Characteristics of skipjack tuna fisheries using FAD and non-FAD methods: an important step for fisheries management in The Gulf of Bone and Flores Sea, Indonesia

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Abstract. Skipjack tuna (*Katsuwonus pelamis*) is an important commodity from the global perspective. Skipjack tuna are caught using various fishing methods, either with or without the use of fish aggregating devices (FADs). In this study, we investigated skipjack tuna fishing characteristics using FAD and non-FAD methods. We used fisheries data from five years (2015-2019), including catch per unit effort (CPUE) and fish size, together with several oceanographic parameters around the fishing grounds in the Gulf of Bone and Flores Sea. We used statistical and spatial analyses to evaluate the differences in characteristics between the two fishing methods. The results showed that both the size at capture and the CPUE were significantly different between non-FAD and FAD fisheries. The size (fork length) of skipjack tuna caught using non-FAD methods ranged from 29 to 79 cm (average 55.3±9.4 cm) and was greater than for the FAD fisheries with a range of 18 to 58 cm (average 41.7±7.0 cm). Mean CPUE was also higher (85 fish/setting) for non-FAD compared to FAD fisheries (46 fish/setting). Skipjack tuna captured near non-FAD or free schooling areas showed a stronger association with relatively higher chlorophyll-*a* concentrations and deeper fishing areas than was the case in the FAD locations. This study suggests that to improve the potential catch, the proportion of fishing activities using non-FAD methods should be increased, implying that management of both FAD and non-FAD fisheries is vital for sustainable tuna fisheries and resource conservation.

Key Words: fish aggregating devices, non-FAD fisheries, skipjack tuna, CPUE, fork length, chlorophyll-*a*.

Introduction. Skipjack tuna (*Katsuwonus pelamis*) is prime fisheries commodity with a high economic value in the international market (Grande et al 2014; Miyake et al 2010). About 58.1% of tuna production worldwide is dominated by skipjack tuna (Miyake et al 2010). With an extensive distribution area covering tropical and sub-tropical seas (WCPFC 2017), even the global high-seas industrial fishing fleets exploit this resource (Matsumoto et al 1984). The production of skipjack tuna in relatively restricted sea areas such as the Gulf of Bone and Flores Sea in Indonesia is also of high economic value. Based on the statistical data available, skipjack tuna stocks have not been exploited to the maximum level, or in other words are not overfished (KKP 2017).

Exploitation levels below the theoretical maximum level do not necessarily mean that the fisheries are well run (KKP 2017). Skipjack tuna is considered a resilient species with high productivity and long life span; however, several factors make the tuna catch patterns a cause for concern (Cheung et al 2005; Cheung et al 2009; Marshall et al 2009). Skipjack tuna fisheries, especially in the Gulf of Bone and Flores Sea area, are not fully in accordance with the principles of sustainable fisheries management. This can be seen from data on the length of fish caught in this area, which is very diverse (Fajrianti 2019). In principle, only skipjack tuna that have spawned at least once should be caught; on average, this equates to a fork length (FL) of 50 cm or greater (Benevenuti Soares et al 2019).

Fish aggregating devices (FADs) are increasingly common in pelagic fisheries across Indonesia. Fishing operations in the Gulf of Bone and the Flores Sea tend to use pole and line fishing gear and are often FAD-assisted (Hidayat et al 2019a). However, some fishermen continue to use the classical or traditional methods to find schools of fish by relying on natural signs. In this study we attempted to elucidate the characteristics of FAD-using and non-FAD skipjack tuna fisheries and their relationships with oceanographic conditions in an effort to obtain a reliable quantitative predictive tool to support the implementation of sustainable fishing principles.

Material and Method

Fisheries data collection. Data were collected through direct observation by following skipjack tuna fishing operations in the Gulf of Bone and Flores Sea (Figure 1). The data on pole and line fishing catch were divided into two groups based on the use of fish aggregating devices (FADs) in the capture method (FAD and non-FAD fishing). There were a total of 935 catch data points in the dataset used (377 non-FAD and 558 FAD catches), while the total skipjack tuna catch was 44,710 fish (Table 1).

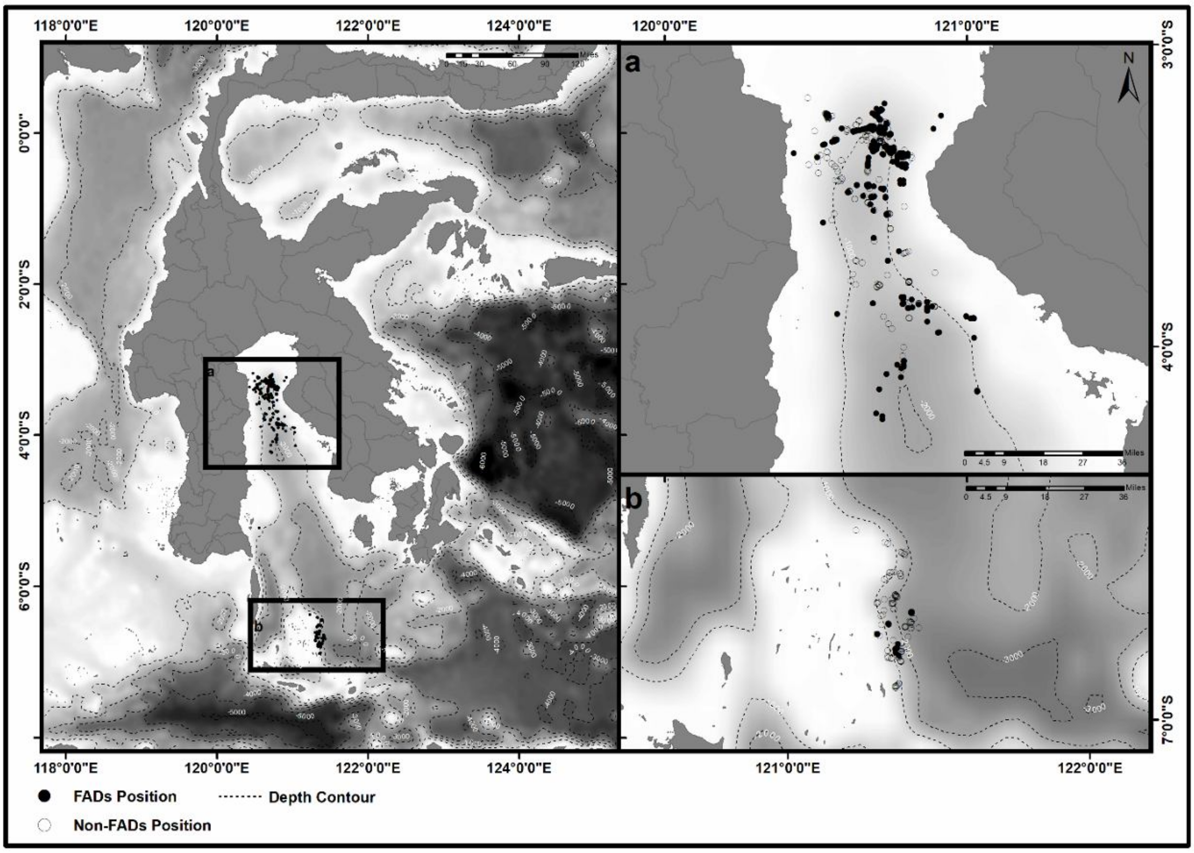

Figure 1. Map of pole and line fishing operations in the Gulf of Bone (a) and Flores Sea (b), South Sulawesi, Indonesia. The fishing operations used two methods: with (filled black circles) and without (unfilled black circles) the use of fish aggregating devices (FADs).

CPUE and length of skipjack tuna collected over a period of five years (Table 1) were used to describe the effect of using FAD or non-FAD fishing patterns. CPUE at time t was calculated using the formula:

$$\text{Catch} = \frac{\text{Catch}_t}{\text{Effort}_t}$$

CPUE is the catch value obtained per fish-catching effort. In this study, the catch data used came from one fishing gear type, so there was no need for ad hoc fishing gear standardization. The fishing effort was skipjack tuna fishing at points in the Gulf of Bone and the Flores Sea.

Table 1

Pole and line data from five years of field observation (2015-2019) in the Gulf of Bone and Flores Sea, South Sulawesi, Indonesia

Year	*Fishing point*	*Fish measured*	*Fork length (cm) (non-FADs)*			*Fork length (cm) (FADs)*		
			Min	Max	$\bar{X}$ (±SD)	Min	Max	$\bar{X}$ (±SD)
2015	65	8208	29	79	51.1 (±12.6)	-	-	-
2016	247	6634	38	71	51.3 (±6.5)	31	55	41.2 (±4.7)
2017	189	13287	48.8	64	56.1 (±3.4)	40.5	46	43.4 (±1.0)
2018	209	8808	39.5	69.5	50.0 (±9.3)	18	58	41.8 (±10.2)
2019	227	7773	43.3	77.6	63.3 (±7.1)	30	54.7	40.1 (±5.6)

Oceanographic data. Comparative data used were several oceanographic data sets: sea surface temperature (SST), chlorophyll-*a* (SSC), net primary productivity (NPP), and depth. These four variables were chosen because they have been shown to significantly impact skipjack tuna distribution, and thus influence total catch, and fork length (FL) (Moresco & Bemvenuti 2006; Zainuddin et al 2017; Hidayat et al 2019b; Putri et al 2019). SST and SSC were obtained from https://oceancolor.gsfc.nasa.gov/; NPP data from http://sites.science.oregonstate.edu/ocean.productivity/; and bathymetric (depth) data from https://www.ngdc.noaa.gov/mgg/global/.

Data analysis. The variables and analysis results were tabulated and/or presented as visual (graphic) comparisons. Statistical tests were used to evaluate the significance of correlations and to what extent the variables can explain the differences in skipjack tuna catch between FAD and non-FAD fishing. Statistical analyses were implemented in SPSS statistic tool version 26.

Results

Oceanographic conditions around FADs and non-FADs. This research used four oceanographic parameters: SST, SSC, NPP, and depth (bathymetry). Oceanographic data variations for these four parameters are presented based on fishing method in Table 2.

Table 2

Variation of oceanography factors

Variable	*n (non-FADs)*	$\bar{X}$ (±SD)	*n (FADs)*	$\bar{X}$ (±SD)
SST (°C)	377	30.31(±0.70)	558	30.46(±0.71)
SSC (mg m^{-3})	377	0.25(±0.08)	558	0.22(±0.11)
Depth (m)	377	1167.03(±546.81)	558	1092(±344.41)
NPP (mgC m^{-2} day^{-1})	377	393.95(±73.54)	558	431.96(±74.69)

The relationship between distribution and fishing effort, and the relationship to catch size (Figure 2) shows that each parameter has some effect, especially on total catch. The values for each parameter producing optimal catch in the FAD fishery ranged from 30.1 to 30.8°C (SST), 0 to 0.15 mg m^{-3} (SSC), 400 to 500 mg C m^{-2} $days^{-1}$ (NPP) at depths of 900 to 1350 m. Meanwhile, the optimum fishing value for Non-FAD only varied for chlorophyll-a with a range of 0.15 to 0.3 mg m^{-3} and net primary productivity in 300 to 400 mg C m^{-2} $days^{-1}$.

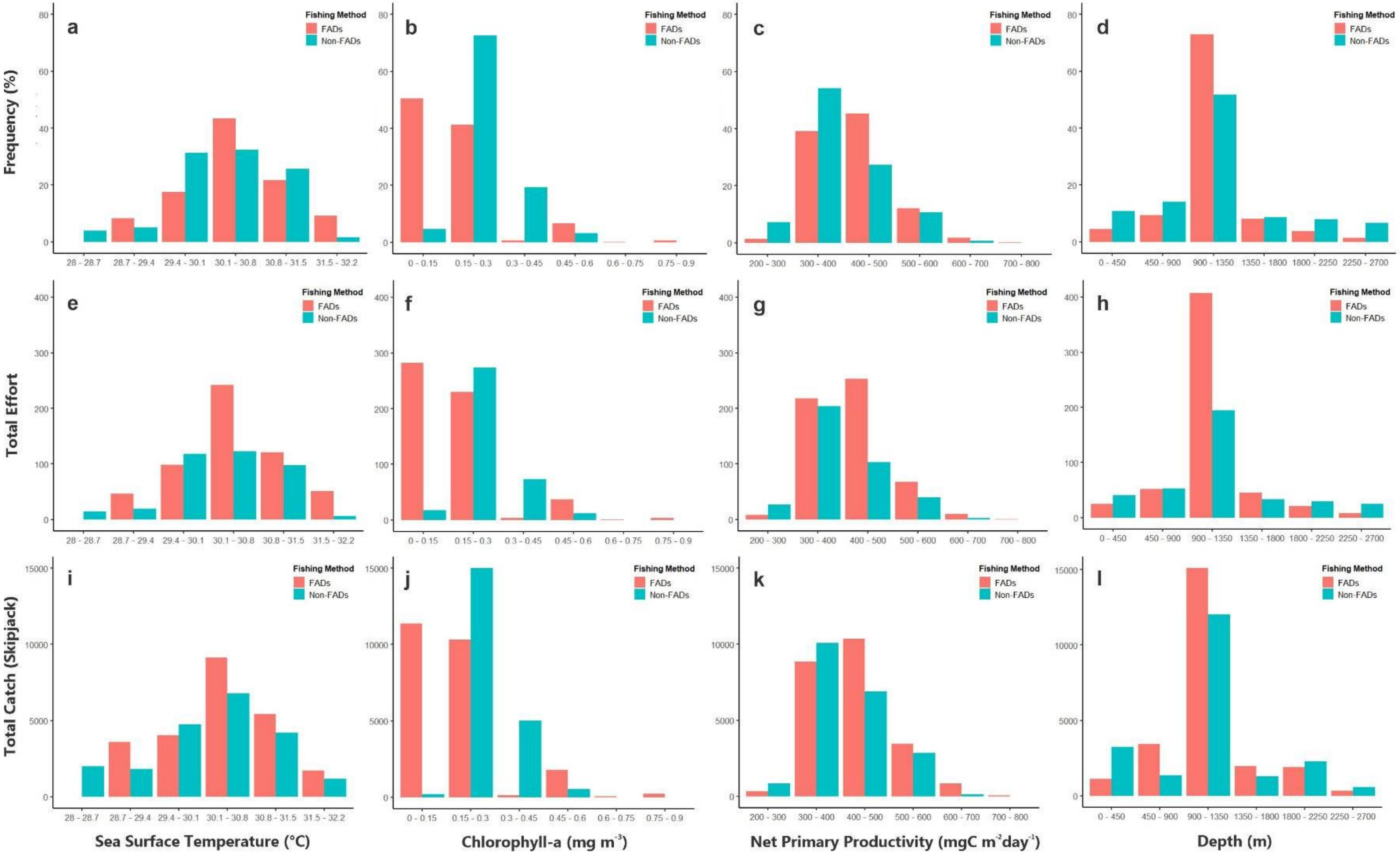

Figure 2. Oceanographic parameter distributions related to total catch and fishing activity of the skipjack tuna. The salmon coloured bars reflect FAD fishing data, while the tosca coloured bars represent non-FAD fishing data. In the top row (a-d), we describe the abundance of the fish in relation to each oceanographic factor (sea surface temperature, chlorophyll-*a*, net primary productivity, and depth); the second row (e-h) presents the total capture effort relative to the four oceanographic factors, and the bottom row (i-l) reports the total catch relative to the four oceanographic factors.

Different fishing methods (FADs and non-FADs). The t-test results in Table 3 show that all parameters analysed differed between the two fishing methods, i.e. using FADs or not. A total of 935 samples were analysed, 558 settings using FADs, and 377 using non-FAD methods. In this test, we used the 95% confidence to determine significance (p-value less than 0.05 or 5 x 10^{-2}). All the factors tested differed significantly, with the highest p-value (0.0184 for water depth) still well below 0.05.

Table 3

Results of t-Tests (FADs vs. non-FADs): two-sample assuming equal variances

Variable	*n (Non-FADs)*	*n (FADs)*	*t*	*Df*	*P-value two-tail*
Catch	377	558	2.18	933	2.98 x 10^{-2}
Fork length (cm)	377	558	25.31	933	5.17 x 10^{-108}
SST (°C)	377	558	-3.13	810	1.82 x 10^{-3}
SSC (mg m^{-3})	377	558	5.04	922	5.72 x 10^{-7}
Depth (m)	377	558	2.36	577	1.84 x 10^{-2}
NPP (mgC m^{-2} day^{-1})	377	558	-7.70	815	3.81 x 10^{-14}

*H1 = p-value < 5 x 10^{-2} (0.05); µ1 = non-FADs; µ2 = FADs.

Skipjack tuna catch comparison using FADs and Non-FAD fishing methods. Based on observations of total fishing effort and catch obtained over five years of observation with data on 21 months of fishing using FADs and 22 months of non-FAD fishing, the catch per unit effort (CPUE) differed between the two fishing methods (Table 4). The mean CPUE for fishing without FADs was 85 fish/setting, substantially higher than the average of 45 fish caught per setting using FADs. This result shows that there are advantages in using fishing methods without FADs in terms of catch effectiveness.

Table 4

CPUE (skipjack tuna per setting) from FAD and Non-FAD fishing methods

	Total catch (number of fish)	*Effort (settings)*	*CPUE (fish/setting)*
Non-FAD	20,790	377	85
FAD	23,920	558	46

Comparison of skipjack tuna size caught by FAD and non-FAD fishing methods. The fork length of skipjack tuna caught in the Gulf of Bone and the Flores Sea recorded in the observation data used in this study was in the range of 18.0-79.0 cm. The length range for skipjack tuna caught using FADs ranged from 18.0-59.0 cm, with a mean of 41.7 cm (SD ±7.0 cm). For fishing without using FADs, the range was 29.0-79.0 cm with a mean of 55.3 cm (SD ±9.4 cm) (Figure 3).

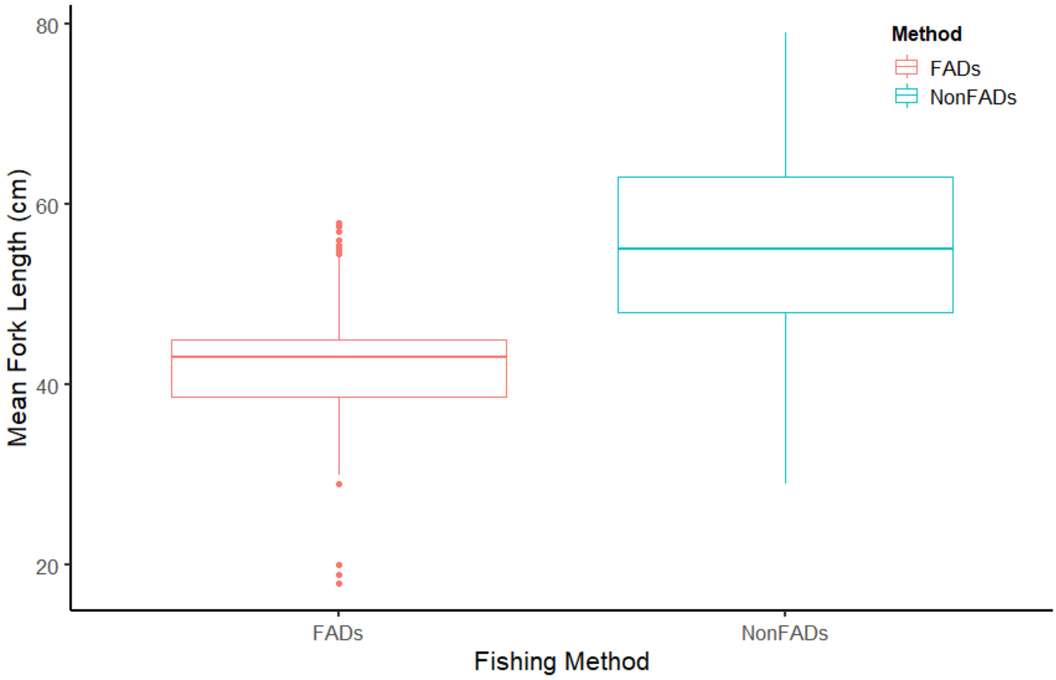

Figure 3. Box plot of skipjack tuna fork length by fishing method (FADs and non-FADs). Boxes show the interquartile range, whiskers indicate 95% confidence interval, dots are outliers.

Discussion. Skipjack tuna habitat is an important topic for study. Some previous studies have described tuna habitats, in both the tropics and sub-tropics. The distribution of skipjack tuna is strongly correlated with oceanographic parameters (Mugo et al 2010; Tseng et al 2010; Wang et al 2016). Not only skipjack tuna but other tuna species also are usually associated with habitat hotspots (Zainuddin et al 2006; Syamsuddin et al 2016; Ashida et al 2020). The natural relationship between skipjack tuna and SST is explained by Andrade & Garcia (1999). They found significant biotic and abiotic factors explaining the relationship between skipjack tuna and SST (Andrade 2003). The optimal temperature of skipjack tuna is not less than a minimum of 18°C in sub-tropical waters such as in Japan (Kiyofuji et al 2019). Whereas skipjack tunas in tropical waters are usually found in waters from 28.5°C to close to 31.5°C (Lehodey et al 1997; Zainuddin et al 2013; Zainuddin et al 2017). In this study, it was found that the optimal temperature for skipjack tuna was in the range of 30.1 to 30.8°C (Figure 2.), although catches were also quite good in the SST ranges of 29.5 to 30.1°C and 30.8 to 31.4°C, especially when using non-FAD fishing methods (Table 1).

With respect to the relation between chlorophyll-*a* and skipjack tuna, this is also an essential relationship to explore. The study of Zainuddin et al (2017) found that skipjack tuna were abundant at a chlorophyll-*a* concentration of 0.2 mg m^{-3}. We found that this species tends to occupy habitat characterised by relatively high chlorophyll-*a* concentrations which may reflect the observed association with fronts (Figure 2 and Table 2). Meanwhile, if chlorophyll-*a* is also connected with additional factors like current velocity, sea surface height (SSH), or the distribution of eddies, these will also be closely related to the productivity of the waters that will identify the likely presence of skipjack tuna (Mugo et al 2010; Nuzula et al 2017; Hidayat & Zainuddin 2019). The depth parameter can also be an important subject for discussion; Matsumoto et al (2014) state that the swimming depths of skipjack tuna are the same during the day and night, and are affected by the layering or vertical distribution of dissolved oxygen (DO). Research by Grande et al (2014) suggested paying attention to higher NPP conditions and the possibility of more prey. These factors can contribute to an increase in energy supply, which will enhance the reproductive process in the face of a high metabolic rate. Our results indicate skipjack prefer deeper waters with relatively high primary production (Figure 2 and Table 2).

Anomalies in environmental factors such as SST and their interactions with reproduction timing, can also affect gametogenesis and fish spawning activity (Wright & Trippel 2009; Lowerre-Barbieri et al 2011). Female skipjack tuna spawning has been observed in waters with SST higher than 23 to 24°C in Western Pacific Ocean (WPO) and Eastern Pacific Ocean (EPO) (Ashida & Horie 2015; Schaefer & Fuller 2019). Skipjack tuna can reach sexual maturity and reproduce at a size of around 50 cm FL (Ashida et al 2008; Ashida et al 2017; Benevenuti Soares et al 2019). The world-wide distribution of skipjack tuna is extensive. Skipjack tuna can be found throughout the year in tropical waters and seasonally in sub-tropical regions (Matsumoto et al 1984; Ashida & Horie 2015). Spawning of other tropical tuna species also appears to occur throughout the year in the tropics, and seasonally in subtropical areas, when SST is above 24°C, especially based on studies of spawning activity by female skipjack tuna, which confirm the occurrence of significant spawning in the tropical East Pacific Ocean (Schaefer 2001). Although in this study we did not explicitly describe the composition of the skipjack tuna sample, the data in Figure 4 were obtained from field observations over five years (2015-2019).

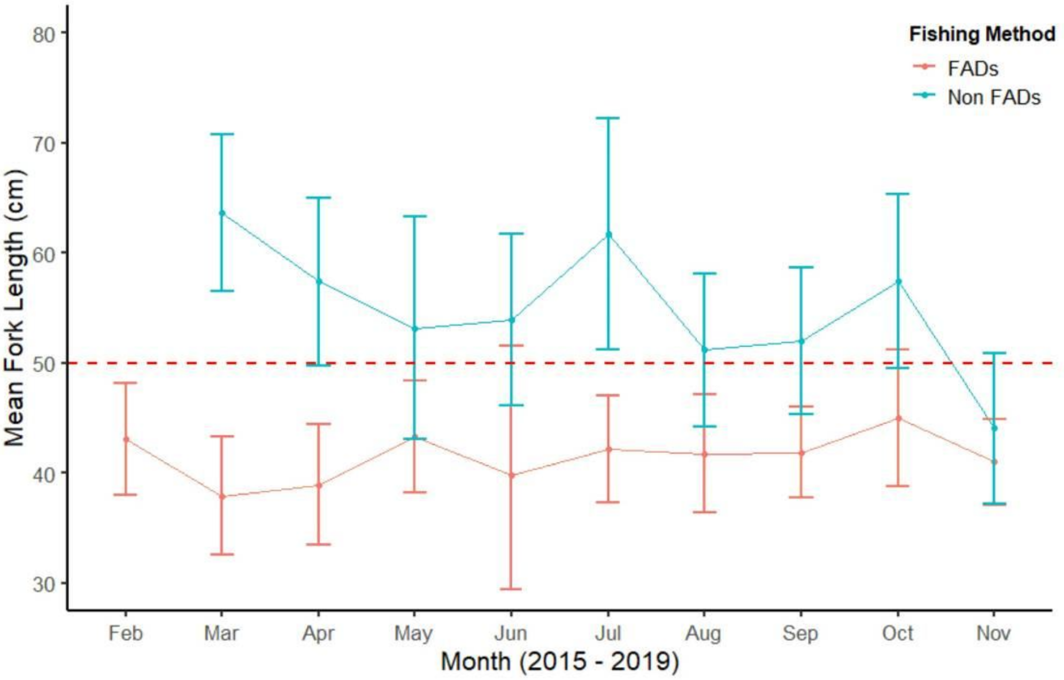

Figure 4. Comparison of the average fork length of skipjack tuna caught using FAD and non-FAD fishing methods (2015-2019). The red line shows the mean size at sexual maturity of skipjack tuna, which is the minimum viable capture size (Benevenuti Soares et al 2019). The error bars show the standard deviation from the mean values (joined by the trend lines) of fork length for the skipjack tuna caught during each month over the five year study period.

The use of FADs is increasingly prevalent. Socio-economic factors are considered when installing FADs: the distance between the FADs installation and fishing area. The quality of the FADs installed is also based on the economic conditions of individual fishermen (Macusi et al 2017a), fishing operation costs and fishing efficiency (Cayre 1991; Macusi et al 2017b), as well as post-fishing facilities to maintain the quality of the fish caught (Macusi et al 2015). The use of FADs in fishing operations aims to maximise or increase the catch. This idea is based on the natural instincts of many pelagic fishes which mean that they tend to be attracted to floating objects (Matsumoto et al 1984; Matsumoto et al 2016). Some studies indeed show relatively high catch volumes using FADs. However, there are also some surprising facts, such as the results reported from this study. With a higher number of capture attempts than non-FADs, the resulting CPUE was much lower than for fishing without FADs (Tables 1, 4). This result indicates that, in practice, catching skipjack tuna in the waters of the Gulf of Bone and Flores Sea by using FADs is not advantageous in terms of the number of fish caught or their size. In the context of sustainable fishing, where the minimum standard should be set at the mean size at first maturity of 50 cm FL, the method of catching fish without FADs is clearly preferable, with a much larger mean size at capture (Figure 3, 4). This suggests that to improve the viable catch and sustainability of the skipjack tuna fisheries, fishing activities should be encouraged to use non-FAD methods. This implies that fisheries management of both FAD and non-FAD approaches is vital for sustainable tuna fisheries and conservation of these valuable fish stocks.

Conclusions. Skipjack tuna fishing using FAD and non-FAD methods differ significantly, in terms of the oceanographic parameters, the total catch volume and the size of the fish caught. Considering both the CPUE and the size of the skipjack tuna caught, fishing without FADs is both more effective and potentially more sustainable than fishing using FADs. As part of a wider approach to sustainable fisheries, we recommend that the use of FADs for the skipjack tuna fisheries in the Gulf of Bone and the Flores Sea should be limited. Furthermore, the use of non-FAD and FAD fishing methods needs to be effectively controlled and managed in this region.

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