Reliance and usage of anchored Fish Aggregating Devices (aFADs) in the Indonesian tuna fisheries

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Abstract

The development of tuna fisheries in the Indian Ocean is closely linked to the use of Fish Aggregating Devices (FADs). While FADs increase fishing efficiency, their sustainability raises concerns. Information on FAD utilization, particularly in Indonesia, remains limited. This study investigates Indonesia's anchored FADs tuna fisheries through a semi-structured survey of 293 tuna fishers using FADs in eight major Indonesian fishing ports in the Indian Ocean. With the exception of one group of handline vessels that use lights to attract tuna and operate at night, all other groups (purse seiners, troll-line, and handline vessels) utilize aFADs in over 90% of their tuna-targeted fishing operations. All aFADs were reported to be privately owned, either by vessel captains, vessel owners, fishing associations, or companies, with aFAD sharing primarily occurring within the same aFAD ownership group. On average, vessels or group of vessels owned between 1 aFAD (hook and line vessels) to 8 aFADs (purse seiners). aFAD arrays reported by respondents, showed an average of 4-5 aFADs within 10 nm of the aFADs they utilize. Long aFAD lifetimes (2-4 years on average) indicated the skilled knowledge of fishers in using and maintaining these devices. Interestingly, the number of aFADs visited by fishing vessels was not correlated with the trip duration and remained relatively low (< 16 aFADs visited for all vessels). This suggests that vessels tend to exploit the same aFAD array throughout their trip, even when it lasts several months. Landing data supported these findings and revealed seasonal patterns in aFAD use, including partial shifts in target species for hook and line vessels. The findings of this study

are expected to provide quantitative insights and contribute to the management of tuna FAD fisheries in Indonesia and the Indian Ocean.

Keywords: Tuna, Anchored FADs, Indonesia, Small scale fisheries, Management

1. Introduction

Tuna and tuna-like species are important commercial species, with a global production reaching 8.3 million metric tonnes in 2022 (FAO, 2024). Tropical tuna species (i.e skipjack tuna/*Katsuwonus pelamis*, yellowfin tuna/*Thunnus albacares* and bigeye tuna/*Thunnus obesus*) account for 94% of the world's major commercial tuna catches, with skipjack tuna and yellowfin tuna being ranked the 3rd and 5th species, respectively, in terms of world fisheries production (FAO, 2024; ISSF, 2024). In the Indian Ocean, the second largest world tuna production after the Pacific Ocean (Heidrich et al., 2022; ISSF, 2024), the stock status of yellowfin tuna and bigeye tuna has been a source of concern, since both species have experienced overfishing (IOTC, 2023d). Despite the last stock assessment of yellowfin tuna provides more optimistic projections, there are still important uncertainties on the data used (IOTC, 2024b). In the Indian Ocean, tropical tuna is targeted by both industrial fisheries, that generally operate in international waters, and small-scale fisheries, that generally operate in the offshore waters of coastal states. Around 38% of the tropical tuna catches in the Indian Ocean originate from artisanal/small-scale fisheries (IOTC, 2023b). Ensuring the sustainable management of all fisheries, both industrial and artisanal ones, is key for rebuilding and maintaining the tuna stocks at healthy levels, as well as for ensuring their essential contribution to the income and food security of many coastal communities.

Many tuna fishers deploy Fish Aggregating Devices (FADs) to facilitate their catches in all oceans. FADs are floating objects, such as buoys or rafts, drifting or anchored at the sea bottom (Higashi, 1994; Itano et al., 2004). The use of FADs in tuna fisheries consists in exploiting the natural behaviour of tropical tuna that form large aggregations around floating objects together with other pelagic species (Fréon & Dagorn, 2000). This behaviour allows fishers to locate more easily the tuna aggregations, thus increasing their catchability. Drifting FADs (dFADs) are mainly exploited by industrial purse seiners in international waters, while anchored FADs (aFADs) are generally used by small-scale fisheries in their Exclusive Economic Zone (EEZ). Currently, around 38% of the world's tropical tuna catches are estimated to originate from FAD fisheries (Murua et al., 2021). However, this percentage is certainly higher, since catch data from artisanal fisheries are often lacking information on FAD use. The use of FADs not only increases the tuna catchability but also leads to higher catches of juvenile yellowfin and bigeye tuna (Dagorn, et al., 2013b; Leroy et al., 2013). This increased fishing mortality of juveniles could significantly affect their stocks (Fonteneau et al., 2013; Griffiths et al., 2019; Leroy et al., 2013; Vasilakopoulos et al., 2012). Furthermore, FADs have also other impacts on the pelagic ecosystem, including habitat changes (since FADs increase the numbers of floating objects in the open ocean) which in turn may alter tuna behaviour and ecology (Capello et al., 2023; Dagorn et al., 2013a; Dupaix et al., 2024b). The Indian Ocean Tuna Commission (IOTC), the fisheries management organization in charge of the sustainable management of tuna fisheries in the Indian Ocean, has managed the use of FADs since 2012 (Res 12/08) (IOTC, 2012). While the main focus of the FAD management was initially on dFADs, the recent resolutions also aim at managing aFADs (Res 23/01) (IOTC, 2023e). Currently, ensuring a sustainable use of FADs figures among the top priority of all tuna regional fisheries management organizations (RFMOs) and to achieve it, scientific advice based on complete and reliable data is required. Data available on dFADs consist in logbook and scientific observers' data, as well as data on FAD positions remotely transmitted from echosounder buoys that instrument the dFADs (IOTC, 2024c). Despite additional data on dFADs is still needed (such as reliable data on the number of dFADs deployed/retrieved (Capello et al., 2023)), with the currently available data it is already possible to assess catches and effort conducted at dFADs, as well as to estimate densities of aFADs to evaluate habitat changes (Dupaix et al., 2021). On the other hand, data availability on aFADs is still more fragmentary (IOTC, 2023c).

Indonesia figures among the largest contributor of the tropical tuna production in the Indian Ocean (IOTC, 2023b). Tuna is caught by a various fishing gears, such as Purse Seine (PS), Longline (LL), Handline (HL), Trolline (TR), Pole and Line (PL), and Gillnet (GN). Tuna fishing in Indonesia developed with the introduction of LL and PS gear by Japan, Taiwan, and Korea in the 1960s and 1970s (McElroy, 1989; Sunoko & Huang, 2014). Together with the Maldives, Indonesia is a leading player in the use of aFADs in the Indian Ocean. The Maldivian FAD array is constituted by around 55 aFADs deployed and maintained by the Government, and used exclusively by the pole and line fisheries which fish around one third of their tuna catches at FADs (Jauharee et al., 2021). In Indonesia, aFADs are mostly deployed directly by the fishers or the fishing companies (Proctor et al., 2019), with no involvement by the government. This different type of management, as well as the large extent of the Indonesian fisheries and its complexity in terms of number of vessels, gears and aFADs, makes the aFAD management more complex. Despite past studies highlighted the importance of aFADs in Indonesia, a clear figure of the use of aFADs in this country is still missing. aFADs have been introduced in tuna fisheries in Indonesia since 1986 (Monintja & Mathews, 2000). The development of the use of aFADs with purse seine, handline, and pole and line fishing gear occurred in 2003–2004 under national policy of tuna revitalisation (Nugroho & Atmaja, 2013). Proctor et al. (2019) estimated between 5,000–10,000 aFADs deployed throughout the Indonesian waters (both in the Indian Ocean and Pacific Ocean), of which a total of 1,909 aFADs have been recently reported to IOTC (IOTC, 2024a). This number may not be representative of the exact number deployed, as companies, vessel owners and captains have not formally updated the positions of their FADs (Widodo, et al., 2023a).

Indonesia has issued regulations on FAD deployment since 2007, beginning with Minister Regulation No. 51/KPTS/IK.250/1/1997 (MoA, 1997) and subsequently updated by Minister Regulation No. 26/PERMEN KP/2014 (MMAF, 2014) and most recently by Minister Regulation No. 18/2021 (MMAF, 2021). The latest regulations cover the registration, deployment, and limitation on the number aFADs for each fishing area (i.e., maximum number of 15 aFADs per vessel in high seas, 3 aFADs per vessel in EEZ). In addition, the Indonesian government has developed fishing logbooks to provide more accurate baseline data for FAD management. However, these regulations are still being implemented, resulting in partial information on the number and position of deployed FADs. This study investigates the extent of aFAD reliance and usage patterns within Indonesian tuna fisheries in the Indian Ocean. Using a combination of landing data and interviews with fishers, this study quantifies the use of aFADs by artisanal and semi-industrial of aFADs tuna fishers that operate in different locations and employ various gears. This study discusses the diverse use of anchored fish aggregating devices in Indonesia, aiming to support effective management actions and ensure their sustainable use in the Indian Ocean.

2. Materials and Methods

2.1. Study Area

The study was conducted in West Sumatra and South Java, Indonesia, where fishing vessels generally operate within two main Indonesian fisheries management areas (FMA) adjacent to the Indian Ocean: FMA 572 (Western of Sumatra) and FMA 573 (Southern of Java, Bali and Nusa Tenggara) (MMAF, 2014). Geomorphologically, these two FMAs are characterized by tropical waters (5°N to 15°S) reaching over 5500 meters depth (Lemenkova, 2020). Eight tuna Fishing Ports (FP) were selected for sampling, including 5 FPs (Nizam Zachman FP, Palabuhanratu FP, Cilacap FP , Sadeng FP and Pondok Dadap FP) in Java and 3 FPs (Sibolga FP, Kutaraja FP, Bungus FP) in Sumatra (Fig. 1). We selected these FPs to ensure the inclusion of major tuna landing ports representing both industrial, semi-industrial and artisanal fisheries, based on prior research and national reports (Proctor, 2003;Proctor et al., 2019;IOTC, 2023a).

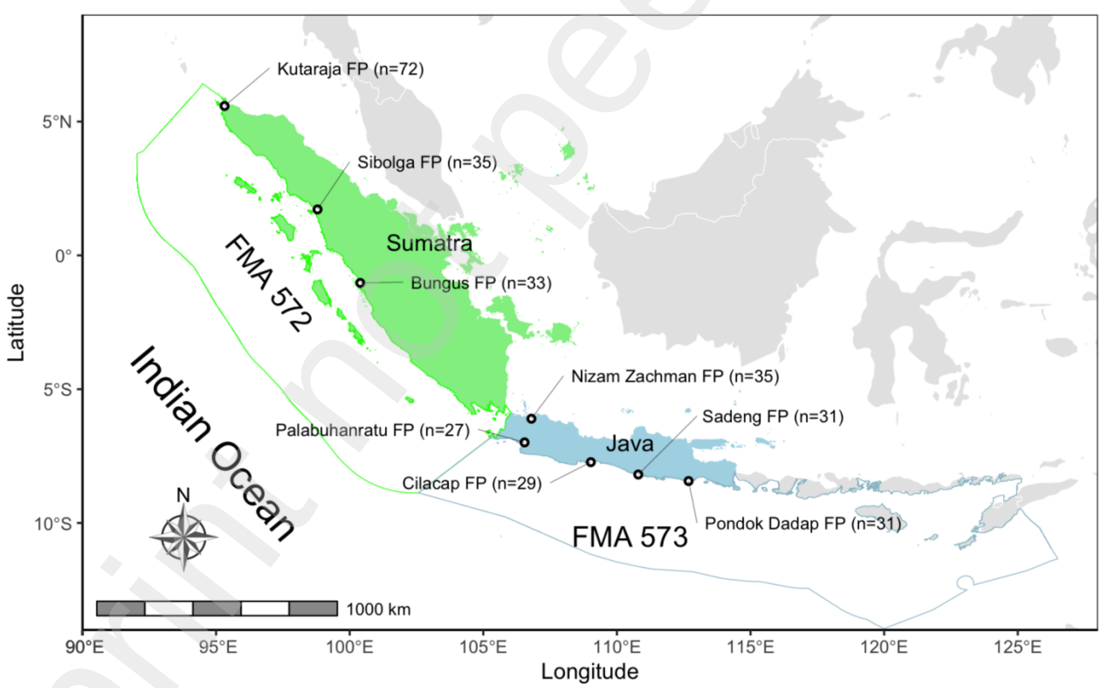

Fig. 1. Study area. Location of the 8 fishing ports (FPs) where the survey was conducted. The green area represents Sumatra, with the green line indicating the boundary of Fisheries Management Area (FMA) 572. The light blue area represents Java, with the light blue line marking the boundary of FMA 573. Numbers of surveyed vessels are reported in each FP.

2.2. Data Collection

2.2.1. Survey data

Survey data were collected using semi-structured questionnaires. The target respondents were experienced captains or vice captains of purse seine, handline and trolline vessels, the main and dominant fishing gears known to target tuna at FADs in the study area (Proctor et al., 2019; Widodo et al., 2023a). We did not interview longline and gillnet tuna fishers since that these fisheries do not use aFADs and tend to avoid them during fishing operations. However, interviews with local field officers, particularly in Cilacap FP, revealed that some vessels using handline gear with FADs were formerly longline vessels still registered with longline licenses. These vessels, that are currently transitioning from longline to handline gear, were included in the survey. A total of 293 respondents were sampled, with their distribution across location and fishing gear detailed in Table S1.

We conducted the interviews in person, each lasting approximately 30 minutes. To ensure effective communication, interviews were conducted in “Bahasa Indonesia”. We scheduled the interviews during the interviewees' free time to facilitate a more relaxed and unhindered conversation. All fishers who participated in this survey gave their verbal consent. The surveys were conducted during two main periods : the first period took place in 2020 in South Java, the second period took place during October 2021- April 2022 in West Sumatra and Nizam Zachman FP (Fig. 1).

The questionnaires consisted in 32 questions divided into 5 main sections: (i) vessel identification and ownership (vessel ID, vessel owner, captain name, owner address, registered port, landing port) (ii) description of vessel (gross tonnage/GT, vessel length, gear license, fishing equipment) (iii) general information on fishing practices (fishing location, average fishing trip duration, average number of fishing trips per year, target species) (iv) aFADs (proportion of aFAD use, number of aFADs owned, lifespan of aFADs, distance to the nearest aFAD, total number of aFADs present within a 10-nautical-miles radius from the aFADs they use) and (v) information on the last fishing trip (days at sea, number of other vessels observed at the same aFADs, number of aFADs visited, number aFADs fished, total catch). In section (iv) the proportion of aFAD use was provided by each respondent as the ratio of fishing operations conducted on aFADs relative to the overall fishing operations targeting tuna. All questions can be found in Supplementary Material 1.

2.2.2. Landing data

For each FP considered in the survey, landing data covering the period 2019-2022 was sourced from the *Information Center of Fishing Port* (Pusat Informasi Pelabuhan Perikanan/PIPP), the official data collection program established by the Directorate General Capture Fisheries (DGCF) - Indonesian Ministry of Marine Affairs and Fisheries. The data consisted of vessel ID, gross tonnage (GT), gear licence, landing port, date of landing, duration of fishing trip (in days), fishing location (Number of the FMA or high seas/international waters), and catch per species (in kg).

2.3. Data analysis

2.3.1. Survey data analysis

Respondents were classified into groups (or *métiers*) based on the vessel gear licence, the fishing grounds and the use of lights during fishing operations from questionnaire data. First, respondents were divided into two groups, considering the gear type reported in their licence: purse seiners (including large pelagic purse seiners and small pelagic purse seiners) and hook and line vessels (handline, troll line, and longline). To further differentiate purse seiners, we divided them according to the fishing zones reported by respondents: purse seiners operating both in the EEZ and in the high seas were gathered into Group 1 (PS-HighS) and purse seiners operating exclusively in the EEZ formed Group 2 (PS-EEZ). Finally, to differentiate hook and line vessels, we considered whether they reported never using lights during fishing operations (Group 3, H&L-NoLi) or, reversely, whether they made use of lights to attract fish (Group 4, H&L-Li). Fig. S1A illustrates the decision tree used for building the four groups.

For each group, descriptive statistics (mean, standard deviation and percentage of respondents), was provided for each answer. Kruskal-Wallis tests were used to test the null hypothesis that responses did not differ across different groups and FPs. Finally, for each group, Pearson correlation coefficients were used to measure linear correlations between the number of aFADs visited, the number of aFADs fished, the number of days at sea, and the catch per day reported for the last trip (calculated by dividing the total reported catch and the fishing trip duration). All statistical analysis was conducted using the R software (CRAN, R version 4.4.1) (R Core Team, 2024).

2.3.2. Landing data analysis

A modified decision tree was used to classify vessels into *métier* groups (Fig. S1B), to account for information not reported in the landing data, such as the use of lights. Several fishing gear licences were identified in the landing data: large pelagic purse seine, small pelagic purse seine, troll line, kite fishing, and handline. First, vessels were divided based on their gear licence, into purse seiners, trolline (which include both trolline and kite fishing licences, since kite fishing is a variation of trolline fishing (Hargiyatno et al., 2013)) and handline vessels. Purse seiners were further categorized based on their fishing grounds (high seas and EEZ) leading to the same categories identified in the survey data (PS-HighS and PS-EEZ). Trolline vessels were categorized as H&L-NoLi. For handline vessels, as a proxy of light usage, we used the fishing port (FP) location, since from the survey data only handline vessels from specific landing sites (Bungus and Cilacap FPs) utilize lights and these were categorized as H&L-Li. Handline vessels from other ports fell in the same category as the trollines (H&L-NoLi). Finally, longline vessels licenced in Cilacap FP were excluded from the analysis to avoid including vessels that still operate as longliners. As this gear completely avoid the anchored FADs during their fishing operation.

To analyze the catch composition of each fishing group, we selected fish species comprising more than 0.5% of total landings in each *métier* group. We classified the remaining species as "others". Furthermore, we grouped fish species into broader categories, including tropical tuna, temperate tuna, neritic tuna, billfish, sharks, other large pelagic fish, small pelagic fish, hairtail, squid and others. Supplementary Material 3 provides a comprehensive list of these species groupings. We analysed monthly catch composition data to investigate seasonal fishing fluctuations, often linked to the seasonal use of FADs.

3. Results

A total of 293 questionnaires were collected, representing 14.1% (range 4.5–46.7%, depending on the FP) of the total number of active vessels at each FP. Respondents were experienced captains or vice captains with an average of 12 ±6 s.d. years of experience on the tuna fishing vessel. The total number of respondents per site shown in Fig 1.

3.1. Fisheries characteristics

Over the 293 surveyed vessels, the majority of the gear licences were handline (42%), followed by small pelagic purse seine (27.3%), large pelagic purse seine (15%), trolline (13.3%), and longline (2.4%) (Fig. S2A). As explained in materials and methods (see section 2.2.1), the longline vessels considered in the survey were vessels with a longline licence that had been converted to handline fishing. All vessels were equipped with GPS. Around 96% of them used underwater echosounder (fish finder) and 59% were also equipped with lights to attract fish. Finally, 43% of all vessels were equipped with GPS, fish finder, lights, vessel monitoring system (VMS). Since these vessels are purse seiners, the majority of them (42%) were also equipped with hydraulic winches (Fig. S2B). 85.7% of the surveyed vessels fished only in the Indonesian EEZ, while the rest fished in both the EEZ and high seas or international waters (Fig. S2C).

Based on the vessel gear licence, the fishing area, and the use of lights during fishing operations, respondents were classified into four groups or *métiers*: Group 1 (PS-HighS, n=44) consists of large and small pelagic purse seiners, which use lights and operate both in the EEZ and high seas. Group 2 (PS-EEZ, n=80) consists of large and small pelagic purse seine vessels that use lights during fishing operations, and only operate in EEZ waters. Group 3 (H&L-NoLi, n=119) are vessels that operate with trolline or handline licences in EEZ waters and do not use lights in fishing operations. Group 4 (H&L-Li, n=50) are vessels with handline and longline licences operating in EEZ waters that use lights during their fishing operations.

The vessel Gross Tonnage (GT) and vessel length or Length Overall (LoA) significantly differed over the *métiers* groups (Kruskall Wallis test, p-value < 0.05, Fig. 2A and 2B). PS-HighS vessels were significantly larger, with average GT and LoA of 161 ± 35 s.d. and 28 ± 2 s.d. meters, respectively. In contrast, PS-EEZ vessels had average GT and LoA of 67 ± 17 s.d. and 22 ± 3 s.d. meters. H&L-NoLi and H&L-Li vessels were the smallest, with average GT and LoA of 12 ± 6 s.d. and 15 ± 2 s.d. meters, and 28 ± 9 s.d. and 17 ± 3 s.d. meters, respectively. Trip durations also significantly differed over the groups (Kruskall Wallis test, p-value < 0.05, Fig. 2C), with PS-HighS vessels showing the longest fishing trips, reaching 156 ± 63 s.d. days. The other *métiers* had significantly shorter fishing trip durations: H&L-Li (31 ± 20 s.d. days), PS-EEZ (14 ± 4 s.d.

days), and H&L-NoLi (13 ± 9 s.d. days). A positive correlation was observed between vessel size (both GT and LoA) and trip duration for all groups, except for H&L-NoLi (Fig. S3). Within each group, vessel size and trip durations significantly differed among FPs, except for vessel length in H&L-Li (Fig. S4).

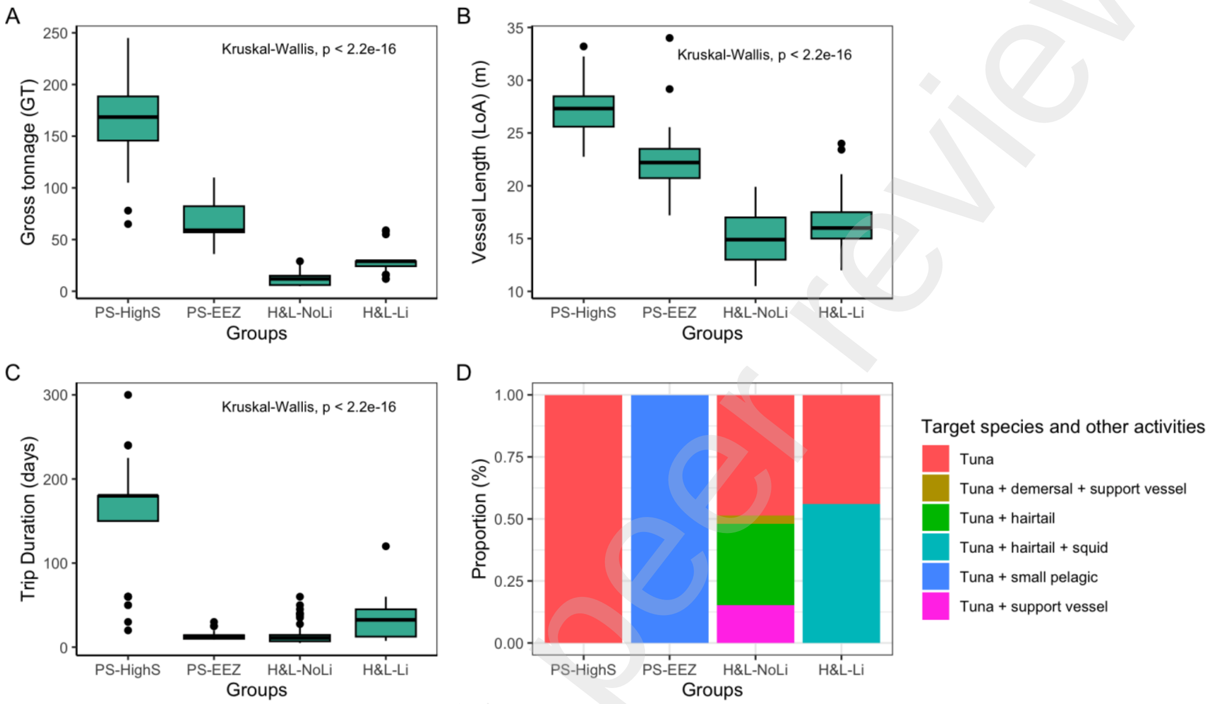

Fig 2. Main characteristics of the surveyed vessels for each *métier* group: Gross Tonnage (GT) (A), Vessel Length (LoA) (B), fishing trip duration (C), target species and other activities (D)

Most vessels reported targeting tuna along with other species, but some also dedicated part of their time as support vessels for other fishers (i.e., supporting aFAD surveillance, providing assistance and logistics support for fishing operations), depending on the group (Fig.2D). PS-HighS targeted tuna all year-round, while PS-EEZ targeted both tuna and small pelagic fish species at the same time. H&L-NoLi vessels exhibited a more varied operational mode, with approximately 49% of them targeting tuna only (primarily from Pondok Dadap FP, Fig. S5), 33% targeting tuna and hairtail: family Trichiuridae (from Palabuhanratu and Sadeng FPs), 15% targeting tuna and serving as support vessels to purse seiners (from Kutaraja FP), and 3% targeting tuna, demersal fish, and serving as support vessels to purse seiners (from Bungus FP). Among H&L-Li vessels (primarily from Bungus FP, Fig. S5), 44% targeted tuna year-round, while the remainder (from Cilacap FP) shifted their focus to hairtail and squid during certain seasons.

3.2. Anchored FADs use

All fishing groups, with the exception of H&L-Li, largely utilized anchored FADs (aFADs) when targeting tuna, with percentages varying from 90.5% to 98.3% (Fig. 3A). Apart from PS-EEZ, significant differences in aFAD usage were found among different FPs (Fig. S6). Notably, the large variability in H&L-Li group of vessels can be explained by the fact that vessels from Cilacap FP utilized aFADs in approximately 31.4% of their tuna fishing operations, while those from Bungus FP did not rely on aFADs.

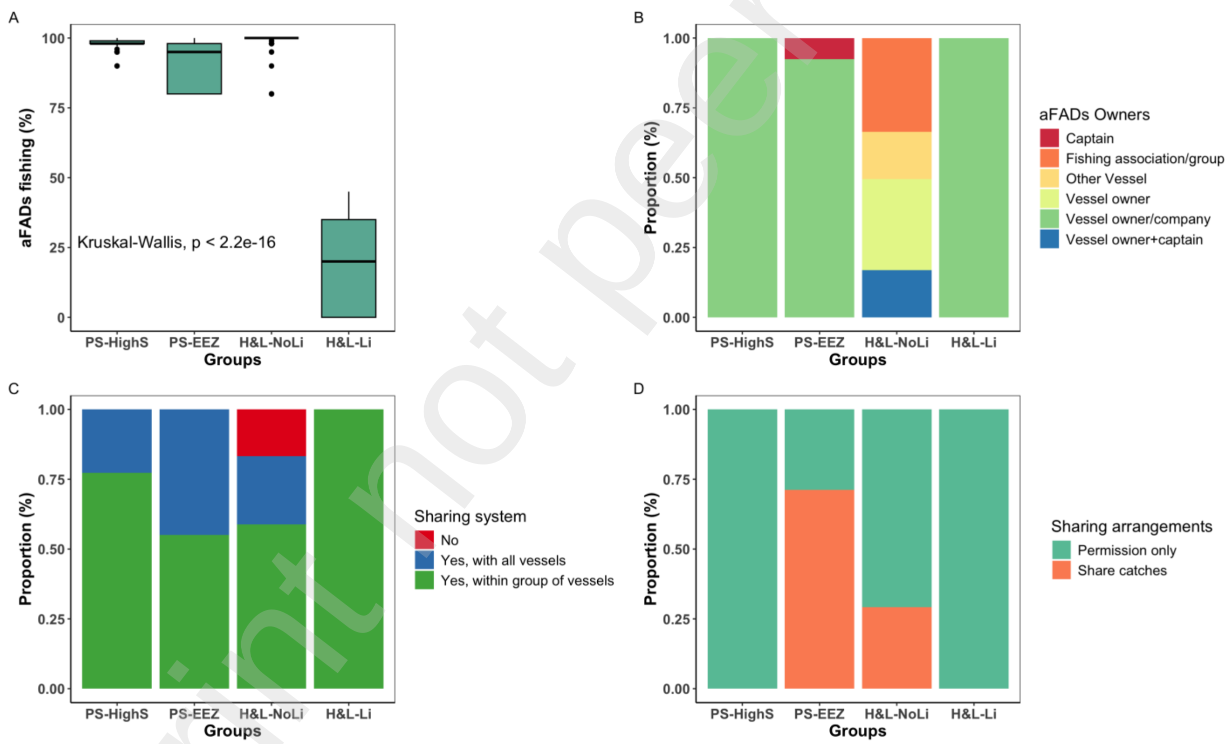

Fig. 3. Proportion of fishing operations conducted at aFADs relative to the total fishing operations when targeting tuna, for each *métier* group (A); aFADs ownership scheme (B); aFADs sharing system (C); and aFADs sharing arrangements (D), based on questionnaire data

The aFAD ownership scheme largely varied among groups (Fig. 3B). All aFADs owned by PS-HighS and H&L-Li belonged to the vessel owner or the vessel company. This is also found for

PS-EEZ, with a minority of aFADs (7%) belonging to the vessel's captain. On the other hand, aFAD ownership among H&L-NoLi vessels was diverse. Approximately 30% of vessels collaborate to deploy aFADs, meaning that their aFADs are owned by a fishing association or group. Another 29% were owned by the vessel owner, while 25% of vessels utilized aFADs owned by other vessels. For the remaining vessels, the captain, who also owns the vessel, was the owner of the aFADs. In the following, we will refer to "owned aFADs" as the aFADs belonging to the vessel's captain, vessel's owner, fishing association or company. Groups also adopt different aFAD sharing systems and arrangements (Fig 3C; Fig 3D). While most respondents from all groups indicated that aFADs are primarily used by vessels within the same ownership group (owner, company, or association), a smaller proportion of vessels—12% for PS-HighS 37% for PS-EEZ, and 26% for H&L-NoLi —allow any vessel to use their own aFADs. Generally, respondents indicated that there are no formal agreements governing aFAD usage. Most fishers (63%) simply seek permission from the aFADs owners. However, some fishers, particularly in the PS-EEZ and H&L-NoLi groups, are required to obtain permission and share a portion of their catch (typically 10-20% of the total catch) with the aFADs owners. Additionally, aFADs owned by individual captains who also own vessels in the H&L-NoLi group are generally not shared with other vessels.

The number of owned aFADs significantly differs over groups of vessels (Fig. 4A). In average, PS-HighS vessels owned the largest number of aFADs (8 aFADs ± 3.5 s.d.), which was higher than PS-EEZ (5 aFADs ± 4 s.d.), H&L-NoLi (2 aFADs ± 1 s.d.), and H&L-Li (1 aFADs ± 0.4 s.d.). However, the number of aFADs owned by PS-EEZ showed the largest variability, with vessels owning up to 25 aFADs. The lifespan of aFADs was also showing a high variability and depended on the group of vessels. PS-HighS, in comparison to other vessels, reported the longest average aFAD lifespan (3.8 years ± 1.4 s.d.), compared to 3.2 years ± 1.2 s.d. on PS-EEZ, 3.2 years ±1.6 s.d. on H&L-NoLi vessels, and 2.6 years ±0.7 s.d. on H&L-Li vessels (Fig. 4B). Except for H&L-Li, variations in the number of owned aFADs and aFAD lifespan exist between landing ports within each *métier*, with significant differences primarily observed in Group PS-HighS (Fig. S7A and S7B).

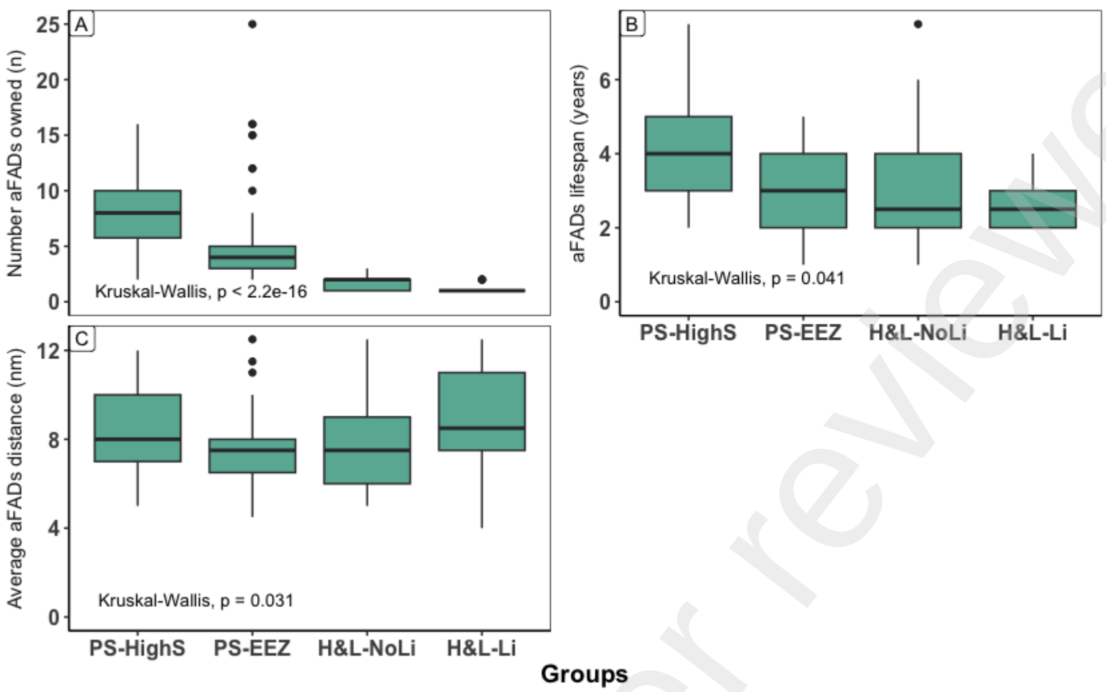

Fig. 4. Distribution of the number of owned aFADs (A); lifespan of aFADs (B); and average distance between aFADs (C); for each *métier* group based on questionnaire data. In (B) and (C), all aFADs are considered, independently on their ownership.

The reported average distance to the nearest aFAD (independently on their ownership) showed lower variability between groups, and only the H&L-NoLi group was significantly different between ports (Fig. 4C; S7C). Overall, the average reported distance to the nearest aFAD was 7.7 nautical miles (nm); the closest distance was 4 nm, and the largest distance was 12.5 nm, signaling relatively dense aFAD arrays. In average, the distance to the closest aFAD used by H&L-Li was larger (8.7 nm ± 2.4 s.d.) when compared to other vessels. Globally, both the distance to the closest aFAD and the number of aFADs within 10 nm show consistent results, with slightly denser aFAD arrays used by groups PS-EEZ compared to groups PS-HighS and H&L-Li vessels.

3.3. aFADs use during the last fishing trip

The information on the last fishing trip was consistent with previous results of the survey. Trip duration was significantly different among groups (Kruskall -Wallis test, p value < 0.05; Table 1).

For PS-HighS, the last fishing trip was much longer than the other groups (Table 1). Almost all fishing operations were carried out at aFADs for PS-HighS, PS-EEZ and H&L-NoLi. On the other hand, all vessels from group H&L-Li conducted fishing operations targeting free swimming tuna schools, operating at night and using lights as attractors. The information on the number of other vessels present at the aFAD of fishing demonstrated that PS-HighS operated exclusively, while PS-EEZ and H&L-NoLi vessels could share the aFAD with up to 2 and 7 different fishing vessels, respectively.

Table 1. Statistical summary of the last fishing trip information for each group. The numbers presented are min-max (mean±s.d.).

Last trip information	**PS-HighS**	**PS-EEZ**	**H&L-NoLi**	**H&L-Li**
Day at sea (days)	47-258 (148±59)	5-37(9±6)	5-70 (13±12)	6-79 (30±21)
Proportion fishing at aFADs (%)	93-98 (98.84±1.75)	80-100 (99.75±2.23)	67-100 (99.64±3.15)	0
Number of other vessels at the same aFAD (n)	0-1(0.5±0.5)	1-2(1±0.11)	0-7 (3±1.52)	0
Number of different aFADs visited (n)	6-16(11±2.6)	2-11(5±1.9)	1-15(5±3.7)	0
Number of different aFADs fished (n)	3-14(8±2.97)	1-8(3±1.5)	1-11(3±2.26)	0
Catch per trip (kg)	38,100-300,000 (125,597±51,717)	1,820-36,000 (9,489±6,780)	315±6,913 (1,691±1,264)	110-17,900 (4,245±4,203)
Catch per day (kg)	279-2,307 (1,073±412)	406-5,375 (1,461±918)	33-1,289 (206±164)	8-416 (151±97)

Group PS-HighS visited in average a larger number of different aFADs compared to the other groups (Table 1). There was no correlation between the number of different aFADs visited during the last fishing trip and the number of aFADs owned by the vessel (or its company/association), the number of aFADs visited being often higher than the number of aFADs owned (Fig. 5A), confirming that vessels also exploit aFADs that do not belong to them. Interestingly, there was no correlation between the number of days at sea and the number of different aFADs visited for PS-HighS (Pearson correlation test, $R^2 = 0.0099$, $p = 0.52$), while for the PS-EEZ and H&L-NoLi there was a weak correlation ($R^2 = 0.12$, $p=0.002$ and $R^2 = 0.19$, $p<0.001$, respectively) (Fig. 5B), signaling that vessels return to the same aFAD, even if their fishing trip can be very long such as for PS-HighS. For all groups, the number of different fished aFADs (i.e., the visited aFADs where fishing operations were successful) was lower than the number of different visited aFADs for all groups, i.e., fishing did not occur on all different visited aFADs (Table 1), and a linear correlation was found between the two quantities for all groups (Fig. 5C). However, for H&L-NoLi, the number of aFADs fished showed a larger variability, particularly when large numbers of aFADs were visited, and lower correlations were found.

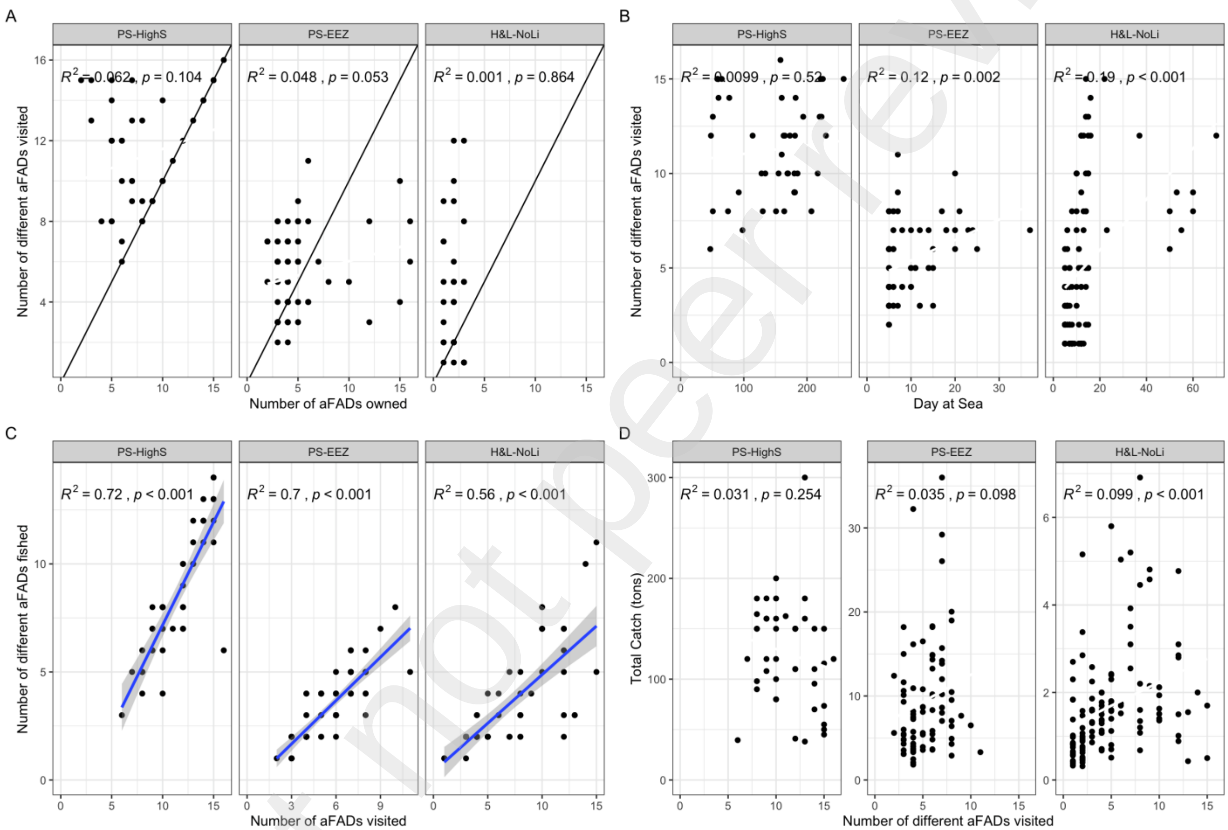

Fig. 5. Exploitation of aFADs during the last fishing trip. Correlation between: number of different aFADs visited and number of aFADs owned (A), number of different aFADs visited and number of days at sea (B), number of different aFADs fished and visited (C), total catch and number of different aFADs visited (D), for each *métier* group. The black line in (A) indicates $y=x$ (number of different aFADs visited equal to the number of aFADs owned). The blue line in (C) denotes the linear regression.

Accordingly, the H&L-NoLi showed lower success rates (56%) at aFADS than the other groups (PS-HighS: 72%; PS-EEZ: 70%). Although PS-HighS vessels caught more fish per trip due to their longer time at sea, PS-EEZ vessels had higher daily catches compared to other groups (Table 1). Globally, the total catch and the number of different aFADs visited during the last fishing trip showed no correlation (Fig. 5D).

3.4. Catch Composition and Seasonality

The landing data demonstrate that the three major tropical tuna species (*Thunnus albacares, T. obesus,* and *Katsuwonus pelamis*) constituted the majority of catches for all groups: 89% for PS-HighS, 74% for PS-EEZ, 79% for H&L-NoLi, and 66% for H&L-Li (Fig. 6; Fig. S8). Consistently with the survey data, small pelagic fish were also targeted, especially by PS-EEZ, contributing about 20% of their catch. However, PS-HighS and H&L-NoLi (particularly in the Bungus and Kutaraja FPs) also caught small pelagic fish in smaller quantities (Fig. S9). Beyond tuna, other species were caught: hairtail (1-6%) in H&L-NoLi and H&L-Li, primarily in Palabuhanratu, Cilacap, and Sadeng FPs, and squid (up to 19%) in H&L-Li in Cilacap FP. Temperate tuna (*Thunnus alalunga*) was also caught by H&L-NoLi, specifically in Pondok Dadap FP.

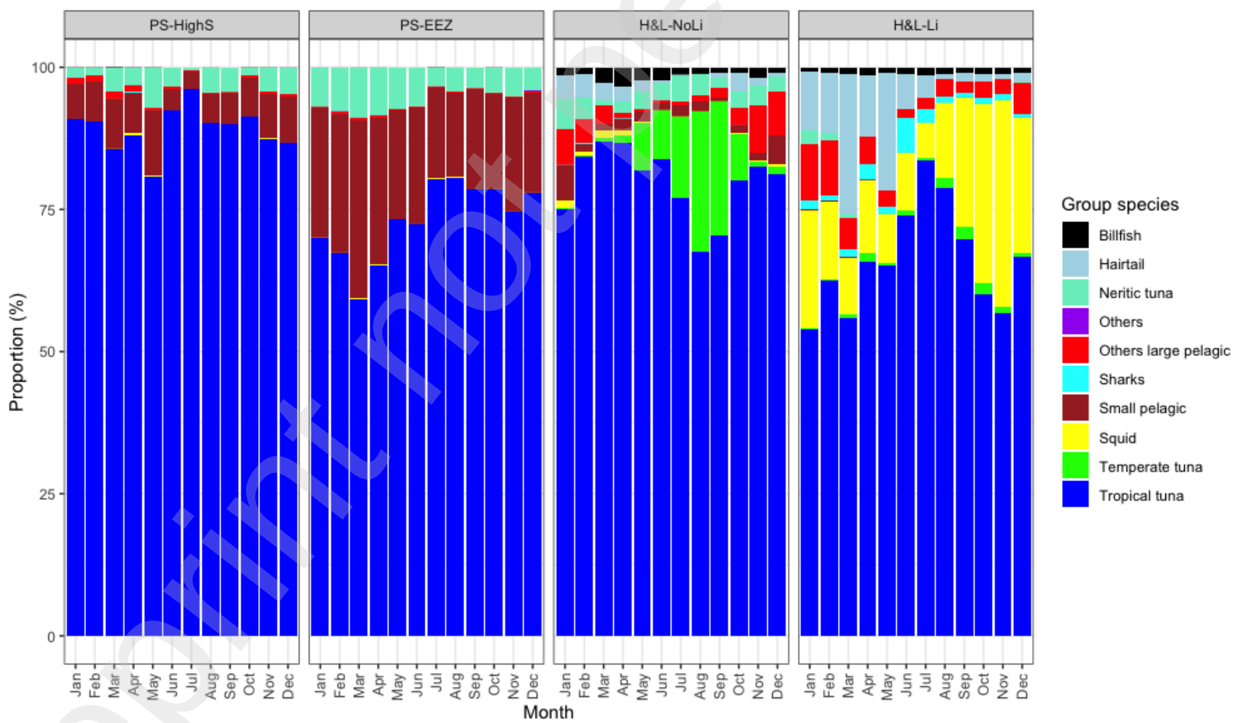

Fig. 6. Monthly catch composition of each group obtained from landing data.

Catch composition showed seasonal patterns, with all groups except H&L-NoLi exhibiting a higher proportion of tropical tuna during June–October (Fig. 6). Conversely, the H&L-NoLi group primarily landed hairtails from January to May and again from October to December, while caught important amounts of temperate tuna between May and October. Similarly, the H&L-Li group harvested an important quantity of hairtails from January to August. Moreover, this group also landed a substantial amount of squid, particularly from September to December. These patterns suggest that during these months, fishers adjust their fishing strategies to target species away from the aFADs.

4. Discussion

4.1. Diversity of the Indonesian tuna fisheries

Indonesian fisheries present a complex landscape, encompassing numerous types of fishing gears and a large diversity of vessel types and fishing practices (Jaya et al., 2022). Fishing gear licence and vessel type are often used as the main criteria to categorize fishery types (Smith & Basurto, 2019). However, vessels of the same length and/or with the same gear licence can present different fishing strategies, and conversely, a single fishery may be associated with multiple gear licences. To simplify this complexity and identify appropriate groups of vessels allowing to assess aFAD use, this study categorized them into groups (or *métiers*) considering ad-hoc decision trees that not only encompass the gear licence, but also other criteria such as the fishing grounds or the use of lights. *Métier* analysis is widely used in fisheries, particularly in the European Union, where it is essential for fleet-based management, especially in mixed fisheries (Castro et al., 2011; Ulrich et al., 2012). By grouping vessels into more homogeneous *métiers*, decision-makers can better evaluate management policies (Parsa et al., 2020). This approach has led to the identification of four distinct groups (PS-HighS, PS-EEZ, H&L-NoLi, and H&L-Li) that utilize aFADs providing a simplified classification to investigate FAD use by Indonesian fisheries.

The first group, PS-HighS, represents purse seiners with an average length (LoA) of 28 ± 2s.d. meters (with the range between 22.75-33.20 meters, Fig 2B) that operate both in the high seas and within the Indonesian EEZ. Indonesian purse seiners are unique in their construction, made of wood and equipped with relatively basic technology such as small power blocks and fish finders

(Murua et al., 2018). Their expansion in the Indian Ocean coincided with the proliferation of aFADs in 2002-2003 (Atmaja & Sadhotomo, 2012; Moreno & Herrera, 2013). Overfishing in the Java Sea drove this shift, leading many vessels to relocate to the Indian Ocean (Atmaja & Sadhotomo, 2012; Nugroho & Atmaja, 2013). Despite these vessels are classified as industrial (Moreno & Herrera, 2013), they are significantly smaller than those found in other parts of the Indian Ocean (Fig. S10). Currently, there are 126 Indonesian industrial purse seine vessels, each with an average capacity ranging from 78 to 200 GT, contributing a total of 60,465 tons of tuna reported to the IOTC in 2021 (IOTC, 2023a). In contrast, the European Union (EU) has a significantly smaller purse seine fleet, consisting of only 26 active vessels. However, these EU vessels have an average capacity exceeding 800 GT, enabling them to harvest over 200,000 tons of tuna in 2022 (Marot, 2023). This stark contrast in fleet size, capacity, and production capability complicates direct comparisons between the two fisheries.

Vessels that do not belong to the PS-HighS category are typically classified as artisanal or semi-industrial fisheries, generally wooden vessels measuring in average length 22 ± 3 s.d meters (Fig 2B). The PS-EEZ fishery, targeting small pelagics and neritic tunas, emerged in Aceh waters (including Kutaraja-Lampulo FP) in the 1970s and subsequently in North Sumatra (Sibolga FP) and Padang (Bungus FP) in 1984 (Marcille et al., 1984; Merta, 1986). These fisheries primarily target fish schools in shallow waters through daily fishing trips. The early '80s marked the introduction of aFADs into the purse seine fishery in western Sumatra, since, in addition to night-time light-assisted fishing, purse seine fishers also began using aFADs (Merta, 1986). Additionally, in term of size purse seine vessels becomes larger, increasing from 30 gross tons (GT) in the 1990s to 80 GT by 2003. This expansion coincided with a shift toward tuna fishing, characterized by the use of larger mesh nets and an extension of fishing activities to the western Mentawai Islands, offshore West Sumatra (Hariati, 2005; Hariati & Sadhotomo, 2007), and farther in the high seas. The number of active PS-EEZ vessels has steadily increased, rising from approximately recorded as 150 vessels in Kutaraja-Aceh and Sibolga during the 1980s (Hariati, 2005; Marcille et al., 1984) to around 300 small pelagic purse seine vessels currently reported in Kutaraja and Sibolga fishing ports.

Another small-scale fishery that expanded in the last decades corresponds to the H&L-NoLi group. Troll line vessels reportedly grew from approximately 500 vessels in the 1970s to 972 by the 2000s in Western Sumatra (Marcille et al., 1984; Proctor et al., 2003). These vessels, typically less than 15 meters in length, initially operated farther from their landing ports and spent more days at sea compared to PS-EEZ (Merta, 1986). It is unclear exactly when this fishery began using aFADs. However, given the development of purse seiners targeting tuna and employing aFADs (Hariati, 2005), it is likely that these fishers adopted aFAD fishing around the same time. In the southern waters of Java, troll line vessels were introduced at Pondok Dadap FP in 1997 along with the introduction of aFADs by local authorities (Nurdin & Nugraha, 2008). This development was further accelerated by the migration of South Sulawesi fishers (e.g., from Sinjai) to various locations, including Pondok Dadap and Palabuhanratu FP, during the years 2002-2003 (Merta et al., 2006; Nurdin & Nugraha, 2008). These fishers contributed to the developments of aFADs in this area. The proliferation of aFADs in southern Java prompted a shift in fishing gear and methods, moving from gillnets to hook and line fishing (Merta et al., 2006). Currently, many H&L-NoLi vessels operating in the waters of western Sumatra and southern Java, which initially targeted tuna, have transitioned to supporting purse seine vessels and targeting other fish resources, such as hairtail (Fig. 2D).

Changes in fishing gears add an additional complexity to the picture. Some of the vessels that have been grouped in the H&L-Li *métier*, that use light for targeting tuna, were originally designed for longline fishing but have been adapted for handline fishing, even if they still continue to operate under the longline fishing licence. Moreover, hook and line vessels (H&L-NoLi & H&L-Li) are known to employ a variety of gears and target different species (Anggawangsa et al., 2021; Hargiyatno et al., 2013). This emerges from both the survey and landing data analyses (Fig. 2D and 6), which demonstrate shifts in target species and catch composition, corresponding to changes in gear type. The high proportion of squid and hairtail caught by H&L-Li vessels is not consistent with the handline/troll-line gear licences and demonstrates the multi-faceted nature of these small-scale vessels, capable of adopting different fishing strategies and gears. Economic factors significantly influence the choice of fishing gear and target species (Carvalho et al., 2011; Young et al., 2019). In this respect, the higher market value of squid and hairtail, compared to tuna, constitutes an incentive to target these species.

Another complexity arises from the large spatial spread of the Indonesian tuna fisheries, distributed over numerous fishing ports along the coast facing FMAs 572 and 573. This geographical spread presents a significant challenge for data collection and fisheries management (Pita et al., 2019). To manage this extensive area, the Indonesian fisheries management system is structured with both central and local authorities. The central authority, which operates under the Ministry of Marine Affair and Fisheries, oversees vessels greater than 30 GT and collects landing data at major fishing ports. Local authorities, which are organized at the district and provincial levels, are responsible for managing smaller vessels and gathering landing data at small or large fishing ports, depending on the location. Fisheries extension units, under the central authority, are also deployed at the local level to collect landing data from smaller fishing communities. The multiple layers of management require careful coordination and synchronization to ensure a comprehensive data collection. Covering a large number of landing sites, as well as the specificities of their fishing fleets, was also one of the main challenges of this study. The selected ports for this study, located in western Sumatra and southern Java, correspond to the primary landing sites identified in the national fisheries database system, accounting for approximately 78% of tuna landings in the Indian Ocean region. However, tuna fishers using aFADs are also active in southern Bali (with seasonal landings) and Nusa Tenggara. Further research in these regions would provide a more comprehensive understanding of Indonesia's aFAD-based artisanal tuna fisheries in the Indian Ocean.

4.2. aFADs use

4.2.1. How much do the Indonesian tuna fishers rely on aFADs?

This study revealed that most Indonesian fishers (except for those using gillnets and longlines, which are known not to rely on FADs) largely rely on aFADs when targeting tropical tuna. Previous studies already underlined that Indonesian tuna fishers made use of aFADs, including purse seine, pole and line, handline, and troll line fishing (Proctor et al., 2019; Widodo et al., 2023a, Beverly et al. 2012). However, the exact amount of tuna production attributable to aFAD fisheries remained unclear. Furthermore, the lack of detailed monitoring data, particularly from logbooks and observer programs, hinders our ability to accurately describe fishing activities involving aFADs. This information is crucial for developing effective tuna fisheries management strategies, especially in assessing the impact of aFAD usage. Therefore, this approach offers a preliminary estimate of the contribution of aFAD-based tuna fisheries. Our analysis revealed that for three of the four *métiers* that were surveyed, fishers make use of aFADs during more than 90% of their fishing operations when targeting tuna. Only the H&L-Li vessels in Bungus and Cilacap FPs make a relatively low use of aFADs (below 30%), since they employ lights and drifting vessels for attracting tuna during fishing operations conducted at nightime. This large-scale use of aFADs in the Indonesian tuna fishery poses a significant challenge to its management. Banning the use of aFADs, even temporarily (as implemented in the WCPFC region (WCPFC, 2023)), would have a substantial impact on the Indonesian fishing industry, as well as on the income and well-being of many artisanal fishers.

In addition to aFADs, some vessels may also utilize other floating objects, such as dFADs and natural logs, a practice that has been found in other aFAD fisheries, such as in the Maldives (Jauharee et al. 2021). Ocean currents sometimes incidentally carry dFADs from the western Indian Ocean to waters west of Sumatra (Imzilen et al., 2019). Furthermore, natural logs of terrestrial origin can also be found during specific months (Dupaix, et al., 2024a). Further studies should quantify at which extent these other types of floating objects are utilized by the Indonesian fishers.

Due to the unavailability of data, it is not possible to precisely describe monthly aFAD utilization. However, based on the *métier* groups that relied heavily on FADs (PS-HighS, PS-EEZ, and H&L-NoLi), it can be inferred that aFAD usage in recent year is likely to be higher between June and August, as indicated by the peak in tuna catch composition during these months (Fig. 6). This is further supported by the high proportion of hairtail and squid caught in the hook and line fishery at the beginning and end of the year (Fig. 6). Fishing operations targeting hairtail and squid were primarily conducted independently of aFADs, suggesting a reduced reliance on aFADs during these periods. This observation aligns with previous research demonstrating that the peak season for hairtail catch in this fishery occurs from October to March (Wijopriono & Akbar, 2017). However, these findings provide only a preliminary indication of monthly aFADs utilization patterns. Accurate data on aFADs utilization can only be obtained through detailed information on fishing operations, which requires improvements in both fishing logbook and observer data collection systems.

4.2.2. aFAD ownership and sharing

Consistently with previous findings (Proctor et al., 2019), our survey confirms that Indonesian aFADs are privately owned by vessel owners, companies, fishing associations, or captains who also own vessels. This ownership structure is similar to that of aFADs in the Philippines (Dickson & Natividad, 2000; Macusi et al., 2015). Compared to previous findings, a novel ownership scheme has emerged in this study, where aFADs are owned by the captain but not the vessel owner, particularly in the case of purse seiners. This scheme allows captains to maintain ownership of their aFADs even when they move to others vessels, making the aFAD-vessel association more dynamic. The private ownership system adopted in Indonesia represents clear management challenges compared to government-owned aFADs such as those in the Maldives (Jauharee et al., 2021) or Mauritius (Appadoo et al., 2023). Private owners often feel empowered to build, install, and maintain aFADs, as they bear all associated costs. On the other hand, due to this private aFAD status, they may hesitate to report the presence of their aFADs. Competition with other boat owners leads them to keep their fishing locations, particularly the locations of their aFADs, confidential. However, this challenge is not insurmountable. The Indonesian government, in collaboration with the NGO "Masyarakat dan Perikanan Indonesia/MDPI," has successfully registered aFADs in North Maluku waters (MDPI, 2024).

The collaboration in aFADs utilization between purse seiners and handliners is evident from the sharing system scheme (Fig. 3B), the number of vessels operating at the same aFADs (Table 1), and the small-pelagic species found in the catch composition of handliners (group H&L-NoLi, Fig. 6). This practice has long been established in the Philippines (Dickson & Natividad, 2000). In Indonesia, initial conflicts over aFADs usage evolved into collaborative partnerships (Anggawangsa et al., 2023; Proctor et al., 2019). PS-EEZ vessel owners began employing H&L-NoLi as support vessels, benefiting from the following services: (1) tuna location reporting: information of the presence of tuna nearby aFADs; (2) aFAD protection: preventing other vessels from using their own aFADs; (3) assistance with fishing operations: supporting purse-seine fishing activities; and (4) logistical support: the provision of supplies and services to vessels engaged with purse seiners. H&L-NoLi fishers receive a share of the catch in exchange for these services. This practice raises concerns about potential discrepancies between reported catches and the fishing gear used, as well as the potential for illegal transhipment at sea.

4.2.3. aFAD lifetime

Despite the management challenges intrinsic to a private system, the maintenance and use of aFADs in Indonesia appear to be very effective for ensuring long aFAD lifetimes. To prevent the aFADs from breaking or being lost, fishermen always bring spare materials and repair the aFADs during each fishing operation (Widodo, et al., 2023a). The average lifespan of aFADs in the EEZ (used by PS-EEZ and H&L-NoLi vessels) ranges from 2 to 4 years, while those in the high seas (used by PS-HighS) last 3 to 5 years (Fig 4B). Indonesian aFADs tend to have a longer lifespan than those in other areas, likely due to the materials used (Beverly et al., 2012; Murua et al., 2018; Proctor et al., 2019; Shainee & Leira, 2011). Indonesian aFADs are made of bamboo, metal pontoon, or cork, synthetic ropes with diameters of 2.5 to 4.0 inches, coconut leaves as attractants, and concrete blocks as ballast (Proctor et al., 2019). Apart from the materials used, the potential for aFADs to be lost is increased by competition for utilization due to overlapping fishing grounds between purse seine and longline vessels, as aFADs can interfere with longline operations (ISSF, 2019).

One of the significant negative impacts of FADs is the increase of marine debris due to their loss or abandonment, which can be a source of concern for both marine pollution (depending on their material) and coastal habitat damages (Gilman et al., 2021; Imzilen et al., 2022). In this respect, the longer lifespan of the Indonesian aFADs potentially indicates that their environmental impacts (as marine debris) are minor compared to dFADs, which can be lost only few months after deployment (Lau-Medrano et al., 2024; Zudaire et al., 2023) .

4.2.4. aFAD density

aFADs owned by individual vessels or groups of vessels (companies, vessel owners, or associations) typically range from 1 to 15 units, with an average of 1 to 3 aFADs for hook-and-line vessels and 2 to 8 aFADs for purse seiners. While this number is much lower than the IOTC limit of 250 operational buoys per vessel adopted for the dFADs fishery (IOTC, 2024c), high aFAD densities can still emerge, depending on the number of vessels. To address this potential for high density, the Indonesian government has established its own limits on aFAD deployment per vessel, especially for purse seines: a maximum of 3 in EEZ waters and 15 in high seas waters (MMAF, 2021).

Although the exact number of aFADs remains uncertain, information on the inter-FADs distance can already provide valuable insights. Figure 4C shows that inter-FAD distances in Indonesian (Western Sumatra and Southern Java) waters range from 4 to 12.5 nm , averaging 7.7 nm (around 7 to 23 km, averaging 14.4 km), consistent with previous studies reporting average distances under 10 nm (ISSF, 2019; Proctor et al., 2019). This distance is similar to the distance between aFADs in Hawaiian waters (15 km) but greater than the distances between aFADs in Philippine (5.5 km) and Mauritius (6 km). It is also lower than the distance between aFADs in the Guadeloupe (8–33 km) and Maldives (38 km) and dFADs in the western Indian Ocean (the distance can reach 37 km) (see Table 2 and references therein). High FAD densities, resulting from closer inter-FAD distances, can influence tuna behavior, leading to increased residence time spent around denser FAD arrays (Pérez et al., 2020). This, in turn, may increase their vulnerability to fishing, particularly for juvenile yellowfin and bigeye tuna (Dupaix et al., 2024b). Additionally, high FAD densities may have other potential impacts on tuna, such as lowering their fitness according to the "ecological trap" hypothesis (Dupaix et al., 2024b; Marsac et al., 2000) and leading to school fragmentation (Capello et al., 2022; Sempo et al., 2013), although these effects have not been demonstrated and require further investigation.

Table 2. Average inter-FADs distance (km) in different FAD arrays.

No	Location	FADs types	Inter FADs distance (km)		Source
			average	range	
1	Indonesia, Bone Bay	aFADs	4.9	0.8-33	Widodo et al. (2023b)
2	Philippines	aFADs	5.5	-	Macusi et al. (2015)
3	Mauritius	aFADs	6	2-14	Pérez et al. (2020); Rodriguez-Tress et al., (2017)
4	Indonesia, all area	aFADs	< 9	-	Proctor et al. (2019)

5	Indonesia, Moluccas Sea	aFADs	9.4	0.4-33	
6	Indonesia, Banda Seas	aFADs	10.7	0.4-40	Widodo et al. (2023b)
7	Western Pacific Ocean	dFADs	-	6-22	Escalle et al. (2020)
8	Indonesia, Western Sumatra and Southern Java	aFADs	14.4	7-23	Current study
9	Hawaii	aFADs	15	7-31	Dagorn et al. (2007); Pérez et al. (2020)
10	Guadeloupe	aFADs	-	8-33	Guyader et al. (2017)
11	Western Indian Ocean	dFADs	37	-	Dupaix et al. (2021)
12	Maldives	aFADs	38	25-48	Jauharee et al. (2021); Pérez et al. (2020)

Improvement of logbook data collection could allow better quantifying local aFADs distances in the study area. Government-developed logbook forms already include sections for reporting the use of floating objects; unfortunately, these sections are often left incomplete. Observers data present another potential source of information. The IOTC observer program, initiated in 2005, has grown steadily and included 67 observers by 2022 (IOTC, 2023a; Sadiyah et al., 2012). However, funding constraints have resulted in limited coverage, and comprehensive information on fishing activities at aFADs is currently unavailable (Sunoko & Huang, 2014). Improving data collection through logbooks and observer programs is crucial for establishing a robust scientific framework for FAD management (Capello et al., 2023). Finally, future studies could more accurately quantify the distances between aFADs in the study area by utilizing available logbook data from purse seiners. Based on the findings of this study — specifically, that Indonesian purse seiners predominantly operate at aFADs and that these aFADs have a relatively long lifespan — it may be possible to use the positions of purse-seine fishing sets as a proxy for aFAD locations. This approach could enable the creation of precise maps depicting the aFAD arrays exploited by this fishery.

4.2.5. FAD use from last fishing trip

The number of days at sea is weakly correlated with the number of aFADs visited for all vessels. PS-HighS vessels, with fishing operations lasting around 200 days per trip visited a maximum of 16 different aFADs. PS-EEZ vessels, with a maximum operating time of 38 days, visited at most 11 aFADs. H&L-NoLi vessels, with a maximum operating time of 70 days, visited at most 16 aFADs. The difference between the number of aFADs visited and the number of sea day at sea suggests that vessels often revisit the same aFAD multiple times during a single trip, as already observed in other aFADs arrays (Macusi et al., 2017), and, globally, they exploit a relatively small aFADs array, even during fishing trips that can last several months (Fig 5B). However, the spatial extent of this array is unknown since fishers often do not provide aFAD positions in their reported logbooks and were reluctant to communicate them during the survey.

The number of aFADs visited per fishing trip exceeded the number of aFADs owned by individual vessels (Fig 5A). This suggests that these vessels are either sharing aFADs informally with other vessels within their own or different fishing groups or accessing other vessel/owner aFADs without authorization. When comparing the number of fished aFADs and the number of visits, H&L-NoLi vessels appear to have a lower success rate compared to other fishing gears. In addition to their support vessel activity, these vessels often operate on empty aFADs previously fished by purse seiners (Proctor et al., 2019), and also serve as "fish finders", i.e., they visit aFADs and provide info on fish presence to purse seiners to support their fishing activities.

The results of this study indicate that the daily catch of the PS-HighS group is lower compared to the PS-EEZ group (Table 1). This discrepancy likely due to the practice of transhipment at sea. Transhipment at sea is a common practice among purse seine tuna fisheries in Indonesia (Satria et al., 2018). The Indonesian government regulates transhipment at sea, adhering to the provisions of IOTC through the use of registered wooden carrier vessels (IOTC, 2024d). Beyond transhipment, PS-HighS in Indonesia often have lower daily catch rates compared to other regions (Macusi et al., 2015; Widodo & Suryanto, 2015), partly due to fishing sets not being conducted daily. On average, these vessels may only engage in fishing set activities on half of the days at sea (Atmaja & Sadhotomo, 2012). To mitigate potential data bias arising from transhipment and fishing practices, it is essential to strengthen monitoring and surveillance efforts. Implementing on-board observers and deploying electronic monitoring systems could significantly enhance data accuracy and transparency (Briand et al., 2023).

In this study, we observed a weak negative correlation or no correlation between total catch and the number of different aFADs visited, suggesting that increasing the number of aFADs visited does not necessarily lead to higher catches. Widyatmoko et al., (2021) mentioned that handline fisheries typically achieve successful trips by visiting no more than three aFADs. Beyond this threshold, catch rates tend to decline. In this study, data were only collected at the scale of the fishing trip, which limited our ability to determine whether low yields are a cause or a consequence of the higher number of aFADs visited. Further studies could be conducted, using catch data from fishing logbooks and observer data reporting aFAD visits, to obtain a better understanding of fishers' behaviour and aFAD use.

The need to sustainably manage FAD fisheries is a priority of all tuna RFMOs. During the last decade, the primary focus has been on regulating the massive use of dFADs, with resolutions that progressively reduced the limits on the number of instrumented buoys attached to them (Res 24/02 IOTC, Res C-24-06 IATTC, Rc 22-01 & Rec 23-01 ICCAT, CMM-2023-01 WCPFC). However, in recent years, questions have been raised on the management of aFADs and the IOTC, through Resolution No. 23/01, requires member countries to develop aFAD management plans and gather data on fishing activities related to aFADs. The Indonesian government has established a tuna fisheries management plan, including aFADs management component, through Ministerial Decree No. 121 of 2011. Additionally, Ministry Regulation No. 36 of 2023 regulates the placement of fishing gears and tools in Indonesian waters, including aFADs. Within the EEZ waters, this regulation permits each fishing vessel to deploy a maximum of three aFADs, while in high seas waters, the limit is set at fifteen aFADs per vessel. However, comprehensive data collection and reporting on aFADs is still a challenge, due to fishers' reluctance to report this information and the current limits of the data collection systems (Yuniarta et al., 2017) and lack of knowledge of the fishers on these particular regulation. To enhance data accuracy, it is crucial to raise awareness among all fisheries stakeholders, from industrial-scale companies to vessel owners and captains, on the need to improve data quality to achieve a sustainable management of tuna fisheries.

Conclusion

This study provides an overview of anchored Fish Aggregating Devices (aFADs) usage by Indonesian tuna fishers in the Indian Ocean. It combines survey data from 293 aFADs tuna fishers across 8 major ports with landing data to analyze aFAD utilization patterns and operational modes, addressing a significant knowledge gap in the region. The study reveals a highly dependence and widespread of aFADs use among purse seine and handline fishers, primarily those operating at a small-scale. It is important to improve data collection systems of aFADs and promote greater awareness and engagement among fishers in reporting their associated catch with aFADs.

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