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Developing indicators to detect the use of fish-aggregating devices

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ABSTRACT

Context. The growing demand for global food security has resulted in rising fishing intensity, sometimes leading to overexploitation of fish resources, including tuna. Increasingly, fishers are using anchored fish aggregating devices (aFADs) to improve efficiencies and reduce costs. **Aims.** To identify locations and use patterns of FADs and characterise aFAD usage in Indonesia and beyond. **Methods.** We identified general patterns of aFAD usage by tuna purse-seine, pole and line, hand-line and troll-line vessels operating in Indonesian waters through reviewing relevant literature and focal-group discussions. **Key results.** aFADs usage can be characterised by gear type and fishing strategy; vessel behaviour; equipment and spare parts for aFADs installation; association with light; trip duration, catch per unit effort (CPUE), ratio of live bait to catch, fuel consumption; existence of aFAD floats on board vessels and by-catch composition. **Conclusions.** aFAD usage has been widely adopted by both industrial and small-scale tuna fishers to efficiency. However, this efficiency comes at the cost of significant increases in catches of juveniles and non-target species, which raises sustainability concerns for Indonesian officials. **Implications.** Ultimately, quantifying the numbers, types and locations of aFADs is key to fisheries management to avoid overfishing, overcrowding and limit by-catch and fishing-associated waste.

Keywords: aFAD, anchored fish-aggregating device, fisheries management, hand-line, pole and line, purse seine, sustainable fisheries, troll line.

Introduction

Increased demand for global food security has resulted in an increase in fishing intensity (Food and Agriculture Organization of the United Nations 2022), and motivated technological improvements for greater capacity and efficiency of fishing fleets. This increased fishing intensity and capacity has resulted in over-exploitation of global fish stocks, including tuna species such as yellowfin tuna (*Thunnus albacares,* YFT) in the Indian Ocean (IOTC Secretariat 2020). As a result of declining stocks, fishers have experienced difficulty in catching tuna with common gear (without auxiliary fishing gear). One means of improving fishing efficiency has been the use of fish-aggregating devices (FADs). Although known to increase efficiency and catch rates of target species, the use of FADs also has potentially negative impacts on ecosystems, including catch of juvenile tunas and by-catch of unintended species (Bromhead *et al.* 2003; Amandè *et al.* 2008, 2010). Furthermore, FADs become marine pollution when they are lost, abandoned or discarded (Dagorn *et al* 2013; Escalle *et al.* 2019).

Indonesia is one of the main contributors to fish catch in the world, accounting for 8% of the global fisheries catches. The total tuna catch in Indonesia in 2015 alone was ~1 326 156 tonnes (Mg), nearly a quarter of the global annual tuna catch. The main fishing-gear types used to catch tuna include longline (LL), purse seine (PS), pole and line (PL), hand-line (HL), troll line (TL), and gill net (GN). Until now, longline fishing has contributed significantly to the total tuna catch in Indonesia, with longline vessels mostly operating in the Indian Ocean, the Pacific Ocean and parts of Banda Sea.

Recently, however, the productivity of tuna caught using LL has decreased; the catch rate of YFT per hook has declined from one fish per 100 hooks (Merta 2005) to fewer than one fish per 1000 hooks (Ruchimat *et al.* 2017). This decline is also indicated by the smaller size distribution of tuna overall and the increased travel time required to reach high-seas fishing grounds (Wudianto *et al.* 2003; Merta 2005; Chodrijah and Nugraha 2013). Indonesia's total tuna catch and catch size have also decreased, which has been exacerbated by the increased price of fuel, the current foreign-vessel fishing license moratorium and a ban on transhipment at sea (Ministry of Marine Affairs and Fisheries Decree Number 57/2014).

One of the approaches for addressing this decline in catch rates has been the expansion in the use of fish-aggregating devices (FADs), which provide a physical structure, acting as a fish attractor (Fig. 1*d*) that encourages fish to aggregate. There are two types of FADs, namely, drifting FADs (dFADs), which are unattached and drift with currents, and anchored FADs (aFADs), which are secured or anchored to the bottom in a particular location. They are used in offshore and coastal tuna fisheries respectively (Jaquemet *et al.* 2011). Anchored FADs are most commonly used in the Indonesian tuna fisheries by purse seine, pole and line, hand-line and troll-line fishers that mostly operate in the coastal areas (Proctor *et al.* 2019). Although initially used in Papua and Sulawesi in the 1980s (Tuasamu 1985), aFAD usage was modest before 2000. The deployment of aFADs has since spread widely throughout Indonesian territorial waters. This expansion was driven in part by the national program for tuna revitalisation in 2004, known as 'rumponisasi' by the Directorate General of Capture Fisheries, in the Ministry of Marine Affairs and Fisheries (MMAF). The purpose of this program was to increase tuna production through improving fishing operation efficiency by using aFADs to reduce search times and decrease fuel costs. The program was quite successful, as indicated by the increasing number of aFADs deployed either by fishers independently or with government subsidies. However, with the increased number of aFADs and non-selective fishing gear (such as purse seine) used around them, we have seen an increase in issues such as tuna availability (catching small sizes of tuna and a decrease in overall catch rate; Ruchimat *et al.* 2017), the use of destructive fishing methods (blast fishing) and conflict among fishers. Indonesian fisheries have benefited from the introduction of aFADs, but are now facing the challenge of managing an estimated 5000–10 000 unauthorised aFADs deployed in their national waters (Proctor *et al.* 2019).

Addressing this issue has become an increasing domestic and international priority, as evidenced by the release of seven domestic regulations for aFADs since 1997. Both regional fisheries management organisations in the region, the Western and Central Pacific Commission (WCPFC) and the Indian Ocean Tuna Commission (IOTC), now require

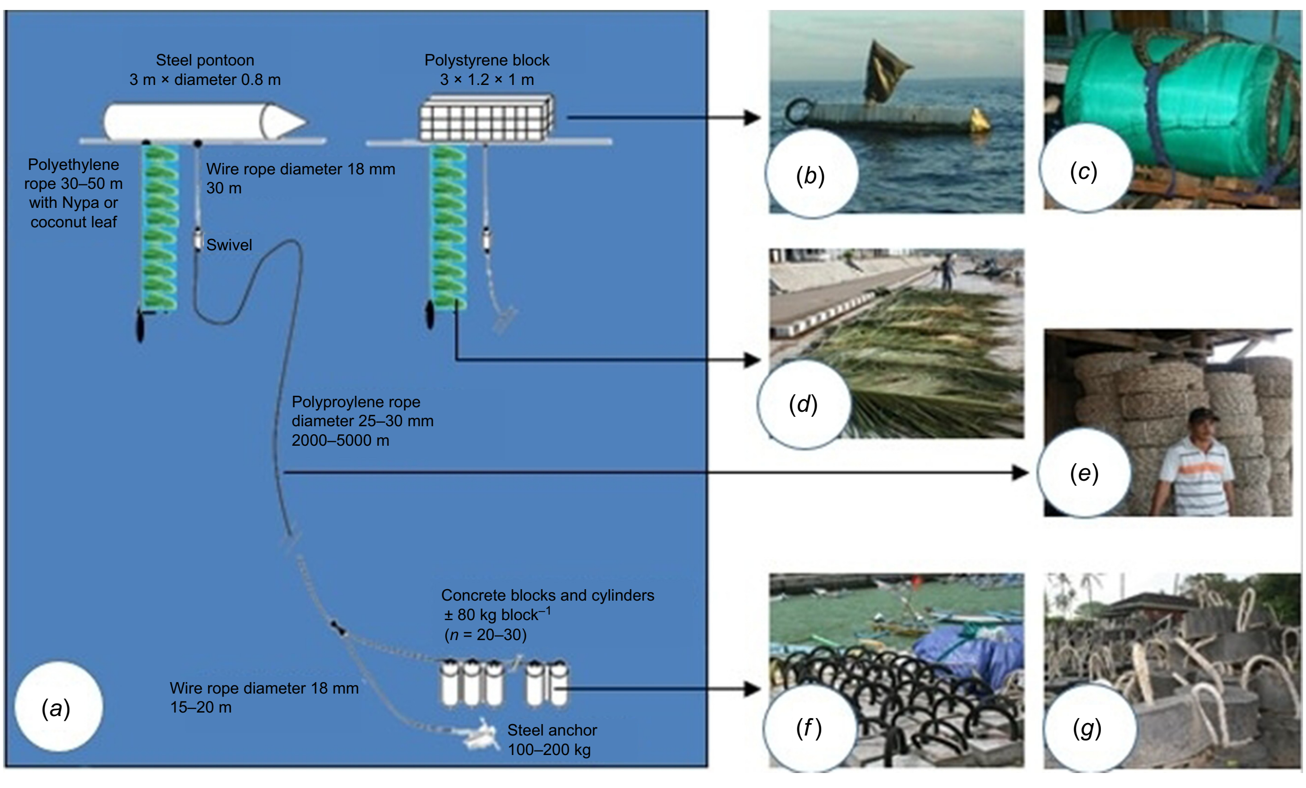

Fig. 1. Construction of aFADs. (*a*) general FAD construction; (*b*, *c*) pontoon types; (*d*) fish attractor; (*e*) ropes used in construction; (*f*, *g*) blocks used to anchor FAD in place. Photos courtesy Craig Proctor, CSIRO (2015).

member states to develop and implement FAD management plans. Currently, according to Indonesian national regulation number 26/2014, aFADs must be registered to MMAF and marked prior to deployment, in addition to abiding by management measures established by WCPFC and IOTC. However, implementation of these FAD regulations remains a significant challenge, in part because of the difficulty in detecting and monitoring FAD-associated fishing. In particular, vast numbers of small scale and artisanal fisheries have not had appropriate catch-monitoring reporting systems in place. Hence, the utility of indicators that can be used to infer FAD fishing events from vessel data would be useful.

Aims

There has been no synthesis of indicators for detecting FAD fishing practices from fishing data globally, much less in Indonesian waters. Here, we provide an overview of FAD-associated fishing, we discuss current regulations that specifically address FAD-related fishing, and we present a suite of indicators for tuna purse seine, pole and line, hand-line and troll-line fishing. We focus our efforts on activities in Indonesian waters as a case study, highlighting this approach as a useful tool to underpin monitoring, control and surveillance activities to reduce illegal fishing associated with FADs.

Methods

General patterns of FAD fishing by tuna purse-seine, pole and line, hand-line and troll-line vessels operating in the Indonesian waters were determined through a review of the existing literature. This was followed by focus-group discussions (FGD) that engaged relevant stakeholders that were intereested to improve FAD fishery management following guidelines developed by Johnson and van Densen (2007). These discussions involved fisheries and statistical modelling experts (national and international), scientists, fisheries managers (from the Directorate General for Capture Fisheries and Surveillance Division under MMAF) and fishing association members (Indonesian Tuna Longline Association) who gathered to develop a common understanding on characteristics of FAD-associated fishing events, on the basis of their knowledge and experience in a professional capacity.

The focus-group discussion process resulted in a list of potential indicators for FAD-associated fishing activities, which broadly fell into two categories, namely, quantitative indicators and qualitative indicators. After the first FGD, two subsequent FGD workshops took place, in which participants clarified and provided additional information. FGD workshops were attended by nominated staff of various agencies and stakeholder groups (most of whom had previously provided input). In total, more than 35 participants contributed identifying and ranking the indicators. Through iterative discussions and a ranking process, a list of indicators was identified (detail in Supplementary Table S1).

Ethical approval

This work was carried out under CSIRO human ethics approval for the project 'DFAT maritime capacity building initiative - Indonesia (162/21)'.

Results and discussion

In general, fishing companies, vessel owners and skippers are reluctant to provide the number and position of FADs. Keeping fishing locations confidential is high priority, because fishing is a competitive industry. Furthermore, with the increase in FAD usage, new markets are springing up. For example, there are now enterprises that are solely deploying FADs, some businesses are renting FADs, and others are working with individual fishers on a profit-sharing basis around FAD fishing and optimisation.

Fish-aggregating devices (types and characteristics therein)

The underwater physical structure provided by FADS encourages fish to aggregate. There are two types of FADs, namely, anchored FADs (aFADs) and free-drifting FADs (dFADs) (Fréon and Dagorn 2000). In contrast to dFADs, which are not affixed to the sea floor, aFADs are fixed by anchor (Fig. 1*a*). Fishers in Indonesia typically use aFADs, which consist of the following components: (1) a float in the form of bamboo raft, cork or pontoon of steel and fibreglass material; (2) an attractor from natural fibres or netting; (3) ropes from natural or human-made materials; (4) a kili-kili (swivel) from steel material; and (5) a sinker and anchors made of concrete and or steel. The length of the rope used can be up to 1.5–2 times from the depth of the waters, where the FADs are deployed (Fig. 1).

In brief, aFAD usage in a fishery can be characterised by (1) gear type and its fishing strategy, (2) vessel behaviour, (3) carrying of equipment and spare parts for aFAD installation on-board and equipment required to interact with aFADs, (4) association with light, (5) fishing efficiency including trip duration, CPUE, ratio of live bait to catch and fuel consumption, (6) existence of aFAD floats on board vessels (for example, large buoys, pontoons or a bamboo raft), (7) environmental conditions, (8) total catch including composition and size of tuna, and (9) composition of by-catch.

Gear types and fishing strategies associated with aFADs

Tuna fishing gear in Indonesia is generally associated with aFADs, with the exception of tuna longlines and drifting gillnet (Australian Centre for International Agricultural Research 2017). The gear used with aFADs include purse seine, pole

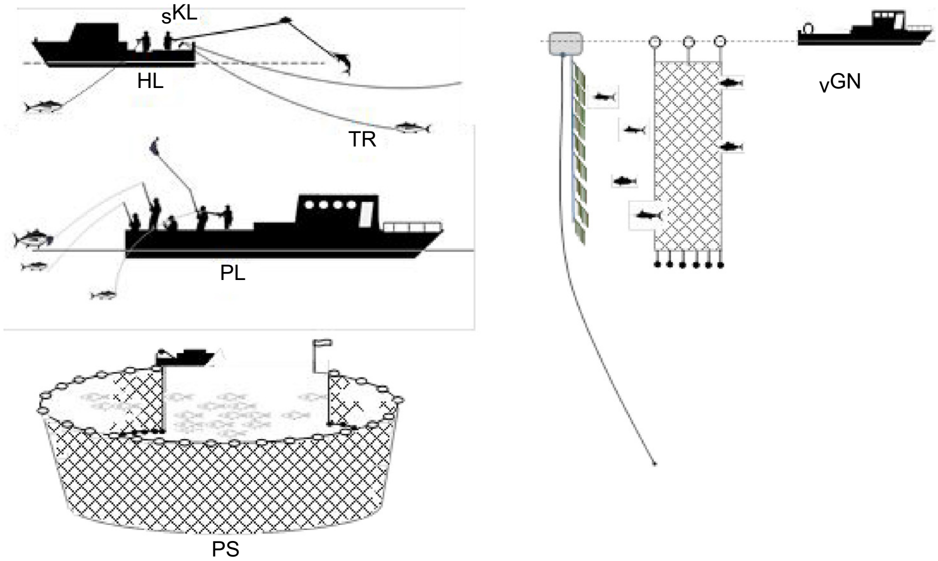

Fig. 2. Illustration of purse seine (PS), pole and line (PL), hand-line (HL), trolling line (TR), surface kite line ($_S$KL) and vertical gillnet ($_V$GN).

and line, surface hand-lines ($_S$HL)–deep hand-lines ($_D$HL), trolling line (TR) and surface kite line ($_s$KL) (Widodo *et al.* 2016). Vertical gillnets ($_v$GN) are also used out of Sadeng Fishing Port,Yogyakarta, in association with aFADs (Fig. 2).

Fishing strategies include group fishing (i.e. carrier vessels and catcher boats and support vessels are used in tandem) to improve fishing efficiency. For example, a purse-seine group may consist of a small light boat (or boats), a fishing or catcher boat, carrier vessels, and possibly a skiff or supporting boats. Even two vessels suggest the possibility of a group-fishing strategy for purse-seine vessels (i.e. four to five vessels are not required, sometimes a fishing vessel and a carrier vessel are all that is needed).

Vessel behaviour and FADs patterns

Vessels associated with aFADs and light fishing demonstrate specific behaviour such as regular movement to and from the same site, stopping at a FAD location for an extended period of time and visiting a FAD location repeatedly. Large purse-seine vessels often have an associated light boat of ~10–12 m in length. The light boat will arrive at the aFAD approximately at sunset and remains in position with lights on until *c*. 00:00 hours. The light boat will then estimate fish activity below the aFAD at *c*. 00:00 hours and will inform their associated purse-seine vessel. If the fish activity is deemed good, the fishing purse-seine vessel will travel to the aFAD and fish the aFAD in the early hours of the morning (by sunrise). The fishing vessel is likely to be no more than ~40 miles (~64.3 km) away (given ~4 h of steaming at 10 knots or ~18.52 km h^{-1} to arrive and fish by sunrise).

Furthermore, purse-seine, hand-line and trolling vessels regularly fish in the same place. This is especially evident when there are multiple vessels within a single company. Usually vessels within a company, for example, three or four vessels, will use the same aFADs, despite regulations stating that a maximum of three aFADs are permitted and licensed to a single vessel (Ministry of Marine and Fisheries Regulation Number 26/PERMEN/2014). However, small-scale fisheries, particularly sHL-TR in certain areas (e.g. in the Indian Ocean Western Sumatra and Southern Java), may use aFADs that belong to other fishers.

Purse-seine boats usually set nets in the early morning, whereas during the night-time, light will be used to attract fish to the aFAD. Thus, there will likely be repeated light in the same position (which may or may not be detectable by visible infrared imaging radiometer suite, VIIRS). However, there are other light-fishing activities in Indonesia that are not related to aFADs, such as squid jigging and lift nets. These fishing behaviours can be distinguished using catch composition, and structure and configuration of lights on-board (i.e. squid jigger lights are in a circle, whereas aFADs associated light boats tend to have only one light on the port side and one on the starboard side). Furthermore, geography and environmental conditions provide additional cues; squid jigging is more coastal and more dependent on environmental conditions and squid jigging vessels will be stationary when setting, whereas PS will be in motion.

Equipment on board a vessel that indicates FADs usage

There are specific types of equipment that when observed may indicate FAD usage. For example, a radio direction finder (RDF) on-board is one useful indicator. If aFADs are sitting below the surface, a radio buoy and an RDF is required to locate it (using a signal specific to that aFAD). Submerging

Fig. 3. Anchorage rope and concrete weights for aFAD construction on board a purse seiner (PS) vessel. Photograph © Itano/Murua, 2018.

aFADs is common practice because this approach avoids the aFAD being used by others. Drifting FADs (dFADs) will also use this method. However, RDF use is not unique to aFADs vessels; LL vessels may also carry and use RDFs to find their beacons.

Many boats carry materials onboard for one or two aFADs in case they need to repair or replace heavily damaged or lost aFADs (Murua *et al.* 2018) (Fig. 3). Furthermore, the presence of large buoys or pontoons or bamboo rafts indicate FAD usage (see Fig. 1*b*).

Fishing efficiency and environmental conditions

According to Bromhead *et al.* (2003), the use of FADs has increased the catch efficiency for purse-seine fisheries and Macusi *et al.* (2015) reported that the presence of 'payao' (aFADs) increased the fishing efficiency of tuna hand-line and purse-seine fishing in the Philippines. Other advantages of FADS include savings on time spent fishing and fuel, as well as a reported increase in catch rate of up to three times (Atapattu 1991; Soeboer *et al.* 2008; Nugroho and Atmadja 2013).

Beverly *et al.* (2012) noted that the primary motivation for artisanal fishers in Southeast Asia to use FADs is icreasing fishing efficiency, increasing CPUE and reducing fishing costs. This can be achieved by reducing search time and, thus, improving earnings. Vessels travelling directly to aFADs rather than spending time searching for fishing grounds decreases their fuel costs. Result of research in Sikka-Nusa Tenggara Timur (WPEA-Project 2017) showed that PLs associated with aFADs use less live bait than do PLs unassociated with aFAD, also reducing costs. Overall, the average CPUE of PL fishers associated with FADs are higher than PLs fishing unassociated with FADs (Table 1).

Anchored FADs are associated with specific environmental conditions such as upwelling areas, and areas no more than 3000 m deep. This type of FAD tends to be found in areas with a level sea floor (which is better for anchoring), away from shipping lanes, because FADs are a navigation hazard. Finally, aFADs typically occur outside of marine protected areas (MPAs) and conservation areas.

Fish size

Catch size is one of the best indicators of whether fishers are using FADs. However, because of the prevalence of FAD-associated-fishing in Indonesia, there is a general lack of data on the size of unassociated FAD-caught tuna. Most SKJ (~76%) and all YFT–BET caught on FADs are juvenile-stage

Table 1. Catch per unit effort (CPUE) and live bait used in PLs unassociated with FADs and associated with FADs based in Sikka-NTT.

Month	Unassociated FADs					Associated FDs				
	Number of trips	Bait use (kg)	Total catch (kg)	CPUE (kg trip^{-1})	Bait ratio (kg catch kg^{-1} bait)	Number of trips	Bait use (kg)	Total catch (kg)	CPUE (kg trip^{-1})	Bait ratio (kg catch kg^{-1} bait)
March	49	4900	93 246	1903	19.0	6	650	6500	1083	10.0
April						37	6600	56 005	1514	8.5
May	22	2650	17 600	8000	6.6	22	1050	26 745	1216	25.5
June	6	900	4450	7417	4.9	3	300	1800	600	6.0
July										
August	5	700	2400	4800	3.4	4	450	3500	875	7.8
September	37	4400	23 420	6330	5.3	7	650	6950	993	10.7
October	39	4350	44 373	1138	10.2	15	750	10 900	727	14.5
November	19	2900	17 369	9142	6.0					
December	22	3150	21 150	9614	6.7	8	950	6000	750	6.3
Average	25	2994	28 001	946	8	13	1425	14 800	970	11

Source: WCPFC-WPEA Project 2017.

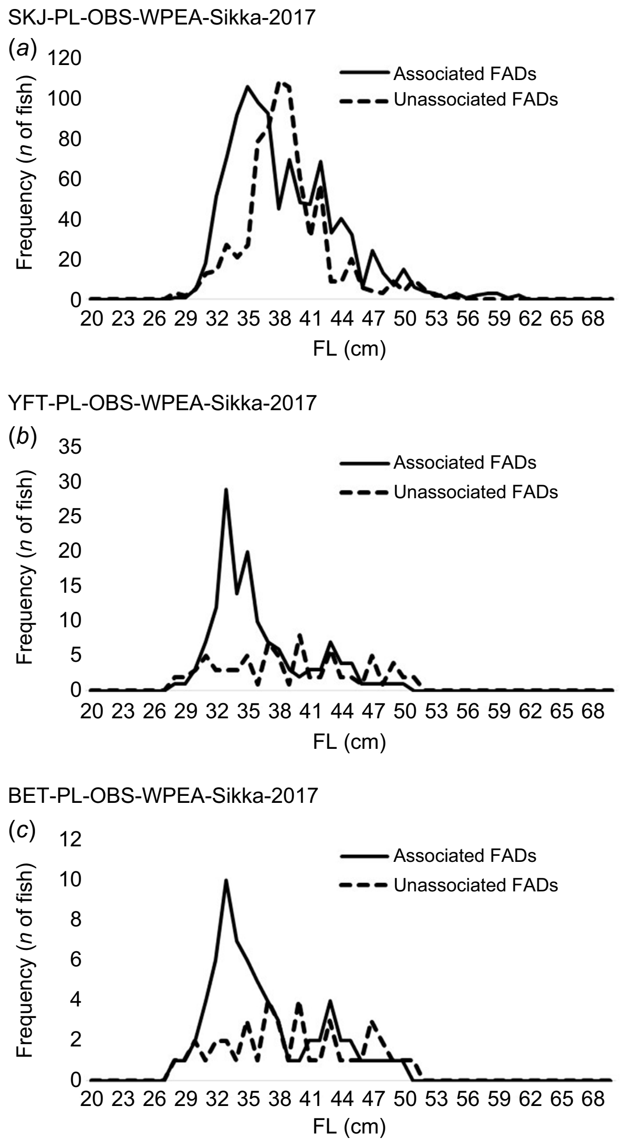

Fig. 4. Size (fish length, cm) of skipjack (SKJ), yellowfin tuna (YFT) and big-eyed tuna (BET) caught (OBS, observed) by pole and line (PL) fishers in Indonesian Fisheries Management Area 716-717 (WPEA Project 2010–2017).

fish. Previous research has compared catch size using various fishing gear when associated and unassociated with aFADs (WPEA Project 2010–2017). The study reported that YFT, BET, and SKJ catch were all larger when unassociated with FADs. However, overall catch numbers were higher when fishing on FADs (Fig. 4).

Bycatch and by-product composition

The composition and variety of by-catch species can be used as an additional indicator of FAD fishing. There is usually a greater diversity of species under FADs, than elsewhere nearby, which results in increased by-catch, including, for example, small shark, bramidae, mahi-mahi (dolphin fish) and rainbow fish. Free-schooling species are usually independent and thus there will be less variety in by-catch when fishing away from FADs (free schooling). In addition to by-catch, some species also are caught as by-product; for example, a 2-year port-sampling program in Kendari (2013–2015) showed that purse-seine fishing associated with FADs has by-product that consisted of neritic tuna and scad (see Table S1). In addition, hand-line and troll-line fishing associated with FADs also shows high levels of by-catch (Table S2). By-catch species composition from free-set purse seiners in the WCPO was reportedly substantially lower (0.11%) than that from FAD-associated fishing (1.52%) (Morgan 2011).

Descriptions of FAD indicators

The FGD identified several indicators that were classified as main and secondary indicators (Table 2). In detecting the use of FADs, the secondary indicators aimed not to substitute for the main indicators, but were instead included to strengthen or complement the main indicators.

Conclusions

The use of aFADs has been commonly adopted by both industrial and small-scale tuna fishers as a technology for improving efficiency. However, this efficiency is coming at the cost of significant increases in catches of juveniles and non-target species, which is raising sustainability concerns for Indonesian officials. An increasing number of aFADs are being deployed by fishers on their own or with government assistance, although the actual total number and position of aFADs in Indonesian waters remains unknown. Quantifying the numbers, types and locations of aFADs will be important in fisheries management moving forward to avoid overfishing, overcrowding and to limit by-catch and fishing-associated waste. Furthermore, more rigorous collection of data on the use of FADs will be useful for fisheries management, in Indonesia and more widely.

Here, we have identified several main and secondary indicators that can be used to detect the use of aFADs in the fishing operation such as the type of fishing gear, equipment and spare parts for aFADs onboard vessels. We also highlighted the change in fish capture proportions shifting to a large proportional of small fish. Additional indicators suggest that fishing associated with aFADs is marked by shorter trip duration, particular patterns of vessel movement, a wide variety of by-catch species and lower fuel consumption.

Implications

The indicators can be used to detect whether a vessel may be associated with aFADs and to estimate the number and

Table 2. Indicators of fish aggregating device- (FAD) associated fishing, with detailed description.

Indicator	Descriptions	Fishing methods
Main indicators		
Catch composition: small length or size of big-eye and yellowfin in catch composition	Given catch of big-eye and yellowfin, a large amount of small length or size fish is indicative of catch near a FAD. This is important as small size bigeye and yellowfin are relatively similar to size of skipjack.	PS, $_{S}$HL, PL
Catch composition: large proportion of small size of big-eye and yellowfin in catch composition	Given all species in catch, big proportion of big-eye and yellowfin in total catch composition is indicative of catch near a FAD. FADs *v.* non-FAD: around FADs catch usually has a bigger number of (small) yellowfin than for free schooling away from a FAD.	PS, $_{S}$HL, PL
Movement: regular return visit to same site	Regularly fishing in the same place. This is especially evident for multiple vessels within the same company. Usually vessels within a company, e.g. three or four vessels, will use the same FADs, as despite regulations (maximum three FADs per vessel, and licensed to a vessel) the company usually owns the FAD. For small fisheries in certain areas this condition does not apply because small-scale vessel may use FADs that belong to other fishers.	PS, PL, TR, $_{S}$HL or $_{D}$HL
Catch composition: lots of catch of similar size	Catch composition with similar size fish because schooling of fish near FADs often results in schools of fish of similar size.	PS, PL, $_{S}$HL, TR
Equipment: spare parts for FAD on-board	Equipment on-board likely to be for a FAD include rope, attractor, pontoon/buoy, and anchor or weight. Fishing vessels will fix FADs they are fishing on, this is not undertaken by support vessels.	PS, $_{S}$HL or $_{D}$HL
Gear type: gear type other than longline	All gear types that are not longline are potentially associated with FADs, including: PS, TR, sHL, dHL, PL, and vertical gillnet.	PS, $_{S}$HL or $_{D}$HL, TR, PL, vertical gillnet
The existence of a large buoy, pontoon or bamboo raft at sea	FAD installation use big buoy, pontoon or bamboo raft	
Secondary indicators		
Catch composition: bycatch	There is usually a bigger variety of species under FADs than elsewhere and will result in more bycatch ,e.g. small sharks, bramidae, mahi-mahi (dolphin fish), rainbow fish. Free-schooling species are usually independent and thus there will be less variety in bycatch when caught free-schooling (not at aFADs).	PS
Trip duration *v.* amount of catch	Shorter trips with high catch (fishing on FADs is more efficient).	PS, PL
Ratio of live bait to catch	For PL that use live bait because they operate on the FAD, they get higher catch with a smaller amount of bait. (Usually, they would be searching for fishing grounds and using bait as they search.) Hence, there is a more efficient ratio of live bait to catch.	PL
Fuel consumption	Fuel consumption on vessels targeting FADs is likely to be lower because of more efficient fishing. Vessels will likely go directly to a FAD and will not be searching for fishing grounds as would occur when not using a FAD. Each trip is likely to have more efficient fuel use given the trip duration.	PS, $_{S}$HL or $_{D}$HL, TR, PL, vertical gillnet
Location or environmental conditions	aFADs are associated with specific environmental conditions: - Usually in upwelling areas - Will try to avoid extreme depth, maximum ~3000 m (if anchored) - A flat sea floor is best to anchor on - Not in shipping lanes - Not in marine protected areas (MPAs) or conservation areas.	PS, $_{S}$HL or $_{D}$HL, TR, PL, vertical gillnet
Movement: stop in location for period of time	Large PS often have associated light boat of ~10–12 m. It will arrive at the FAD at approximately sunset, and sit there with lights on until *c.* 00:00 hours, then it will estimate activity below the FAD at c. 00:00 hours and will inform the associated fishing vessel of activity. If activity is good, the fishing vessel will travel to the FAD, and fish the FAD in the early hours of the morning (by sunrise). The fishing vessel is likely to be no more than ~40 miles away (~64.3 km) (given ~4 h of steaming at 10 knots or ~18.52 km h^{-1} to arrive and fish by sunrise). This scenario could be one light boat on one aFAD, or (for example) three light boats on three aFADs, all in contact with the same fishing vessel , which will choose which FAD to go to, on the basis of reported activity from the light boats.	PS

(*Continued on next page*)

Table 2. (*Continued*).

Indicator	Descriptions	Fishing methods
Movement: more fishing activity (direct travel, or not to fads)	More fishing activity, specific for PL in the Sulawesi or Pacific Ocean: because vessels fishing FADs are more efficient, they can get more fishing events in a day. Most vessels generally have one fishing event, but because the vessels fishing on FADs are more efficient, they may have two or more fishing events.	PL (Sulawesi or Pacific Ocean), TR, HL
Equipment: equipment required to interact with fad successfully	Radio direction finder (RDF) on-board; if an aFAD is sitting below the surface, it will have a radio buoy and an RDF, which is required to locate the aFAD. Drifting FADs will also use this method. Anchored FADs that sit below the surface will use RDFs, because these tags avoid FAD usage by others (e.g. it is not visible). However, RDF use is solely used by aFAD vessels. LL vessels also may carry RDFs to find their beacons.	PS
Gear type: vertical gillnet	Vertical gillnets are specifically designed to operate close to aFADs. This occurs only in South Java–Indian Ocean, especially around Sadeng.	Vertical gillnet
Group-fishing strategy, i.e. carrier and catcher and support vessels.	For PS: a group may consist of a small light boat, fishing vessel(s), a carrier vessel, and possibly a skiff or supporting boat. Even two vessels indicate the possibility of a group-fishing strategy for PS vessels (i.e. it does not necessarily need to be four to five vessels,). This behaviour is specific to the Pacific Ocean area.	PS
Associated with light fishing	During night-time, light(s) will be used at aFADs to attract fish. Thus, there will likely be repeated light in the same position (this may or may not be detectable by VIIRS). However, there are other light-fishing activities in Indonesia that are not related to FADs, i.e. squid and lift net. These can be differentiated by catch composition; structure and configuration of lights on-board (i.e. squid lights are in a circle, whereas fishing FAD light boats will have only one on the port side and one on the starboard side). Squid jigging is more coastal and more dependent on environmental conditions and squid jigging vessels will be stationary when setting, whereas PS will be moving when setting.	PS, drift lift nets (bagan perahu) in West Sumatera
Collaboration between PS and TR or $_S$HL vessel at sea while operating	TR or $_S$HL vessels often give information to PS vessels about aFADs (e.g. fish condition).	

aFAD, anchored fish aggregating device; PS, purse seine; PL, pole and line; TR, trolling line; $_S$HL, surface hand-lines; $_D$HL, deep hand-lines; $_S$KL, surface kite line; and $_V$GN, vertical gillnet.

position of aFADs, which, in turn, are required for monitoring the implementation of the aFAD management. So far, the monitoring, control and surveillance for aFAD use have been conducted during regular patrol activities without prior observation using vessel data. It is expected that the aFAD indicators can be used by surveillance teams to inform patrol activities.

Supplementary material

Supplementary material is available online.

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Data availability. All data that were generated or used during the study are included in the Supplementary material.

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