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Fish behavior based on the effect of variations in oceanographic condition variations in FADs Area of Bone Bay Waters, Sulawesi, Indonesia

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Abstract. *Rumpa A, Najamuddin, Safruddin, Hajar MAI. 2022. Fish behavior based on the effect of variations in oceanographic condition variations in FADs Area of Bone Bay Waters, Sulawesi, Indonesia. Biodiversitas 23: 1875-1883.* Fish behavior is the response of fish to conditions existing in their environment. One of the causes is oceanographic factors, which can affect the schooling movement of fish. This study aimed to identify the schooling behavior of fish based on the influence of oceanographic variations in the Fish Aggregating Device (FADs) area. Study took place from March to September 2021 in Bone Bay Waters, Indonesia. The type of research was experimental fishing with an acoustic approach for 57 times. Parameters observed were current velocity, current direction, and water temperature to the distance of schooling fish from FADs vertically and horizontally in the afternoon, evening, night, and early morning. The behavioral data of fish species were namely Decapterus russelli. The results showed namely the variation in current velocity affected the horizontal distance; variation in the direction of currents affected the horizontal distribution distance, while the water temperature affected the vertical schooling of fish. In the operation of fishing gear, especially in the early morning, in terms of the concentration pattern of schooling fish under FADs. The ideal current velocity was in the range of 0.2-0.29 [m s^{-1}], while the ideal current direction is direct current was at the angle of 0°-60°. The schooling of fish approached to the surface and was concentrated under FADs at >30°C. Understanding on the distribution of horizontal and vertical movements and the time of concentration of fish schooling at the central point of FADs due to oceanographic variations will facilitate the effectiveness of fishing gear operation.

Keywords: Current, FADs, fish behavior, temperature, schooling

INTRODUCTION

There are a lot of Fish Aggregating Device (FADs) in Bone Bay waters which are spread from the mouth to the base of the bay. Indirectly, the presence of these FADs greatly affects the distribution pattern or distribution of pelagic fish that reside or migrate out of or into the waters. The habit of fishermen in the waters of Bone Bay in determining whether the FADs area has a lot of fish or not is observing the fish under the FADs visually during the day. If there is no schooling of fish, the fishermen will go to other FADs. This procedure is not necessarily true and it is possible that the schools of fish are located vertically and horizontally away from the FADs area due to variations in oceanographic factors such as currents (Véras et al. 2020) and water temperature (Orue et al. 2020). On the other hand, although there is much fish at certain times, the setting and hauling fishing gear are difficult to fully concentrate under the FADs area, causing fish catches to be less optimal.

Effectiveness of the fishing gear operation by utilizing FADs aims to attract fish to associate with them to facilitate catching (Dagorn et al. 2013; Albert et al. 2014; Chaliluddin et al. 2018; Hamar and Bone 2021), but on the other hand, not all FADs have good productivity. Some FADs are abundant and some are poor in fish resources (Yusfiandayani 2013; Matrutty et al. 2019; Sarianto et al. 2019). This is strongly influenced by variations in oceanographic changes causing schools of fish to appear in the FADs area (Dempster and Taquet 2004; Capello et al. 2012).

Several studies have tried to examine the effect of oceanographic parameters such as surface temperature, currents, salinity, and chlorophyll-a concentration based on remote sensing and geographic Information systems (Arrizabalaga et al. 2015; Ghufron et al. 2019; Seloi et al. 2019) and information based on local knowledge of fishermen (Moreno et al. 2007; Macusi et al. 2017; Jauharee et al. 2021), including the use of GPS buoys to FADs (Irineo et al. 2014; Lopez et al. 2014; Maufroy et al. 2016), providing initial information on potential pelagic fishing zones and habitat distribution of fish in the fishing ground. The results of this study also provide a general description of the influence of oceanographic parameters on fish distribution, but the scope of the research is still for a large area and has not been able to provide a more specific description of the behavior of fish in the FADs area itself as a media for purse seine catching aids.

General description related to the distribution of fish species around FADs has been studied for several years, such as the certain location of depth, especially tuna (Forget et al. 2015; Matsumoto et al. 2016; Lopez et al.

2017a) and the distribution of fish due to the parameters, such as the angle of the current direction on FADs (Rountree 1990; Dempster and Kingsford 2003), current velocity to the distance of tuna fish (*Auxis thazard*) (Priatna et al. 2010) and Bigeye Scad (*Selar crumenophthalmus*) (Capello et al. 2013). However, it is also important to understand the distribution of fish schooling movements based on the variations in current velocity condition, current direction, and temporally different temperature levels at a different time in species mackerel Scad (*Decapterus russelli*), which is dominantly caught in the waters of Bone Bay (Irawati et al. 2021).

The relationship of fish as a fishing destination and water condition is very complex such as physical, chemical, and biological parameters, so it needs to be studied in a sustainable manner. However, among the three parameters, the easiest one observed is physical parameters such as current and temperature. The parameters of these water conditions greatly affect the distribution of fish, aggregation, and fish behaviour (Putri et al. 2019; Khan et al. 2020).

For the success of the operation of fishing gear, it is very dependent on the knowledge of fishermen regarding technical factors of fishing operations and oceanographic factors, especially currents and water temperatures which directly affect the behavior of the type of fish as the target of catching around FADs (Kefi et al. 2013). One of the alternatives to achieve the research objectives is by using the acoustic approach method, which is done by (Trygonis et al. (2016) and Bonanno et al. (2021), and the underwater video, which is conducted by (Brehmer et al. (2019). To strengthen the data related to the composition, the fish were taken from the board. In this research, the combination of echo-sounding techniques, underwater video, and experimental fishing in the field were conducted.

MATERIALS AND METHODS

Study areas

The research was carried out from March 2021 to September 2021 in Bone Bay waters, Sulawesi, Indonesia (Figure 1). The type of this research was experimental fishing with an acoustic approach down directly on the ship by following the fishing operation for 57 times hauling fishing gear.

Procedures

Observation of the influence of oceanographic factors on fish behavior in the FADs area was carried out five times, namely during the day at 10:00-14:00; at 5:00-6:00 p.m.; at 8:00-10:00 p.m.; in the morning when the light was extinguished on the mother ship accompanied by the lighting on the FADs to concentrate fish at 04:00-05:00; and in the early hours of the morning while the setting of fishing gear would begin at 05:30-06:00.

Research tools and materials included mini purse seine, namely fishing gear 25 GT and FADs with torch lighting. To monitor fish behavior or position and distance of schooling fish from the center point of FADs in the sea, an underwater fishing camera unit 50 meters type CR110-7b was used, four units of fish finder type Garmin map 585 with the frequency of 50-200 kHz maximum depth: 1500 ft by installing an underwater transducer that could be directed vertically and horizontally, one gladius mini underwater camera drone and current meter type flowatch meter fl-03 for measuring current and water temperature. Meanwhile, the measurement on the behavior of fish species was based on the type of catch, dominantly caught in the FADs area with purse seine, namely mackerel scad (*Decapterus russelli*).

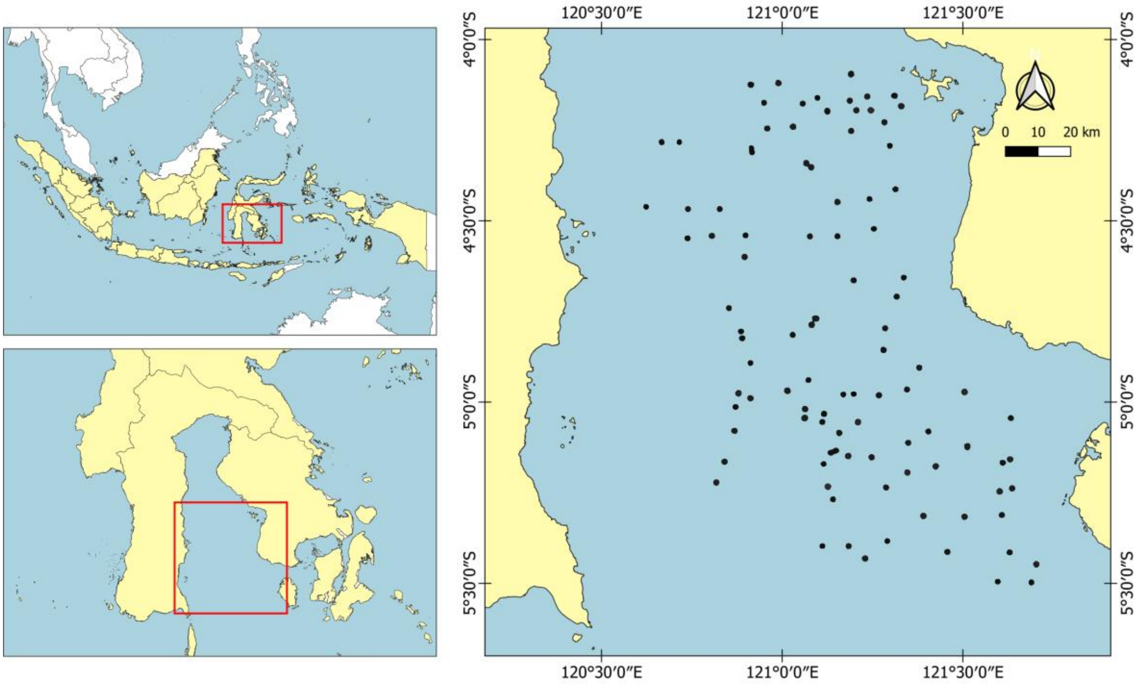

Figure 1. Map of Bone Bay waters, Sulawesi, Indonesia

The approaches to measuring and observing fish behavior were carried out in 2 ways, namely using a spiral track transect model (Josse and Bertrand 2000; Nurdin et al. 2017) and a tenth-meter ring. Then to make it easier to get the schooling position of the fish, the first procedure was measuring the direction and speed of the current on the ship at level 2. Then the next was directing the sopek boat towards the direction of the current flowing to the FADs area. In general, the schooling fish were in a state of swimming against the current, then the measure of the fish position was done with a fish finder. As a limiting factor, observations and measurements were only carried out if there was the schooling of fish in the FADs area.

The relationship between current velocity and movement of fish was related to the position and distance of schooling fish from FADs vertically and horizontally. Parameters measured were current velocity at two levels of depth layer, namely upper layer current (0-10 meters) and lowered current layer (≥ 10 meters). Data on variations in current speed, current direction, and water temperature were calculated by adjusting the position of the fish at the local time, during the day and night. Data were collected at a depth of 10 meters, while in the afternoon and early morning, current data collection was at a depth of 0-10 meters where generally schooling fish was at that depth.

Current speed conditions were divided into 4 categories, namely weak current with code (A), medium current (B), strong current (C), and very strong/fast current (D). The relationship between the presence of schooling fish distances in the FAD area whether it affected the variation in the direction of the current or not. The parameters measured were based on the condition of the current direction of the top and bottom layers, then 3 categories of the angle of arrival were determined, namely direct current with an angle of 0°-59° (Code A), transverse 60°-120° (Code B) and countercurrent >120° (Code C). Water temperature variation was measured to understand the relationship between schooling fish distances vertically and divided into three categories, namely temperature (28.1°-29°), (29.1°-30°) and temperature (≥30°).

Data analysis

Observational data were presented in the form of images using CorelDraw software and the Origin application. Then they were analyzed descriptively to find a model of schooling fish behavior in the FADs area.

RESULTS AND DISCUSSION

Effect of schooling movement and fish distance from FADs on the variation of current velocity

The measurement results showed that the surface and subsurface of the current velocity model in the waters of Bone Bay varied greatly during the day, evening, night, and early morning, namely the current speed generally ranged from 0.05 to 0.4 [m s^{-1}], where there was a difference in the frequency of the varying current speed. Therefore, the available data were not representative enough for each current velocity under different conditions, but they could describe the position and distance of the schooling fish in the FADs area. This was not only due to the different conditions of the day, season, geographical conditions, and the location of the different FADs installation positions at the time of data collection.

The results of fisherman interviews (n: 10) based on their habits in measuring currents related to the decline in purse seine fishing gear were then divided into 4 categories to obtain a simple picture, namely weak currents ranging from <0.1 [m s^{-1}], medium currents of 0.1-0.19 [m s^{-1}], strong current of 0.2-0.29 [m s^{-1}] and very strong/fast of >0.3 [m s^{-1}].

The results of the study (Figure 2) showed that the current velocity of strong, medium and weak conditions affected the distance of the schooling fish horizontally where during the day with a current speed of >3 [m s^{-1}]. It was far from the center point of FADs, at a medium current speed of 0.2-0.29 [m s^{-1}] and weak current speed of 0.1-0.19 [m s^{-1}] schooling of fish closer to FADs. Meanwhile, in the afternoon, schooling of fish moved closer to FADs on average below 5 meters. On the other hand, at night with strong current speed, schooling of fish tended to approach FADs. Whereas on medium and weak currents, schooling of fish tended to move away from boats.

At 04:00-05:00 generally, the lights were turned off onboard, and lighting was done in the FAD area so that schooling fish went straight to FADs. In general, schooling of fish was not directly under the FAD raft but was on 5-15 meters depending on current speed condition. In this case, when the condition of the current was weak, schooling of fish spread far from the center point of the FADs.

On the other hand, the faster the current speed the closer the schooling of fish. In the fast current condition, more schooling of fish moved away from the FAD. At 05.30, when the current was very strong, schooling of fish tended to be in front of FADs and some of them entered under the raft. Compared to weak currents, they were farther from the center of FADs in the range of 2-5 meters. On the one hand, a small portion of schooling of fish at a certain time was far from the FADs raft. This was due to the influence of the moon and predatory fish.

Effect of schooling movement and fish distance from FADs on the variation of the current direction

The surface current direction model in Bone Bay also varied, sometimes showing a difference in the angle of the direction of the upper and lower current layers. This affected the position of the schooling of fish towards the center point of the FADs. The results of measurements in the upper layer at a depth of 1-10 meters were generally in the same direction. There was a change in the direction of the current while at a depth of 10 meters and below caused a difference in the angle of arrival of the current.

To better understand the effect of the movement and schooling distance of fish on the angle of the direction of the current at the center of the FADs, a level category division was carried out based on the habits of fishermen regarding the initial position of the purse seine fishing gear. In this case, the difference in the direction of the flow of the upper and lower layers of 0°-60° was into the direct current category; 60°-120° was into a transverse current category; and >120° was into countercurrent category.

The results of the study (Figure 3) showed that there was a difference between the schooling distance of fish based on the direction of the current. In this case, in the daytime, at night and early morning, the unidirectional current was on during the position of the distance from the center of the FADs was closer. This was exceptional in the afternoon, it was further away from the FADs to be compared with the conditions of the transverse and cross current direction.

In general, the angle of the direction of the current came across (Figure 3) at night and in the early morning was more spread out and away from the ship, whereas in the direction condition of unidirectional current schooling fish tended to be closer to the center point of FADs. Crosscurrent conditions during the day and early morning showed the tendency to be away from the center of FADs.

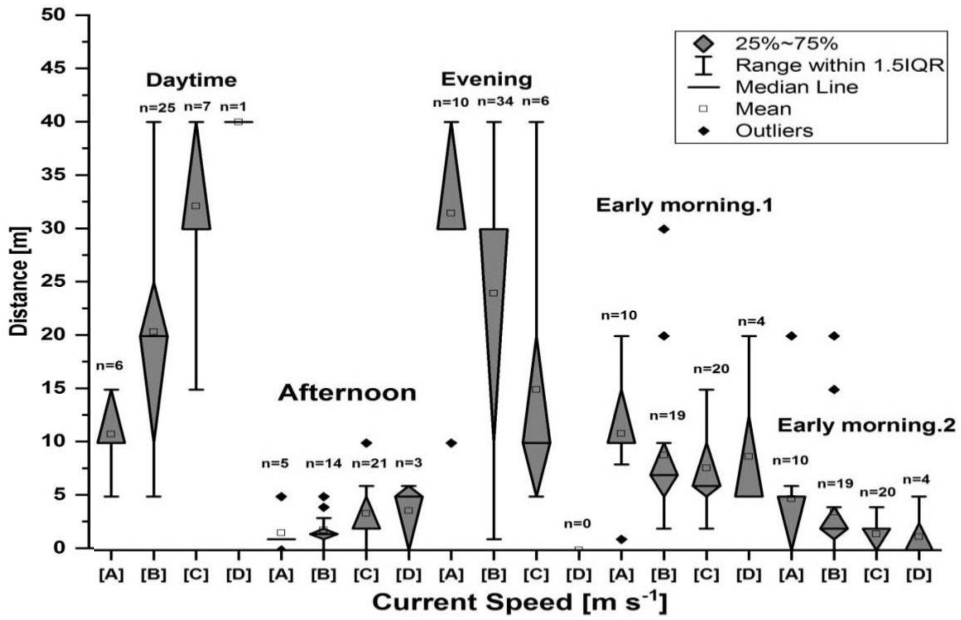

Figure. 2. Position and distance of fish horizontally from the center point of FADs due to variations in current, [A] weak current of : < 0.1 [m s^{-1}], [B]: moderate current of 0.1-0.19 [m s^{-1}], [C]: strong current of 0.2-0.29 [m s^{-1}], and [D]: very strong current of > 0.3 [m s^{-1}]

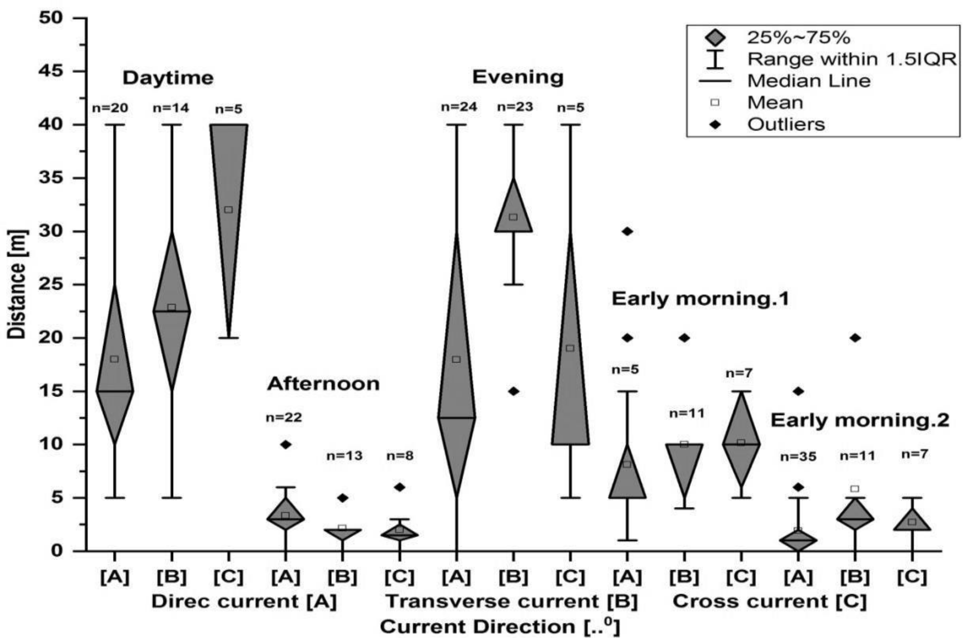

Figure 3. Position and distance of schooling of fish from the center point of FADs due to variations in current direction; [A]: Unidirectional current, [B]: Transverse current and [C]: Cross current

The effect of schooling movement and the distance of fish from FADs on the variation in water temperature

The results of temperature measurements at two levels of depth obtained temperature data at levels varying from a temperature range of 28.1°C to 31.3°C. The temperature range obtained was then divided into three classes of temperature levels to gain a simpler description of fluctuations in the relationship. During the day, the temperature ranged from 28.7°C to 31.3°C. In the afternoon, the temperature range decreased from 28.5°C to 30.6°C. At night, the temperature ranged from 28.1°C to 30.5°C. In the morning, the temperature ranged from 28.1°C to 30.4°C.

The measurement results (Figure 3) revealed that during the day, the dominant schooling fish was concentrated in the temperature range of 29.1°-30°C, and was in the average range of 15 meters below sea level. While in the afternoon, evening and early morning, the schooling fish was closer to sea level in the temperature range of 30°C.

Observation on deviations in position and distance of fish showed a far position from the FAD area, especially in the early hours of the morning (Figure 2,3,4), which was generally due to the moonlight's existence. While the arrival of schooling of fish is approaching the center of FADs due to the large volume of fish associated in FADs. In addition, at the time of the study, predatory fish such as tuna (*Thunnus albacares*) induced the schooling of fish to be closer to FADs, while barracuda fish (*Sphyraena* sp.) caused them to move away from the center of FADs, so that the influence of current and temperature was not significant.

Discussion

Bone Bay Waters ecosystem is an ecosystem that has its peculiarities because the waters are semi-enclosed, the schooling of the existing fish is influenced by the spatial and temporal pattern of environmental biophysical conditions. The biophysical environment where FADs are installed in research sites is very different from one another, as well as varying seasonal patterns affect the biophysical conditions of the environment.

Measurement of current velocity and temperature at the sea surface is relatively higher than the bottom of the waters, such condition certainly affects the presence of pelagic fish, especially mackerel scad in the FADs area. Orue et al. (2019, 2020) revealed that differences in aggregation patterns for tuna and non-tuna species depended on the spatiotemporal dynamics of the FADs installation area.

The results of the study (Figure 2,3,4) clearly show that the schooling movement of fish due to variations in speed, current direction, and water temperature through acoustic techniques in the FADs area directly affects the presence of fish horizontally and vertically, even the frequency of current appearance varies. Changes in the condition of waters (oceanography) can dynamically affect the movement patterns of fish in the waters. This is because naturally, fish will look for water areas that are appropriate with their environment (Simbolon et al. 2011; Lopez et al. 2017b)

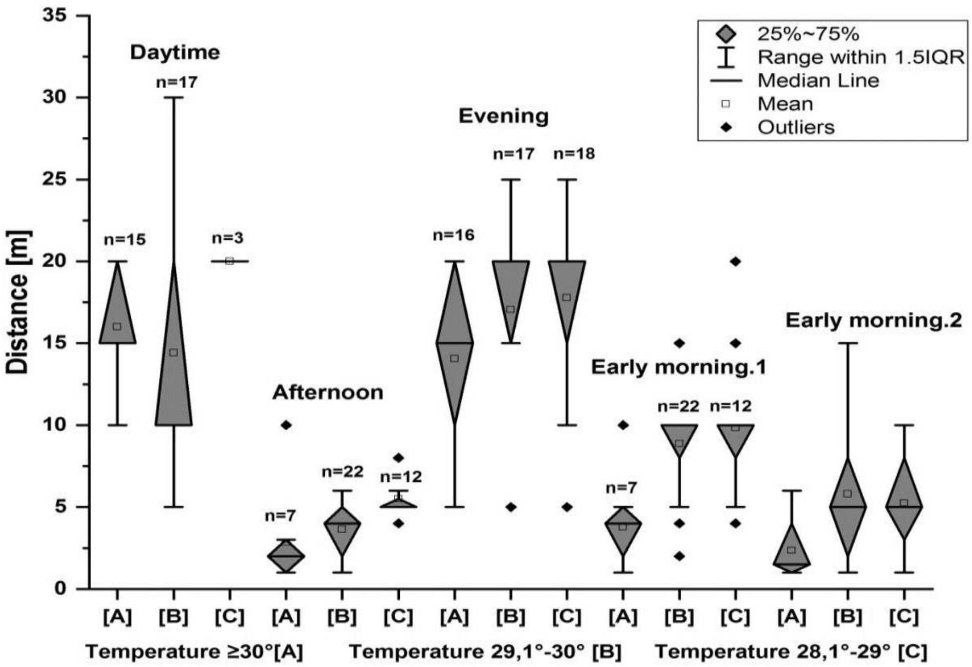

Figure 4. Position and distance of schooling of fish vertically from the center point of FADs due to variations in temperature; [A]: 28.1°-29°, [B]: 29.1°-30° and [C]: >30°

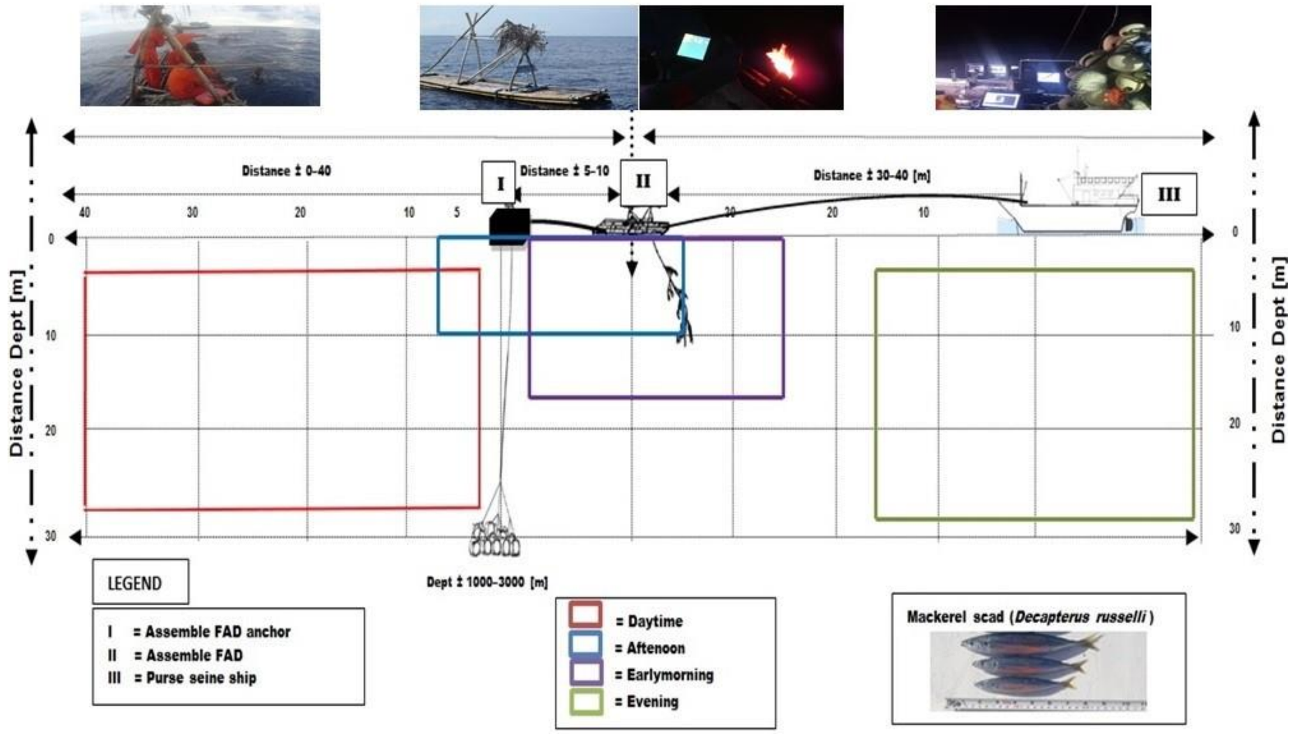

Figure 5. General description measurement the position and distance of schooling fish mackerel from the center point of FADs

The pattern of schooling of fish movement according to time with strong, medium, and weak current velocity affects the distance of horizontal schooling of fish. These findings strengthen the assumption that the proximity of the schooling of fish from the center point of FADs, especially mackerel scad, is strongly influenced by the speed of the current at a point in the FADs area. Similar findings from (Capello et al. 2013) revealed that the effect of currents during the day on the aggregation of small pelagic fish showed that higher current strength caused the distance between fish and FADs to be further apart and vice versa the decreased current speed is going to close the schooling fish to the FADs.

In the movement, mackerel scad tends to face or oppose the current and always swim in groups with their backs to FADs. They sometimes move left or right, but they always return to their original place. Then their presence is relatively strongly influenced by the strength or weakness of the current speed. Research (Priatna et al. 2010) reveals that the aggregation pattern of small pelagic fish tends to be in front of FADs against currents, so understanding this can make it easier to catch fish. A flock movement of schooling of fish will rather ease to catch fish than fish that move with irregular movement pattern.

In catching using mini purse seine, especially at the research location with a current velocity of > 3 [m s^{-1}] in the morning, mackerel fish generally tends to be very close to the center point of FADs with a calm movement pattern facing the current. It is very easy to catch, but in terms of lowering the fishing gear, fishermen are generally very careful in determining the initial position of the descent in fishing gear. An error in calculating the angle of arrival of the current will result in failure in the operation of the fishing gear, which has an impact on the escape of fish from the catchable area. As stated by (Jalil 2013; Zhou et al. 2015, 2019), related to the purse seine fishing gear used, the current velocity has an influence on the stability of the fishing gear when it is operated.

Dempster and Taquet (2004) found that large tuna was caught when current velocity was weak, namely of <0.2 [m s^{-1}]. While Dolphin fish (*Coryphaena hippurus*) in large schooling were around FADs when strong current velocity was of > 0.5 [m s^{-1}]. The difference in these findings was thought to lie in the species and behavior factors around the FADs.

The interesting thing from the research findings is that at 17:30-18:00 (afternoon) with a duration of (±10 minutes) and at 05:30 (early morning), the average duration is ±30 minutes, schooling fish always appears on the surface layer under the FADs attractor. This is presumably because, at these times before sunset and sunrise, the possibility of flying fish species (besides looking for food) is likely to be attracted to the light condition below the sea surface, which is less bright. However, before sunrise and sunset, the schooling of fish will go to deeper waters of >30 meters (Nurdin et al. 2019).

Different findings Josse and Bertrand (2000) revealed that the concentration of schooling of fish in FADs was at its maximum in the morning after sunrise and then decreased in the day until the afternoon. At night after sunset, the presence of schooling of fish was almost not found until the early hours of the morning. They continued to increase in the morning, the difference was probably due to the species of fish and water temperature factors as the object of research.

Thus, the effective time for setting and hauling using purse seine fishing gear based on the schooling behavior of fish in the FAD area is in the afternoon at 17:30-18:00 and twilight at 05:30-06:00 local time. However, the movement pattern of mackerels in the afternoon tends to be less calm and easier to get out of the scope of the fishing gear area than in the early morning.

During the day, the concentration of swarms of mackerel scad was at a depth of 10-20 meters, but there was little frequency of appearance, which was concentrated at depths below 5 meters and above 20 meters. This is similar to the findings (Doray et al. 2007), monitoring of fish schooling in FAD areas using echo-sounding techniques, underwater cameras and fishing to assess the aggregation structure of fish during the day showed that small pelagic fish with a FL size of 12 cm was at a depth of 10-30 meters. Then FL fish with a size of 30 meters were caught at a depth of 0-20 meters, whereas according to (Priatna et al. 2010), the highest density in the FAD area was found in the surface layer to a depth of 25 m and (Taquet 2004), from a few small individual fishes located just below the FAD visually observed by diver range 0 to 30 meters, maximum 50 meters.

At night, even there was lighting on the boat, the concentration of the swimming depth of mackerel scad did not differ much during the day, as stated by (Godo et al. 2004) that about 65% of mackerel fish are between the surface to a depth of 40 meters. Fish tends to rise to the surface because it is attracted to the light, but horizontally it is at the outermost part of the illumination, but sometimes it enters the bottom of the ship.

The swimming depth of the pelagic fish group is largely determined by the vertical distribution of water temperature, especially in the FADs area. Generally, in the afternoon, evening, and early morning the dominant schooling of fish is closer to the sea surface under the boat and FADs towards a temperature range of 30°C, but during the day, it is concentrated at temperatures below 29°-30°C. This indicates that pelagic fish will swim away from higher or lower water temperatures than usual, then head to certain water layers where these fish are more adaptable.

There are allegations that mackerel scad chooses to approach FADs even they have to adapt to temperatures warmer than the ideal temperature. This is in line with the opinion of (Safruddin 2013), stating that mackerel scad tends to occupy spaces with warmer temperatures. From the results of his findings, he noted that the kite was in a narrow temperature range, namely; 29.0º-29.1ºC dan 29.7º-29.8ºC, and caught with the most fishing gear at 29°C (Safruddin et al. 2018).

The combination factor oceanography and presence of FADs can be believed to have a strong attraction for pelagic fish to go to certain layers of water under FADs as stated by Capello et al. (2012), that the shape, chemical, biological and material substances of FADs (Ibrahim et al. 1995; Hasaruddin et al. 2021) contribute to the phenomenon of gathering fish to the surface under FADs.

Observation of fish behavior, especially in FADs areas based on oceanographic factors, is important to understand the behavior of fish as catch target related to the presence of fish's schooling position in FADs areas both during the day and at night by using acoustic (Moreno et al. 2019), knowledge about fish behavior is crucial for the development fishing gear fishing (Tenningen et al. 2017; Rumpa and Isman 2018), then characteristics of fishing areas are the basic references in developing fishing strategies and operation of more effective and efficient (Jufri et al. 2014; Macusi et al. 2015; Cody et al. 2018) then fisheries sustainability management (Fonteneau et al. 2013; Davies et al. 2014; Capello et al. 2016; Wudianto et al. 2019; Widyatmoko et al. 2021).

The results of this study can be used for further research because the success of the operation of fishing gear is highly dependent on oceanographic factors, especially current and water temperature, which have a direct effect on the behavior of fish targeted in the FADs area.

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REFERENCES

Albert JA, Beare D, Schwarz A, Albert S, Warren R, Teri J, Andrew NL. 2014. The contribution of nearshore Fish Aggregating Devices (FADs) to food security and livelihoods in solomon islands. Plos One 9 (12): e115386. DOI: 10.1371/journal.pone.0115386.

Arrizabalaga H, Dufour F, Kell L, Merino G, Ibaibarriaga L, Chust G, Irigoien X, Santiago J, Murua H, Fraile I, Chifflet M, Goikoetxea N, Sagarminaga, Yolanda, Olivier A, Laurent B, Miguel H, Fromentin JM, Bonhomeau, Sylvain. 2015. Global habitat preferences of commercially valuable tuna. Deep Sea-Res Part II 113: 102-112. DOI: 10.1016/j.dsr2.2014.07.001.

Bonanno A, Marco B, Andrea, Marianna B, Magdalena I, Iole L, Ana V, Salvatore, Ilaria, Tičina, Vjekoslav. 2021. Acoustic correction factor estimate for compensating vertical diel migration of small pelagics. Medit Mar Sci 22 (4): 784-799. DOI: 10.12681/mms.25120.

Brehmer P, Sancho G, Trygonis V, Itano D, Dalen J, Fuchs A, Faraj A, Taquet M. 2019. Towards an autonomous pelagic observatory: Experiences from monitoring fish communities around drifting FADs. Thalassas: Intl J Mar Sci 35: 177-189. DOI: 10.1007/s41208-018-0107-9.

Capello M, Soria M, Cotel P, Potin G, Dagorn L, Preon P. 2012. The heterogeneous spatial and temporal patterns of behavior of small pelagic fish in an array of Fish Aggregating Devices (FADs). J Exp Mar Biol Ecol 430-431: 56-62. DOI: 10.1016/j.jembe.2012.06.022.

Capello M, Soria M, Cotel P, Potin G, Dagorn L, Preon P. 2013. Effect of current and daylight variations on small-pelagic fish aggregations (*Selar Crumenophthalmus*) around a coastal fish aggregating device studied by fine-scale acoustic tracking. Aquat Living Resour 26 (1): 63-68. DOI: 10.1051/alr/2012025.

Capello M, Deneubourg JL, Robert M, Holland KN, Schaefer KM, Dagorn L. 2016. Population assessment of tropical tuna based on their

associative behavior around floating objects. Sci Rep 6 (1): 36415. DOI: 10.1038/srep36415.
Chaliluddin MA, Aprill RM, Affan JM, Muhammadar A, Rahmadani H, Miswar E, Firdus F. 2018. Efektivitas penggunaan rumpon sebagai daerah penangkapan ikan di Perairan Pusong Kota Lhokseumawe. Depik 7 (2): 119-126. DOI: 10.13170/depik.7.2.11322. [Indonesia]
Cody CEL, Moreno G, Restrepo V, Roman MH, Maunder MN. 2018. Recent purse-seine FAD fishing strategies in the eastern Pacific Ocean: What is the appropriate number of FADs at sea ? ICES J Mar Sci 75 (5): 1748-1757. DOI: 10.1093/icesjms/fsy046.
Dagorn L, Bez N, Fauvel T, Walker E. 2013. How much do fish aggregating devices (FADs) modify the floating object environment in the ocean? Fish Oceanogr 22 (3): 147-153. DOI: 10.1111/fog.12014.
Davies TK, Mees CC, Gulland EJM. 2014. The past, present and future use of drifting fish aggregating devices (FADs) in the Indian Ocean. Mar Policy 45: 163-170. DOI: 10.1016/j.marpol.2013.12.014.
Dempster T, Kingsford MJ. 2003. Homing of pelagic fish to fish aggregation devices (FADs): The role of sensory cues. Mar Ecol Prog Ser 258: 213-222. DOI: 10.3354/meps258213.
Dempster T, Taquet M. 2004. Fish Aggregation Device (FADs) research: Gaps in current knowledge and future directions for ecological studies. Rev Fish Biol And Fish 14 (1): 21-42. DOI: 10.1007/s11160-004-3151-x.
Doray M, Josse E, Gervain P, Reynal L, Chantrel J. 2007. Joint use of echosounding, fishing and video techniques to assess the structure of fish aggregations around moored fish aggregating devices in martinique (Lesser Antilles). Aquat Living Resour 20 (4): 357-366. DOI: 10.1051/alr:2008004.
Fonteneau A, Chassot E, Bodin N. 2013. Global spatio-temporal patterns in tropical tuna purse seine fisheries on drifting fish aggregating devices (DFADs): Taking a historical perspective to inform current challenges. Aquat Living Resour 26 (1): 37-48. DOI: 10.1051/alr/2013046.
Forget FG, Capello M, Filmalter JD, Govinden R, Soria M, Cowley PD, Dagorn L. 2015. Behaviour and vulnerability of target and non-target species at drifting fish aggregating devices (FADs) in the tropical tuna purse seine fishery determined by acoustic telemetry. Can J Fish Aquat Sci 72 (9): 1398-1405. DOI: 10.1139/cjfas-2014-0458.
Ghufron MZ, Triarso I, Kunarso K. 2019. Analisis hubungan suhu permukaan laut dan klorofil-a citra satelit SUOMI NPP VIIRS terhadap hasil tangkapan purse seine di PPN Pengambengan, Bali. J Fish Sci Technol 14 (2): 128-135. DOI: 10.14710/ijfst.14.2.128-135. [Indonesian]
Godo OR, Hjellvik V, Iversen SA, Slotte A, Tenningen E, Torkelsen T. 2004. Behavior of mackerel schools during summer feeding migration in the norwegian sea, as observed from fishing vessel Sonars. ICES J Mar Sci 61 (7): 1093-1099. DOI: 10.1016/j.icesjms.2004.06.009.
Hamar B, Bone AH. 2021. Utilization of FAD distribution in south buton waters as a fishing app by purse sein fishermen in Kadatua District, Selatan Buton Regency. J Asian Mult Res for Soc Sci Stud 2 (3): 125-131. DOI: 10.47616/jamrems.v2i3.165.
Hasaruddin H, Thahir MA, Yusfiandayani R, Baskoro MS, Jaya I. 2021. Palm fiber as potential material for FADs: Durability enhancement and increasing fish catching for small scale fisheries. IOP Conf Ser Earth Environ Sci 800: 012005. DOI: 10.1088/1755-1315/800/1/012005.
Ibrahim S, Ambak MA, Shamsudin L, Samsudin MZ. 1995. Importance of Fish Aggregating Devices (FADs) as substrates for food organisms of fish. Fish Res 27 (4): 265-273. DOI: 10.1016/0165-7836(96)00473-0.
Irawati A, Baso A, Najamuddin. 2021. Bioeconomic analysis of Indian Scad (*Decapterus ruselli*) in the Bone bay Waters of South Sulawesi. Intl J Environ Agric Biotechnol 6 (1): 112-119. DOI: 10.22161/ijeab.61.15.
Irineo ET, Gaertner D, Chassot E, León MD. 2014. Changes in fishing power and fishing strategies driven by new technologies: The case of tropical tuna purse seiners in the eastern Atlantic Ocean. Fish Res 155: 10-19. DOI: 10.1016/j.fishres.2014.02.017.
Jalil AR 2013. Distribusi kecepatan arus pasang surut pada muson peralihan barat-timur terkait hasil tangkapan ikan pelagis kecil di perairan Spermonde. Depik 2 (1): 26-32. DOI: 10.13170/depik.2.1.583. [Indonesia]
Jauharee AR, Capello M, Simier M, Forget F, Adam MS, Dagorn L. 2021. Tuna behaviour atanchored FADs inferred from Local Ecological Knowledge (LEK) of pole-and line tuna fishers in the Maldives. Plos One 16 (7): e0254617. DOI: 10.1371/journal.pone.0254617.
Josse E, Bertrand A. 2000. In situ acoustic target strength measurements of tuna associated with a Fish Aggregating Device. ICES J Mar Sci 57 (4): 911-918. DOI: 10.1006/jmsc.2000.0578.
Jufri A, Amran MA, Zainuddin M. 2014. Karakteriktik daerah penangkapan ikan cakalang pada musim barat di perairan teluk bone. Jurnal IPTEK PSP 1 (1): 1-10. DOI: 10.20956/jipsp.v1i1.63. [Indonesia]
Kefi OS, Katiandagho EM, Paransa IJ. 2013. Sukses pengoperasian pukat cincin Sinar Lestari 04 dengan alat bantu rumpon yang beroperasi di Perairan Lolak Provinsi Sulawesi Utara. J Capture Fish Sci Technol 1 (3): 69-75. DOI: 10.35800/jitpt.1.3.2013.1345. [Indonesian]
Khan AMA, Nasutionc AM, Purbaa NP, Rizala A, Zahidaha, Hamdania H, Dewantia LP, Juniantoa, Nurruhwatia I, Sahidina A, Supriyadia D, Herawatia H, Apriliania IM, Ridwana M, Grayd TS, Jiange M, Arieff M, Millb AC, Polunin. 2020. Oceanographic characteristics at fish aggregating device sites for tuna pole and line fishery in eastern Indonesia. Fish Res 225: 105471. DOI: 10.1016/j.fishres.2019.105471.
Lopez J, Moreno G, Sancristobal I, Murua J. 2014. Evolution and current state of the technology of echosounder buoys used by Spanish tropical tuna purse seiners in the Atlantic, Indian and Pacific Oceans. Fish Res 155: 127-137. DOI: 10.1016/j.fishres.2014.02.033.
Lopez J, Moreno G, Ibaibarriaga L, Dagorn L. 2017a. Diel behaviour of tuna and non-tuna species at drifting fish aggregating devices (DFADs) in the Western Indian Ocean, determined by fishers' echo-sounder buoys. Mar Biol 164: 44. DOI: 10.1007/s00227-017-3075-3.
Lopez J, Moreno G, Cody LC, Maunder M, Sancristobal I, Caballero A. 2017b. Environmental preferences of tuna and non-tuna species associated with drifting fish aggregating devices (FADs) in the Atlantic Ocean, ascertained through fishers' echo-sounder buoys. Deep Sea Res II Top Stud Oceanogr 140: 127-138. DOI: 10.1016/j.dsr2.2017.02.007.
Macusi ED, Babaran RP, van Zwieten PAM. 2015. Strategies and tactics of tuna fishers in the payao (anchored FAD) fishery from general Santos city, Philippines. Mar Policy 62: 63-73. DOI: 10.1016/j.fishres.2014.02.033.
Macusi ED, Abreo NAS, Babaran RP. 2017. Local ecological knowledge (LEK) on fish behavior around anchored FADs: The case of tuna purse seine and ring net fishers from Southern Philippines. Front Mar Sci 4: 188. DOI: 10.3389/fmars.2017.00188.
Matrutty DDP, Paillin JB, Siahainenia SR, Waileruny W, Rutumalessy K. 2019. Productivity and distribution of Fish Aggregation Devices (FADs) in outer Ambon Bay Waters, Indonesia. Omni-Akuatika 17 (1): 105-112. DOI: 10.20884/1.oa.2021.17.1.777.
Matsumoto T, Satoh K, Semba Y, Toyonaga M. 2016. Comparison of the behavior of skipjack (Katsuwonus pelamis), yellowfin (T*hunnus albacares*) and bigeye (*T. obesus*) tuna associated with drifting FADs in the equatorial central Pacific Ocean. Fish Oceanogr 25 (6): 565-581. DOI: 10.1111/fog.1217.
Maufroy A, Kaplan DM, Bez N, Molina ADD, Murua H, Floch L. 2016. Massive increase in the use of drifting Fish Aggregating Devices (dFADs) by tropical tuna purse seine fisheries in the Atlantic and Indian oceans. ICES J Mar Sci 74: 215-225. DOI: 10.1093/icesjms/fsw175.
Moreno G, Dagorn L, Sancho G, Itano D. 2007. Fish behavior from fishers' knowledge: The case study of tropical tuna around drifting Fish Aggregating Devices (FADs). Can J Fish Aquat Sci 64 (11): 1517-1528. DOI: 10.1139/F07-113.
Moreno G, Boyra G, Sancristobal I, Itano D, Restrepo V. 2019. Towards acoustic discrimination of tropical tuna associated with fish aggregating devices. Plos One 14 (6): e0216353. DOI: 10.1371/journal.pone.0216353.
Nurdin E, Mamun A, Alfi MF, Baskoro MS. 2019. Keberadaan madidihang (*Thunnus Albacares*) di sekitar Rumpon. Fish Res J 25 (1): 35-44. DOI: 10.15578/jppi.25.1.2019.35-44. [Indonesia]
Nurdin E, Natsir M, Hufiadi. 2017. Pengaruh intensitas cahaya terhadap ketertarikan gerombolan ikan pelagis kecil pada mini purse seine di perairan Pemalang Jawa Tengah. Fish Res J 13 (2): 125-132. DOI: 10.15578/jppi.13.2.2007.125-132. [Indonesian]
Orue B, Lopez J, Moreno G, Santiago J, Soto M, Murua H. 2019. Aggregation process of drifting fish Aggregating Devices (DFADs) in the western Indian Ocean: Who arrives first, tuna or non-tuna species? Plos One 14 (1): e0210435. DOI: 10.1371/journal.pone.0210435.
Orue B, Pennino MG, Lopez J, Moreno G, Santiago J, Ramos L, Murua H. 2020. Seasonal distribution of tuna and non-tuna species associated with drifting Fish Aggregating Devices (DFADs) in the

Western Indian ocean using fishery-independent data. Front Mar Sci 7 (441): 1-17. DOI: 10.3389/fmars.2020.00441.

Priatna A, Nugroho D, Mahiswara. 2010. Keberadaan ikan pelagis rumpon laut dalam pada musim timur di perairan Samudera Hindia sebelah selatan Teluk Pelabuhan Ratu dengan metode hidroakustik. Jurnal Penelitian Perikanan Indonesia 16 (2): 83-91. DOI: 10.15578/jppi.16.2.2010.83-91. [Indonesia]

Putri ARS, Zainuddin M, Musbir M, Mustapha MA, Hidayat R. 2019. Effect of oceanographic conditions on skipjack tuna catches from FAD versus free-swimming school fishing in the Makassar Strait. IOP Conf Ser: Earth Environ Sci 370: 012008. DOI: 10.1088/1755-1315/370/1/012008.

Rountree RA. 1990. Community structure of fishes attracted to shallow water fish aggregation devices off South Carolina, U.S.A. Environ Biol Fish 29 (4): 241-262. DOI: 10.1007/BF00001183.

Rumpa A, Isman K. 2018. Desain purse seine yang ideal Berdasarkan tingkah laku ikan layang (*Decapterus macarellus*) dan ikan tongkol deho (*Auxis thazard*) di Rumpon. Prosiding Simposium Nasional Kelautan dan Perikanan V. Universitas Hasanuddin, Makassar, 5 Mei 2018. [Indonesia]

Safruddin. 2013. Distribusi Ikan Layang (*Decapterus Sp*) hubungannya dengan kondisi oseanografi di perairan Kabupaten Pangkep, Sulawesi Selatan. Torani 23 (3): 150-156. [Indonesia]

Safruddin, Hidayat R, Zainuddin M. 2018. Oceanographic conditions on small pelagic fishery in the Gulf of Bone Waters. Torani 1 (2): 48-58. DOI: 10.35911/torani.v1i2.4442.

Sarianto D, Djunaidi, Istrianto K. 2019. Sebaran rumpon di Samudera Hindia pada daerah penangkapan *purse Seine*. Jurnal Airaha 8: 059-066. DOI: 10.15578/ja.v8i02.115. [Indonesia]

Seloi A, Malik FI, Yani, Mallawa A, Safruddin. 2019. Remote chlorophyll-a and SST to determination of fish potential area in makassar strait waters using MODIS satellite data. IOP Conf Ser Earth Environ Sci 270: 012047. DOI: 10.1088/1755-1315/270/1/012047.

Simbolon D, Jeujanan B, Wiyono ES. 2011. Efektivitas pemanfaatan rumpon pada operasi penangkapan ikan di perairan Kei Kecil, Maluku Tenggara. Mar Fish 2 (1): 19-28. DOI: 10.29244/jmf.2.1.19-28. [Indonesia]

Taquet M 2004. Le comportement agrégatif de la dorade coryphène (*Coryphaena hippurus*) autour des objets flottants. [Phd Thesis]. Université de Paris, France.

Tenningen M, Macaulay GJ, Rieucau G, Korneliussen RJ. 2017. Behaviours of Atlantic herring and mackerel in a purse-seine net, observed using multibeam sonar. ICES J Mar Sci 74 (1): 359-368. DOI: 10.1093/icesjms/fsw159.

Trygonis V, Georgakarakos S, Dagorn L, Brehmer P. 2016. Spatio temporal distribution of fish schools around drifting fish aggregating devices. Fish Res 177: 39-49. DOI: 10.1016/j.fishres.2016.01.013.

Véras LQ, Capello M, Forget F, Tolotti MT, Véras DP, Dagorn L, Hazin FH. 2020. Aggregative capacity of experimental anchored fish aggregating devices (FADs) in Northeastern Brazil revealed through electronic tagging data. Ocean Coast Res DOI: 10.1590/s2675-28242020068284.

Widyatmoko AC, Hardesty BD, Wilcox C. 2021. Detecting anchored fish aggregating devices (AFADs) and estimating use patterns from vessel tracking data in small-scale fisheries. Sci Rep 11 (1): 1-11. DOI: 10.1038/s41598-021-97227-1.

Wudianto, Widodo AN, Satria F, Mahiswara. 2019. Kajian Pengelolaan rumpon laut dalam sebagai alat bantu penangkapan tuna di perairan Indonesia. Jurnal Kebijakan Perikanan Indonesia 11 (1): 23-37. DOI: 10.15578/Jkpi.11.1.2019.23-37. [Indonesia]

Yusfiandayani R 2013. Fish aggregating devices in Indonesia: Past and present status on sustainable capture fisheries. Galaxea. J Coral Reef Stud 5: 260-268. DOI: 10.3755/galaxea.15.260.

Zhou C, Xu L, Hu F, Kumazawa T. 2015. The kinetic deformation of tuna purse seine: A model experiment on different shooting patterns at uniform current. Fish Res 169: 18-25. DOI: 10.1016/j.fishres.2015.04.008.

Zhou C, Xu L, Tang H, Hu F, He P, Kumazawa T, Wang X, Wan R, Dong S. 2019. Identifying the design alternatives and flow interference of tuna purse seine by the numerical modelling approach. J Mar Sci Eng 7 (11): 405. DOI: 10.3390/jmse7110405.