Tress et al. 2017). In our study, yellowfin tuna stayed longer at FADs than skipjack tuna, which corresponds to the result by Rodriguez-Tress et al. (2013) who compared residence times of different tuna species within the FAD array in Mauritius. The available knowledge does not allow to explain this specific difference. Possible explanations could be related to different energetic needs or social behaviour for the two species. While the two species are found together around FADs, it is very likely that they form separate schools (see Moreno et al. 2007 and Jauharee et al. 2021? Check references). Different physiological needs between the two species could lead to different foraging behaviours, leading skipjack tuna to more easily loose contact with the FAD during their usual nocturnal excursions (REF) than yellowfin tuna.

A decade ago, Govinden et al. (2013) found unusual short residence times for small yellowfin tuna (mean 0.66 days), questioning whether yellowfin tuna in the Maldives always displayed very short residency patterns to FADs. Our results clearly show that tuna in the Maldives can display variable residence times at FADs, which argues for the role of local environmental factors or social interactions, as advanced by Robert et al. (2013). The distance between FADs, however, can also represent a key factor driving the residence times of tuna at FADs. Pérez et al. (2020) found decreasing FAD residence times for yellowfin tuna when inter-FAD distances increase, by comparing FAD residence times in Hawaii (Robert et al. 2013), Mauritius (Rodriguez-Tress et al. 2017) and the Maldives (Govinden et al. 2013).

5 Conclusion

When combining all acoustic tagging conducted on yellowfin and skipjack tuna around AFADs in the Maldives (Govinden et al. 2013 and this study), for 9 of the 10 tagging replicates, no tagged tuna visited another AFAD. The only tuna that visited several AFADs did not display any clear pattern in directionality within the array. The results seem to suggest that (1) there is no particular directionality in the movements of tuna within the AFAD array, (2) the rather large AFAD distances in the Maldives do not favour movements between AFADs. Each AFAD within the array seems to act as an individual AFAD with no or little influence by other AFADs. Therefore, the AFAD array in the Maldives does not seem to act as a network, i.e. AFADs are poorly connected in terms of tuna inter-FAD movements. Thus, FADs in the Maldives, with large inter-AFAD distances, could be considered to have little effect on the movement behavior of tuna but at the same time, still help fishers to access tuna more easily. Results from this study also provide useful knowledge for management plans of AFADs in other countries or management plans of drifting FADs (purse seine fleets) with the objective of maintaining the role of fishing tools of FADs while minimizing possible effects on movement behavior of tuna, in order to avoid any risk of ecological trap (L Dagorn, Holland, Restrepo, & Moreno, 2013; Hallier & Gaertner, 2008).

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