The level of purse seine sustainability in yellowfin tuna (*Thunnus albacares*) fishing in the Bone Bay waters

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Abstract. Yellowfin tuna (*Thunnus albacares*) is one of the most important pelagic fish in the waters of the Bone Bay where to conserve this resource, it is necessary to use sustainable fishing technology. Research on the level of sustainability of purse seines inside and outside fish aggregation dvices (FADs) was carried out in the Bone Bay waters from January to November 2020. Data about fish size, percentage of eligible size fish to catch, impacts of technology on habitat, biodiversity and fishermen, quality of fish products was obtained through observation during fishing operations. Impacts of fish product on consumers, by catch, fuel used value, investment value, benefit value, the number of labor used, and legality of fishing technology was obtained through direct observation during fishing operations and interviews with business unit owners, policy makers and community leaders. The level of sustainability of the purse seine inside and outside FADs was analyzed using the scoring method. The results showed that the level of sustainability of purse seine inside FADs was classified as moderate, while the level of sustainability of purse seine outside FADs was classified as high. The decrease in the level of purse seine sustainability when fishing in the FAD area is caused by the catch is dominated by small-sized tuna, low percentage of eligible fish to catch, the frequent capture of protected marine organisms, high by-catch and contrary to several existing regulations.
Key words: yellowfin tuna, sustainability, purse seine, FADs

Introduction. Yellowfin tuna (*Thunnus albacares*) is one of the important commodities in the waters of the Fisheries Management Area of the Republic of Indonesia 713 (FMA-RI 713) especially in the waters of the Bone Bay. Yellowfin tuna utilizes the waters of the Bone Bay as a foraging area and also a rearing area and after reaching a certain size or maturing gonads returns to the waters of the Indian Ocean to spawn (Mallawa et al 2020a). Yellowfin tuna production in FMA-RI 713 increased very rapidly, namely from 5,509.9 tons in 2010 to 28,515.5 tons in 2018, of which 13,775.7 tons (48.31%) were produced from the waters of the Bay of Bone (MAFA 2020). In the Bone Bay waters, yellowfin tuna is caught by fishermen using purse seine, pole and line, hand line, trolling line, surface gill net and boat lift but the main fishing gear is purse seine. The catch of yellowfin tuna by purse seine in the waters of Bone Bay is carried out in two methods, namely catching in the fish aggregation dvices (FADs) area and chasing fish schools. In general, the use of FADs in purse seines can increase the number of by-catches and the dominance of small-size fish in the catch, a low percentage of eligible fish to catch, the capture of protected marine organisms, changes movement pattern, fish are easier to catch (Hallier & Gaertner 2008; Romanov 2008; Morgan 2011; Mallawa 2020; Mallawa et al 2020b). Yellowfin tuna is a straddling and highly migratory species so that fish stocks need to be managed properly (FAO 1995), including during their presence in the Bone Bay waters. UNO (1995) explains that in making a policy for the management and utilization of a type of fish resource, it is necessary to use a precautionary approach. Policy decision making must be based on scientific studies. Furthermore, in the utilization of fish resources, sustainable or environmentally friendly fishing technology should be used. Mallawa et al (2018) reported that the sustained rate of the purse seine in fishing for skipjack tuna (*Katsuwonus pelamis*) in FAD areas, decreased as a result of the frequent capture of protected marine organisms and the catch was dominated by small and low percentage of eligible fish to catch. This can also occur in the purse seine-FADs in the yellowfin tuna fishery.

The present study aims to analyze the sustainability level of the purse seine in catching yellowfin tuna in the Bone Bay waters. The results of present study are useful as a basis for policy making by decision makers in the Indonesian fisheries sector, especially in the Bone Bay waters.

Material and Method

Description of the study sites. This research was conducted from January to November 2020 in the Bone Bay waters, South Sulawesi. To represent the waters of the northern part of Bone Bay, fish sample and fish measurements were centered at the Bonepute fisherman's landing, Luwu Regency. To represent the waters of the southern part of Bone Bay, fisherman samples and fish measurements were centered at the Lonrae fisherman landings, Bone Regency (Figure 1).

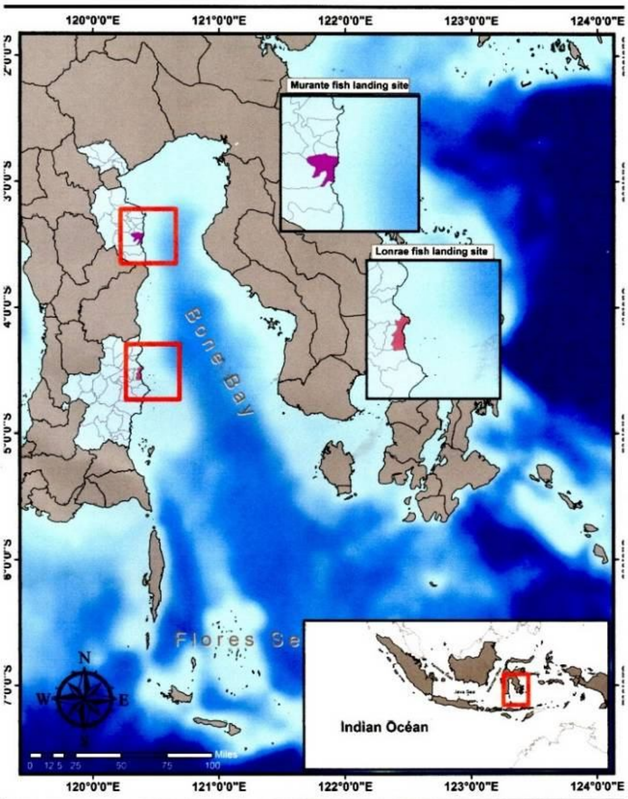

Figure 1. Location of the research (Source: Mallawa et al 2020a).

Materials and equipment. Materials used in the present study included yellowfin tuna fish and some chemicals, namely Bouin's solution for gonad sample preservation, alcohol for washing gonad samples, Mayer's hematoxylin and eosin for staining tissue samples. While the research equipment includes units of purse seiners (fishing vessel and purse seine), "rumpon" (traditional FADs), portable GPS-Garmin Etrex 10, digital camera Canon-EOS-1DX Mark III, measuring boards, computer-Lenovo Ideapad 320 and software such as SPPS and micro-softs excel. The purse seine used by fishermen in the waters of Bone Bay was a mini purse seine with a net length of about 400-600 meters, a net width of 35-45 meters, using nylon polyamide thread. The size of the meshes of the body and wings was 2.5 cm and the bag was 2 cm. The buoyancy of the purse seine was produced from two types of buoys, namely a ball shape with a diameter of 10.5 cm, made of plastic as much as 1500-1600 pieces, and a banana shape float made of fiber with a diameter of 3.0 cm as much as 1500-1600 pieces. Purse seine vessels were made of wood and measured 5-10 GT. The technical specifications of the purse seine used to catch yellowfin tuna, both in the FAD area and outside the FAD area are the same. The difference between the two is that purse seines catch fish using FADs (inside FADs area) and purse seines catch fish by chasing schools of fish (outside FADs area). The purse seiner boats used are presented in Figure 2.

Figure 2. Purse seiner boat in Luwu (left) and Bone (right) used in the present research.

Data collection. The data included the size (fork length - FL - in cm) of the yellowfin tuna caught, by-catch, quality of catches, capture of protected marine organisms, impacts of technology on the habitats, fishing ground location, collected through direct observation during the time when fishing operations took place. While data about fuel use, investment costs, business profits were obtained through interviews and financial records of the owner of the fishing unit. Field data collection was carried out for 20 trips each for the purse seine inside FADs and outside FADs from different vessels. Of the 20 trips for data collection, 10 trips were carried out in the northern part and 10 trips in the southern part of Bone Bay. The sample fish measured in the present study are presented in Figure 3.

Figure 3. Small (left) and large (right) yellowfin tuna caught by purse seine in the Bone Bay waters.

Data analysis. The analysis of the sustainability level of purse seine operated in the FAD area and outside the FAD was analyzed using the scoring method (Mallawa et al 2020a) as presented in Table 1. The dominant size of yellowfin tuna in the catch can be known through descriptive analysis by plotting the middle class length value and the relative frequency (%) of each length class and presented in column diagram. The percentage of eligible fish to catch in the catch was obtained by comparing the number of pre-adult and adult fish and the total number of fish in the catch. In the present study, pre-adult and adult fish were determined based on the level of maturity of the gonads. Fish with maturity level III were stated as pre-adult fish and fish with gonad maturity level IV and above were declared as adult fish. The analysis of the gonads maturity level used a morphological approach. Yellowfin tuna that was categorized eligible fish to catch were fish that had III and IV gonad maturity levels or fish measuring more than 110 cm FL (Mallawa et al 2020a). Catches that were stated as by-catch in the present study were non-target organisms such as non-target fish, cetaceans, sea turtles, sharks, ray, etc. or product was rejected at sea because of low commercial value or the legislation in force.

The sustainability level of purse seine inside and outside FADs areas was calculated using the scoring method (Mallawa et al 2018) as follows:

$$SL = (\sum Wi*Vi)/Vf$$

where: SL is the sustainability level of technology;
Wi is weight of variable i;
Vi is the value of variable i;
Vf is the full value of all variable (40);
i = 1, 2, 3, ..., n.

The categories of the sustainability level of fishing technology are:
≥ 80%, is very high sustainable;
≥ 65 - < 80%, is highly sustainable;
≥ 50 - < 65, is moderate sustainable;
< 50%, is low sustainable.

Table 1
The sustainability analysis used on both the purse seine inside and outside the FADs

No	*Sustainability variables*	*Weight*	*Value*
1	Size structure of yellowfin tuna in catches:	1.00	
	1.1 dominated by young fish;		1
	1.2 dominated by young and pre-adult fish;		2
	1.3 dominated by pre-adult and adult fish;		3
	1.4 dominated by adult fish.		4
2	Percentage of eligible size in catch:	1.00	
	2.1 Less than 10%;		1
	2.2 10 – less than 30%;		2
	2.3 30 – less than 50%;		3
	2.4 ≥ 50%.		4
3	Impact of technology to habitat:	0.75	
	3.1 damaged habitat in wide area;		1
	3.2 damaged habitat in narrow area;		2
	3.3 damaged a part of habitat in narrow area;		3
	3.4 safety for habitat.		4
4	Quality of fish product:	0.50	
	4.1 dead and rotten fishes;		1
	4.2 dead fishes and physical deformity;		2
	4.3 dead fresh fishes;		3
	4.4 live fishes.		4
5	The impact of using technology on fishermen:	0.50	
	5.1 can cause death;		1
	5.2 can result in defects;		2
	5.3 can interfere with the user's health;		3
	5.4 safe for fishermen.		4
6	Impact of fish product on consumers:	0.50	
	6.1 likely to cause death;		1
	6.2 cause health problems;		2
	6.3 relatively safe for consumers;		3
	6.4 safe for consumers.		4
7	By-catches:	0.75	
	7.1 consists of several unsold species;		1
	7.2 consists of several species and there can be sold;		2
	7.3 by-catch ≤ 3 species and sold;		3
	7.4 by-catch < 3 species and high value.		4
8	Impact on diversity of aquatic organisms:	0.75	
	8.1 often captures protected marine organisms;		1
	8.2 several times captures protected marine organisms;		2
	8.3 have ever captured protected marine organisms;		3
	8.4 never catch protected marine organisms.		4

9	Fuel use value: 9.1 fuel use > IDR 2 million $trip^{-1}$; 9.2 fuel usage of IDR 1.0-2.0 million $trip^{-1}$; 9.3 fuel usage IDR 0.5-1.0 million $trip^{-1}$; 9.4 fuel use < IDR 0.5 million $trip^{-1}$.	0.75	 1 2 3 4
10	Value of investment costs: 10.1 > IDR 500 million; 10.2 > IDR 400-500 million; 10.3 IDR 300-400 million; 10.4 < IDR 300 million.	1.00	 1 2 3 4
11	Total labor use: 11.1 using < 5 workers; 11.2 using 5 - < 10 workers; 11.3 using 10 - < 15 workers; 11.4 using > 15 workers.	0.50	 1 2 3 4
12	Value of business profits: 12.1 < IDR 100 million $year^{-1}$; 12.2 IDR 100 - < 250 million $year^{-1}$; 12.3 IDR 250-500 million $year^{-1}$; 12.4 > IDR 500 million $year^{-1}$.	0.50	 1 2 3 4
13	Legality of technology: 13.1 contrary to more than two regulations; 13.2 contrary to two regulations; 13.3 contrary to one regulation; 13.4 not against any of the rules.	0.50	 1 2 3 4
14	Relation to local customs and wisdom: 14.1 very contrary to local customs and wisdom; 14.2 contrary to local customs and wisdom; 14.3 slightly contrary to local customs and wisdom; 14.4 not contrary to local customs and wisdom.	0.50	 1 2 3 4

Result and Discussion

Size structure of yellowfin tuna caught. The results showed that the yellowfin tuna caught by the purse seine inside FADs was the smallest, namely 28.3 cm, and the largest was 128.5 cm, the dominant size ranged from 45.0 to 77.0 cm and the average length was 73.40±24.97 cm. While in case of yellowfin tuna caught by purse seine outside FADs, the smallest was 50.0 cm, the largest was 153.0 cm, and the dominant size was 66.0-130.0 cm and the average length was 95.73±23.76 cm (Figure 4).

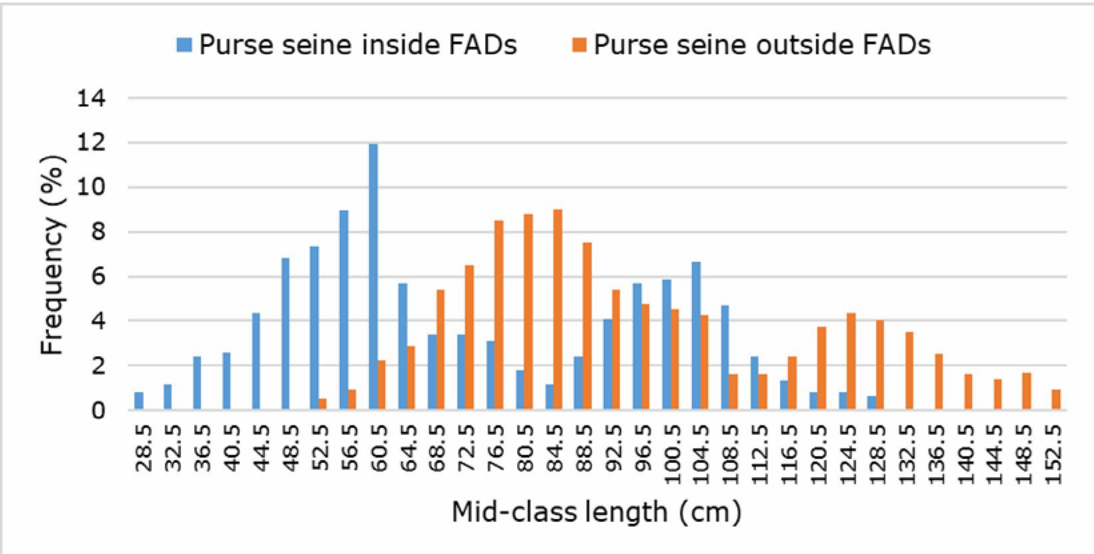

Figure 4. Size structure of yellowfin tuna caught by purse seine inside and outside FADs in Bone Bay waters.

Percentage of eligible fish to catch in catch. The results of the analysis using the morphological level of gonad maturity showed that the percentage of eligible fish to catch on the purse seine inside and outside FADs was very low. The number of yellowfin tuna eligible size to catch in purse seine inside FADs is smaller than a purse seine outside FADs.

Impact of technology on habitat. The habitat damage by the use of purse seines is not significant because both purse seines inside and outside the FADs operate on the surface of the sea waters. Damage to narrow areas can occur on purse seine inside FADs, which is due to the use of FADs. However, in this study, it was not found that the unused portion of FADs was left in the sea.

Quality of fish caught. The results of organoleptic observations show that the yellowfin tuna produced by purse seine inside and outside FADs is of very good quality. Fish that are caught are immediately put into storage boxes that have been given enough ice. In addition, the yellowfin tuna purse seine in the waters of the Gulf of Bone is only one day trip so that the fish they catch are not kept on the boat for long. When the ship docked at the fishing port, the fish are handled properly using a cold chain system so that the fish reaching consumers are still fresh.

Impact of technology on fishermen. Observations show that during the fishing operation, both on the purse seine inside FADs and outside FADs, nothing very real negative things to fishermen occurred. A small impact occurs on the purse seine inside FADS, that is, sometimes before the setting is carried out, visual observations are made to determine the presence of fish through diving by fishermen without using diving equipment. Diving without using equipment can damage health, especially the sense of hearing.

Impact of fish product on consumers. The results of the interview show that in the last five years there were no cases where the community had a health problem because of eating yellowfin tuna.

By-catch. The result of the observation is that the purse seine that catches in the FADs area besides yellowfin tuna also catches several other large pelagic fish such as shark, little tuna, and skipjack and several small pelagic fish such as flying fish, mackerel, sardine and so on. The same incident was observed in purse seine non FADs associated.

Impact on protected marine organisms. The observation showed that purse seines inside FADs always catch protected marine organisms such as turtles, sharks or dolphins while the purse seine outside FADS sometimes catches dolphins or sharks.

The amount of fuel used. The result of the observation showed that the use of fuel in the purse seine inside FADs and outside FADs is different where the use of purse seine fuel outside FADs is higher than the purse seine inside FADS. The high use of fuel in purse seines outside FADs is due to the activity of finding schools of fish.

Business investment. Investment spending includes ships, fishing gear, FADs, machine and others. The results of the analysis showed that the use of FADs causes the investment value of purse seine inside FADs to be slightly higher than the investment value of purse seine outside FADs, but the investment value of both is high.

The amount of labor used. The result of the observation showed that the number of workers used in the purse seine inside and outside FADS is quite large and does not differ. The large number of workers occurs because there are many activities that must be handled in setting and hauling of fishing gear.

Business profit per year. The results of the analysis showed that the benefits obtained by the purse seine inside and outsides FADS are high. This relates to the number of trips per year, the number of catches per trip and the price of fish caught.

Legalization of technology. The result of the observation showed that the purse seine inside FADs conducts operations in shallow waters. FADs are generally installed in the fishing area of the zone I, which contradicts the Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia number 71 of 2016 concerning fishing zone and placement of fishing gear in the Fisheries Management Area of the Republic of Indonesia (MMAF-RI 2016). In addition, the capture of protected fish is contrary to the Regulation of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia number 06 of 2018 concerning the utilization of protected fish species (MMAF 2018). Furthermore, the two types of technology do not conflict with local wisdom. The performance of the purse seine sustainability variables operated inside and outside Fads is presented in Table 2.

Table 2

Sustainability variables of purse seine inside and outside FADs areas in Bone Bay

Sustainability variables	*Purse seine inside FAD*	*Purse seine outside FAD*
Size structure of fish caught	Dominated by young fish	Dominated by young and pre-adult fish
Eligible size to catch	33.01%	47.78%
Impact of technology to habitats	Damage a part of habitat in narrow area	Does not damage the habitat
Quality of fish product	Dead and fresh fishes	Dead and fresh fishes
The impact of using technology on fishermen	Can interfere with the user's health	Safe for fishermen
Impact of fish product to consumers	Safe for consumers	Safe for consumers
By-catches	Consists of several species and there can be sold	Consists of several species and there can be sold
Impact of technology on diversity of marine organisms	Often captures protected marine organisms	Several times capturing protected marine organisms
The use of fuel oil (IDR million)	0.40-0.50	0.60-0.75
Value of investment costs (IDR million)	550-600	450-500
Total labor use (person/unit)	11-13	10-12
Value of business profits (IDR million/year)	500-750	500-750
Legal according to national and international regulations	Contrary to two regulations	Contrary to one regulation
Relation to local customs and wisdom	Not contrary to local customs and wisdom	Not contrary to local customs and wisdom

Based on direct observations and interviews obtained in Table 2, and the values that should be given as shown in Table 1, an analysis of the sustainability of purse seines inside and outside the FADs areas is presented in Tables 3 and 4.

Based on the analysis results (Tables 3 and 4) it can be stated that the purse seine that catch tuna in the FAD area has a moderate level of sustainability, while the purse seine that catches outside the FAD area has a high level of sustainability. The difference in the level of sustainability of the two technologies is caused by, first, the difference in the size structure of yellowfin tuna in the catch. The use of FADs caused a large number of young or small yellowfin tuna in the catches. Second, the use of FADs can argue that there is always the capture of protected marine organisms every hauling, third, the use of FADs increases the number by catch, and fourth, the use of FADs increases the investment amount.

Table 3
Sustainability analysis of purse seine operated inside FADs areas in Bone Bay waters

Sustainability variables	*Weight*	*Value**	*Weight*Value*
The size structure of yellowfin tuna in catch	1.00	1	1.00
Percentage of eligible size to catch in catch	1.00	3	3.00
Impact of technology to habitat	0.75	3	2.25
Quality of fish product	0.50	3	1.50
Impact of using technology on fishermen	0.50	3	1.50
Impact of fish product to consumers	0.50	4	2.00
By-catch	0.75	2	1.50
Impact of technology on diversity of marine organisms	0.75	1	0.75
The use of fuel oil	0.75	3	2.25
Value of investment costs	1.00	1	1.00
Total labor use	1.00	3	3.00
Value of business profits	0.50	4	2.00
Legal according to national and international regulations	0.50	2	1.00
Relation to local customs and wisdom	0.50	4	2.00
Total weight*value			24.75
Sustainability level (%)			61.86
Sustainability category			Moderately sustainable

Table 4
Sustainability analysis of purse seine operated outside FADs areas in Bone Bay waters

Sustainability variables	*Weight*	*Value**	*Weight*Value*
The size structure of yellowfin tuna in catch	1.00	2	2.00
Percentage of eligible size to catch in catch	1.00	3	3.00
Impact of technology to habitat	0.75	3	2.25
Quality of fish product	0.50	3	1.50
Impact of using technology on fishermen	0.50	4	2.00
Impact of fish product to consumers	0.50	4	2.00
By-catch	0.75	2	1.50
Impact of technology on diversity of marine organisms	0.75	2	1.50
The use of fuel oil	0.75	3	2.25
Value of investment costs	1.00	2	2.00
Total labor use	1.00	3	3.00
Value of business profits	0.50	4	2.00
Legal according to national and international regulations	0.50	3	1.50
Relation to local customs and wisdom	0.50	4	2.00
Total weight*value			28.50
Sustainability level (%)			71.25
Sustainability category			Highly sustainable

The phenomenon of an increase in the number of small yellowfin tuna in the purse catches inside the FADs area was also noted by other researchers. Menard et al (2000) and Leroy et al (2013) explained that aggregation of tuna around drifting object increase their vulnerability to purse seine gear, particularly a juvenile and small size class. Scott & Lopez (2014) stated that the use of FADs does not necessarily lead to overfishing of tropical tunas although harvesting large amount of certain small tunas such big eye tuna and yellowfin tuna and can reduce long-term potential maximum sustainable yield (MSY). Furthermore, that juvenile tuna is frequently found at FADs because those FADs provide protection and also provide good food supply, which increase their chances to survive. Rochman et al (2019) reported that in the catch of small-scale tuna fisheries in FADs in the waters of Labuhan Lombok there were 13.44% juvenile tuna. Proctor et al (2019) reported that the results of measuring the length of yellowfin tuna from various fishing ports in Indonesia, 91.69% were categorized as small yellowfin tuna (< 100 cm) and 8.31% large fish (> 100 cm). Furthermore, the yellowfin tuna caught by purse seine inside FADs area was dominated by small fish and a few large fish, but it is possible that larger fish were caught opportunistically by hand line during the fishing trip. The increase in small fish in purse seine catches in FADs also occurred in skipjack fisheries in the Bone Bay and Makassar Strait waters (Mallawa 2020; Mallawa et al 2020b). The number of small yellowfin tuna caught in the FAD area more than outside the FAD area also occurred in pole and line fisheries in the waters of Bone Bay (Mallawa et al 2021).

The situation in which the use of FADs in tuna purse seine can lead to an increase in the types and numbers of protected marine organisms in the catches also occurs in various other waters. Chumchuen et al (2019) explained that the use of FADs on tuna purse seines in the eastern Indian Ocean can lead to the capture of protected marine organisms such as silky sharks (*Carcharhinus falciformis*), requiem sharks (*Carcharhinus* spp.), dolphinfish (*Coryphaena hippurus*). Leroy et al (2013) described that further to impact on target stock, the use of FADs increase the vulnerability of other fishes to purse seine method, including some shark and billfish species.

The increase in the volume of by-catch in the use of FADs in tuna purse seines were also noted by several other researchers. Purse seine on FADs generally has by-catch rates of non-target species that are higher than those of free school sets occurs in the Pacific Ocean and Indian Ocean (Hall & Roman 2013; ISSF 2019). Amande et al (2010) reported that the annual average by-catch tuna purse seine in Atlantic waters is 7.5% of the total catch. Furthermore, from the number of by-catch, tuna represent 83%, followed by bony fishes (10%), billfish (5%), sharks (1%), and ray (1%). Mallawa (2020) reports that the by-catch of skipjack purse seine inside FADs in Bone Bay, Makassar Strait and Flores Sea are 4.59%, 5.68% and 4.52% while by-catch skipjack purse seine outside FADs are 3.42%, 3.56% and 3.03% respectively. Lecomte et al (2017) described that in Indian Ocean, by-catch in purse seine-FADs was quite high, namely 5.3% of total catch and purse free school of 1.17%. By-catch purse seine-FADs and purse seine free school consists of more than three species, namely various tuna, various fish, sharks, sailfish and rays.

Conclusions. The level of sustainability of purse seines inside FADs is classified as moderately sustainable while purse seines outside FADs area are classified as highly sustainable. The cause of the decrease in the level of sustainability of yellowfin tuna purse seine is the use of FADs. The use of FADs resulted in the dominance of young yellowfin tuna in the catch, increased by-catch, always catch of protected marine organism, increased investment costs and in operation some rules are opposed.

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Conflict of interest. The authors declare that there is no conflict of interest.

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