Study of tunas (*Thunnus* spp.) swimming layer using tuna longliner in the Northern Indian Ocean, Indonesia

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Abstract. Research on the depth of the tuna swimming layer was carried out from November 2016 to May 2017 in the Indian Ocean. The present study aims to obtain information about tuna long liner operating techniques, determine the composition of the main catch and determine the depth of the tuna swimming layer in the Indian Ocean. This research is a case study of tuna fishing activities on tuna long liner. The catch obtained in this study consisted of 85 Bigeye tuna (*Thunnus obesus*), 45 Albacore (*Thunnus alalunga*), 23 Yellowfin tuna (*Thunnus albacares*) (15%), and 7 (4%) Southern bluefin tuna (*Thunnus maccoyii*). The swimming layer of *T. obesus*, *T. alalunga* and *T. albacares* was at a depth of 41–327.48 m., whilethe swimming layer of *T.maccoyii* was found at a depth of 189-310.54 m.
Key Words: thermocline layer, hook rate, basket system, South Savu Sea.

Introduction. Tuna longline is one of the most effective fishing gears to catch tuna. In addition, this fishing gear is selective to catch tuna (Nugraha & Setyadji 2013). Tuna longline is a combination of several lines with branch line and is equipped with buoys and hook (Subani & Barus 1989). Tuna longline consists of a series of main lines, and on the main line at a certain distance there are several branch lines that are shorter and smaller in diameter. At the end of the branch line is linked a hook with bait (Sjarif & Mulyadi 2004) (Figure 1). This bait includes sardine (*Sardenilla longiceps*), Indian mackerel (*Rastrelliger kanagurta*), scad mackerel (*Decapterus* spp.), bigeye scad (*Selar crumenophthalmus*), squid (*Loligo* spp.) and milkfish (*Chanos chanos*) (Santoso 1995). *C. chanos* is also used for longline fishing live bait, especially by Taiwanese vessels (Beverly et al 2003).

The distribution and abundance of tuna is strongly influenced by variations in temperature and water depth parameters. Information concerning the distribution of tuna based on temperature and water depth is very important to support the success of tuna fishing operations (Barata et al 2011).

Pelagic fish are fast swimming fish. Tuna is a fast swimmer that differs in epipelagic waters (>500 m) and can swim as far as 55 km every day (Nurjana et al 2014). Tuna fish live by navigating the world's great oceans with a swimming speed of up to 50 km hour^{-1} (Baskoro & Wahyu 2004).

The interaction between target fish and bycatch is strongly influenced by the swimming layer (Novianto & Nugraha 2014). The depth of the swimming layer of tuna is influenced by temperature and salinity. The depth of the hook can be determined by changing the distance between two adjacent buoys. In addition, there are still other ways, namely by changing the length of the tuna longline such as main lines, branch line and buoy lines (Djatikusumo 1977).

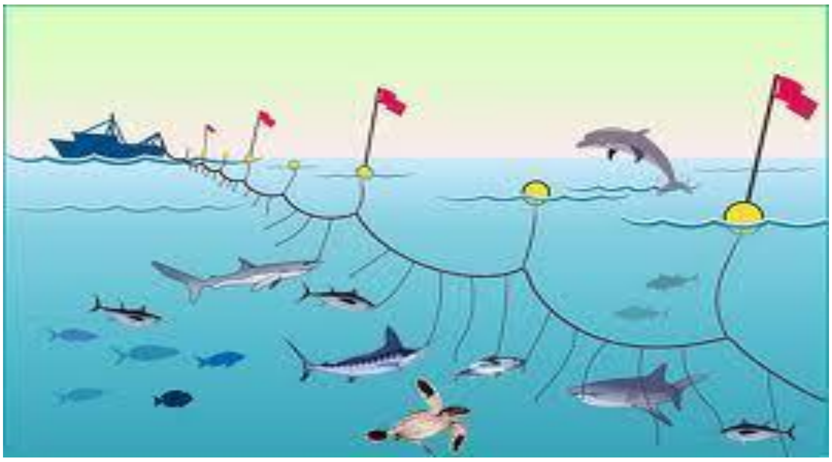

Figure 1. Tuna longline fishing (https://ikantunaku.wordpress.com).

Fishing ground. The fishing areas in Indonesian waters for tuna are Banda Sea, Maluku Sea, waters of south Java Island continuing to the east, as well as south of Sumatra waters, around Andaman and Nicobar, waters of north Irian Jaya, south of Timor waters and so on (Ayodhyoa 1981).

Generally, most pelagic fish rise to the surface before sunset. After sunset, these fish spread out on the water column, and sink into deeper layers after sunrise. Demersal fish usually spend the day at the bottom and then rise and spread in the water column at night (Reddy 1993).

The distribution of tuna's is influenced by several factors, two of which are temperature and the swimming layer of tuna (Nakamura 1969). Sedana (2004) reported parameters of the fishing area according to the target catch species as specified in Table 1.

Table 1

Fishing area parameters according to the target catch species (Sedana 2004)

Species	*Depth (m)*	*Temperature (ºC)*
Bigeye tuna (*T. obesus*)	50-600, thermocline layer	10-17
Yellowfin tuna (*T. albacares*)	50-250, top and middle layers	18-28
Albacore (*T. alalunga*)	50-600, thermocline layer	10-17
Blue Marlin (*Makaira nigricans*)	50-150, top and middle layers	18-22

Fishing season. The fishing season for several types of tuna in Indian Ocean is generally thought to last for six months (Sedana 2004).

Table 2

Season of Indian Ocean tuna fishing (Sedana 2004)

Species	*Season (month)*	*Peak*
Southern bluefin tuna (*T. maccoyii*)	January - April	January
Yellowfin tuna (*T. albacares*)	November - January	December
Bigeye tuna (*T. obesus*)	February - June	June
Albacore (*T. alalunga*)	June - August	June
Other large pelagic species	July - December	October

Swimming layer. The distribution of tuna fish (based on depth of water) is most influenced by swimming layer and temperature (Nugraha et al 2010). Several previous research results also showed differences in the depth of the swimming layer of each type of tuna obtained in the Indian Ocean. *T. obesus* can be found at a depth of 186-285 m, *T. albacares* at 149-185 m, and *T. alalunga* at a depth of 161-220 m (Santoso 1999). *T.*

obesus was caught at a depth of 300-399.9 m, *T. albacares* 250-299.9 m and *T. alalunga* at 150-199.9 m (Nugraha & Triharyuni 2009).

The purpose of the present study was to find out the types of tuna caught in Indonesian waters and to know the depth of the swimming layer in the Nothern Indian Ocean.

Material and Method. The research was carried out from November 2016 to May 2017 using longliners operating in the Indian Ocean (Figure 2). The equipments used in this research were: cameras, stationery, calculators, laptops, meters, and tuna caught as research objects.

Picture. 2 Longliners in Bali, Indonesia.

At the time of research, the catching system used two basket systems, namely basket with thirteen branch lines and basket with six branch lines.

The methods used in data collection consisted of carrying out activities on longliner fishing vessel and using several methods, namely: observation, interview, and literature study.

Data analysis. The data analysis was performed using descriptive method, namely by reducing the data obtained in the field and comparing it with literature studies. Data and information obtained during the implementation of the study was analyzed by descriptive analysis method and qualitative analysis methods. Formula 1 and formula 2 below were used to calculate the depth of the fishing line using the Yoshihara method (1951).

$$D = fl + bl + {}^{1}\!/_{2}\, BK \left\{ \sqrt{(1 + Cotg^2\sigma)} - \sqrt{\left(1 - \frac{2j}{n}\right)^2 + Cotg^2\sigma} \right\}$$

Where:

D - depth of hook (m)
Fl - length of the float line
bl - length of branch line
BK - length of play line in 1 basket (m)
j - number of branch line position
n - number of branch lines in 1 basket + 1

K	θ	Cotg²θ
0.47136	79	0.03778
0.48657	78	0.04777
0.51698	77	0.05330
0.60821	69	0.14232
0.54739	75	0.07127
0.51698	77	0.05330
0.63862	66	0.18960
0.77927	54	0.52786
0.60821	69	0.14232
0.56674	73	0.09079

The value of the angle σ was obtained first by finding the curvature coefficient of the main line.

$$K = \frac{Vk\ x\ Ts}{BK\ x\ \sum b}$$

Where:
K - coefficient of curvature
Vk - ship speed (km h^{-1})
Ts - setting time (hours)
b - number of baskets

Formula 3 below was used to calculate the catch rate in the ratio of the catch to the number of hooks.

$$Hook\ rate = \frac{Number\ of\ fish\ caught/trip}{Number\ of\ hooks\ attached\ /\ trip}\ x\ 100$$

Fishing ground. The area of operation during the voyage was area 1 of the distribution of *T. maccoyii* fishing areas, which is around the south of the islands of Bali, Lombok and Sumbawa (Figure 3).

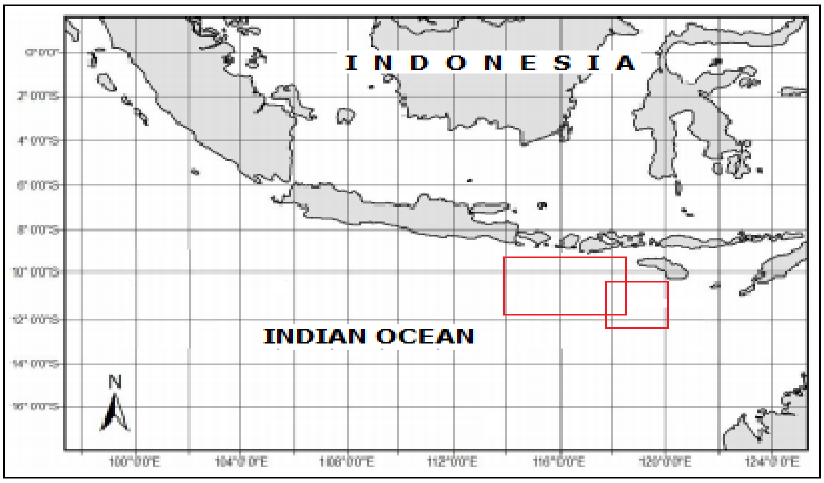

Figure 3. Longliner fishing ground.

Results and Discussion

Basket with thirteen branch lines. From the 64 settings, there were 48 settings using basket with thirteen branch lines (Figure 4), the setting time started at 06.00 central Indonesia time (WITA) until it finishes average five hours per setting time, setting using basket with thirteen branch lines is done when the moon is in the dark moon (not in a full moon) and when hauling is at 17.00 central Indonesia time (WITA) until the end of the hauling time is 9-12 hours depending on the weather and the main line is disconnected or not, the more main line decisions the longer the hauling process.

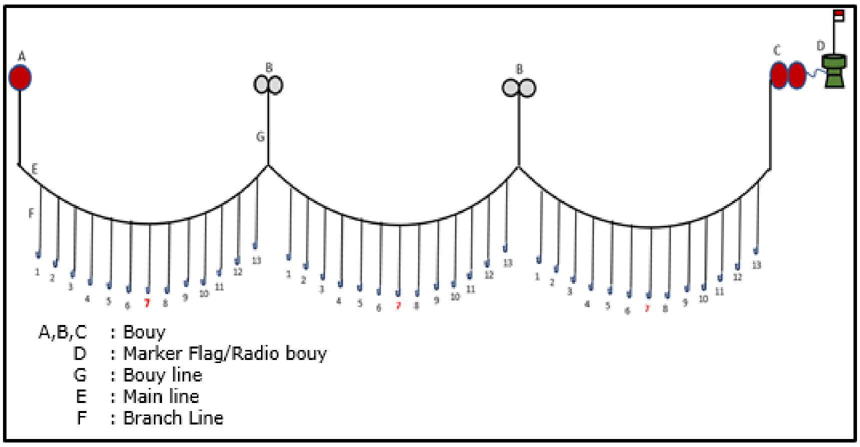

Figure 4. Sketch of basket with 13 branch lines.

The main catch using basket with 13 branch lines was 90 fish, 56.25% of the total main catch. The tuna caught were *T. alalunga*, *T. obesus*, *T. albacares* and *T. maccoyii*.

Basket with six branch lines. From 64 times of the overall settings, for 16 times basket with six branch lines was used (Figure 5). Unlike the thirteen branch line basket, this setting is done at 17.00 central Indonesia time (WITA) until it's finished, the setting takes 6-7 hours because the speed of the main line throwing the speed is slightly reduced when using this basket, because the hooks does not sink too deep due to chasing tuna that swim on the surface of the water, this basket is usually used at full moon, 3 days before full moon and 3 days after full moon.

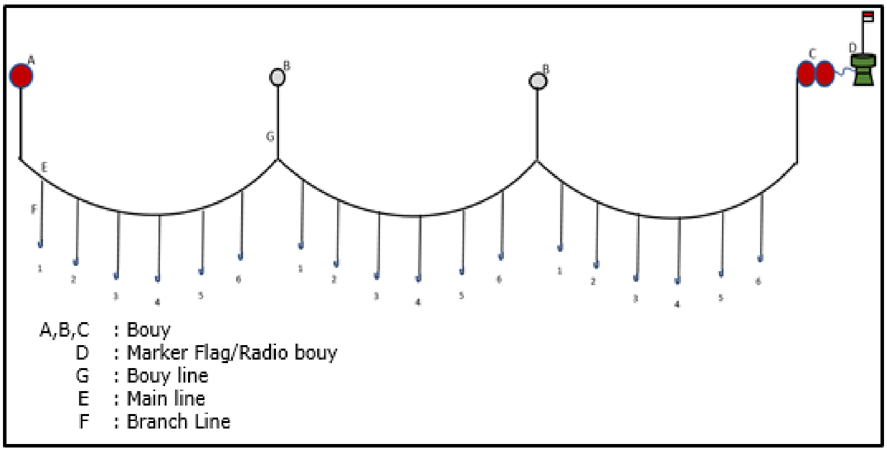

Figure 5. Sketch of basket with 6 branch lines.

The main catch using a basket with six branch lines consisted of 70 fish, 43.75% of the total main catch. From the two types of basket, the highest catches were obtained in basket with 6 branch lines viewed from the catch comparison factor with the number of settings perspective.

Catch composition. The catch obtained was grouped into main catch and bycatch. The main catch was considered to consist of tuna species, while bycatch consisted of any other species.

The total catch obtained during 91 days of fishing operation or 64 settings consisted of 160 fish. The main catch obtained included *T. alalunga*, *T. obesus*, *T. albacares* and *T. maccoyii*. Comparison of the amount of catch can be seen in Figure 6.

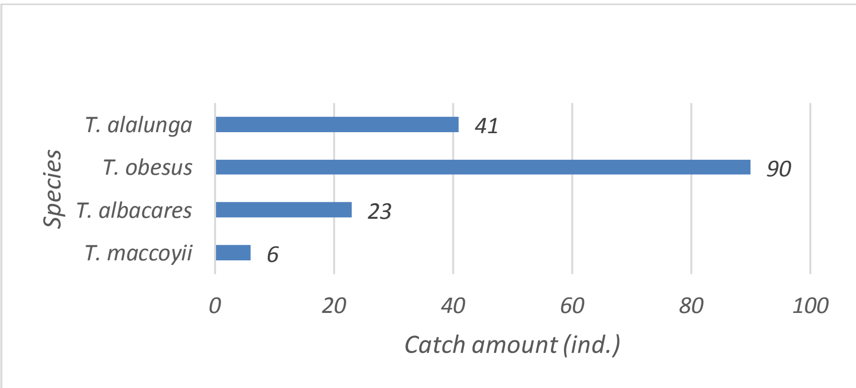

Figure 6. Comparison of the amount of catches.

The total catch was dominated by *T. obesus* with a total catch of 90 fish (56%), 41 *T. alalunga* (26.54%), 23 *T. albacares*. (14.20%) while the lowest catch was recorded for *T. maccoyii* amounting 6 fish (4%).

Catch composition of based on size. The tuna species caught had different lengths according to species. The length measurement divided the catch into several categories, namely size 50-100 cm, 100-150 cm, and >150 cm. The distribution of the catch based on length can be seen in Figure 7.

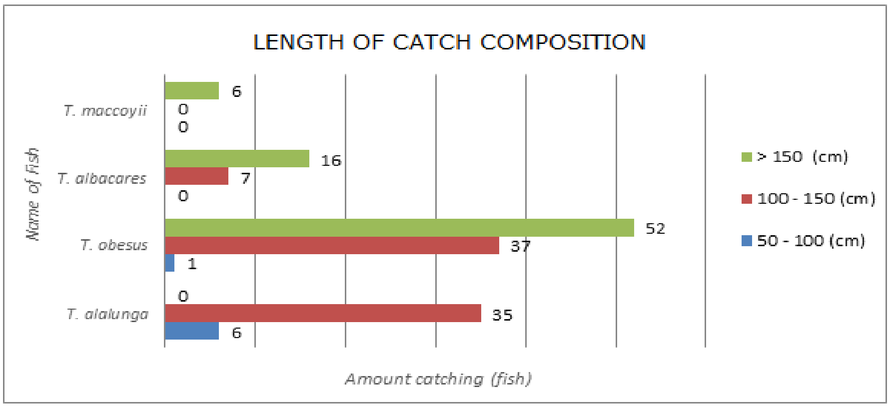

Figure 7. Length of catch composition.

There were 35 *T. alalunga* caught at 100-150 cm size or 44.30%. *T. obesus* was caught mostly at >150 cm in size as many as 52 individuals or about 70.27%. *T. albacares* was mostly caught at a size of >150 cm as many as 16 fish or 21.62%. All individuals of *T. maccoyii* caught were all, over 150 cm amounting 6 fish or 4%.

However, all the catch has a size of more than 150 cm which means it was in the feasible catch category. The feasible catch category implies individuals over 120 cm (Pranata 2013). *T. maccoyii* in Northern Indian Ocean was similar with those captured in the Northern Hemisphere, only smaller in size (Pranata 2013).

Catch results based on fishing position. The first basket uses thirteen branch lines to catch tuna whose fishing area is deeper, usually performed when it is not a full moon. The second basket uses six branch lines to catch tuna swimming to the surface of the water, six branch lines are used when the full moon is around 7 days.

a. Basket with 13 branch lines

The composition of the catch based on the number of hooks can be seen in the Table 3.

Table 3

Catch based on 13 fishing lines positions

Species	*Branch lines*							*Fish*
	1, 13	*2, 12*	*3, 11*	*4, 10*	*5, 9*	*6, 8*	*7*	*(ind.)*
Albacore (*T. alalunga*)	2	1	3	3	7	3	3	22
Bigeye tuna (*T. obesus*)	6	6	6	11	12	8	6	55
Yellowfin tuna (*T. albacares*)	2	0	2	2	2	3	0	11
Southern bluefin tuna (*T. maccoyii*)	0	0	0	0	0	2	0	2
Fish (individuals)	10	7	11	16	21	16	9	90
Number hook	10,150	10,150	10,150	10,150	10,150	10,150	5,075	-
Hook rate (%)	0.0985	0.0690	0.1084	0.1576	0.2069	0.1576	0.1773	-

Based on the Table 3, *T. alalunga* and *T. obesus* were mostly caught on branch line 5 and 9. *T. albacares* was almost evenly caught in each branch lines, but was not caught on lure numbers 2, 7 and 12. *T. maccoyii* was caught on hook number 6 and number 8 only.

b. Basket with 6 branch lines

The composition of the catch based on the number of 6 hooks can be seen in Table 4.

Table 4

Catch based on position of 6 branch lines

Species	*Branch lines*			*Fish (ind.)*
	1,6	*2,5*	*3,4*	
Albacore (*T. alalunga*)	6	6	7	19
Bigeye tuna (*T. obesus*)	10	11	14	35
Yellowfin tuna (*T. albacares*)	4	4	4	12
Southern bluefin tuna (*T. maccoyii*)	1	2	1	4
Fish (individuals)	21	23	26	70
Number hook	7,180	7,180	7,180	-
Hook rate (%)	0.292	0.320	0.362	-

Based on Table 4, *T. alalunga* was mostly caught on fishing lines 3 and 4, and were caught evenly on all fishing lines. *T. obesus* was caught mostly in branch line number 3 and 4, and was caught almost evenly on all fishing lines. *T. albacares* was captured evenly on all hooks. *T. maccoyii* was mostly caught on line 2 and 5 and evenly caught on the other hooks.

Hook rate. The hook rate is a real calculation in quantity proportional to the number of fish caught at one time, for tuna longline itself calculated for 100 hooks. So this hook rate determines whether the area still has good fishing potential or not, so that future availability can be calculated.

Figure 8 shows the result of tuna hook rate for 64 settings, these results are for all the four tuna species captured *T. obesus*, *T. albacares*, *T. alalunga*, and *T. maccoyii*. The results showed that the average hook rate was 0.18% with the highest hook rate at setting 64, with a hook rate of 0.79%.

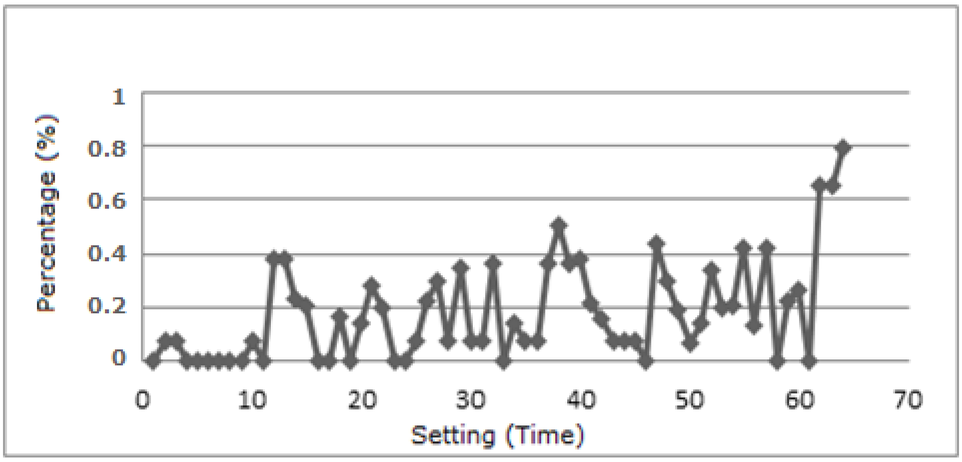

Figure 8. Percentage of hook rate.

Estimated depth of tuna swimming layer

a. Basket with 13 branch lines

The depth of the fishing line in operation with 13 branch lines has different depths as it is shown in Table 5.

Table 5

Calculation of the depth for each fishing line

Branch line number	*Depth (m)*		
	Upper limit	*Lower limit*	*Average*
1, 13	41.29	56.87	44.50
2, 12	80.35	113.10	87.49
3, 11	116.25	168.30	128.25
4, 10	147.65	221.56	165.58
5, 9	172.70	270.82	197.47
6, 8	189.14	310.54	220.47
7	194.10	327.49	229.32

b. Basket with 6 branch lines

The depth of the branch lines in operation with 6 hooks has different depths, as it is shown in Table 6.

Table 6

The results of the calculation of the depth of each fishing line number

Branch line number	*Depth (m)*		
	Upper limit	*Lower limit*	*Average*
1, 6	41.76	52.99	44.71
2, 5	75.47	103.72	82.38
3, 4	95.28	145.11	106.19

Swimming layer. The spread of tuna in the sea is determined by two factors, namely internal factors and external factors. Internal factors include genetics, age, size and behavior. Different genetics causes differences in morphology, physiological responses, and adaptability to the environment. External factors are environmental factors, including oceanographic parameters such as temperature, salinity, density, depth of the thermocline layer, currents, water mass circulation, oxygen and food abundance. The swimming depth of tuna varies depending on the species.

In general, tuna is caught at a depth of 0-400 meters. The preferred water salinity ranges from 32 to 35 ppt or in oceanic waters and water temperature ranges of 17-31ºC (Pranata 2013).

Tuna catches based on the position of the fishing line (Table 3 and Table 4) and the calculation results of each fishing line number depth value (Table 5 and Table 6) obtained can be used as material for estimating the depth of the swimming layer for each species of tuna.

T. alalunga was caught in all branch lines, the majority was caught on branch line 5 and 9 (Table 3) as much as 31.82%. It is suspected that *T. alalunga* swimming layer is at a depth of 172.70-270.82 m. The distribution of *T. alalunga* is strongly influenced by temperature and this tuna prefers lower temperatures. According to Nugraha & Triharyuni (2009), the distribution of *T. alalunga* is in a temperature range of 14-24ºC with a catching temperature range of 17-24ºC. At juvenile stage, *T. alalunga* prefers habitat in the area around the equator and its swimming layer is near the surface layer. After maturity (>95 cm), begins to move to a deeper layer (Block & Stevens 2001).

T. obesus catches were recorded almost evenly across the hooks. The depth of the swimming layer of this species is estimated to be at a depth of 41.30–327.49 m, the majority being caught at 172.70–270.82 m depth interval (branch line 5 and 8). *T. obesus* are often caught on deeper branch lines (no. 4, 5, and 6), because *T. obesus* prefer deep water with cooler temperatures (Block & Stevens 2001). The swimming area for *T. obesus* is located just below the thermocline layer, so it is advisable to use the deep sea tuna longline type (Santoso 1999).

T. albacares caught on all hooks consisted of 23 individuals (81.81%). The swimming layer of this species is thought to be at a depth of 189.14–310.54 m. *T.*

albacares is often found in fishing lines close to the surface. Mainly this species is generally found above 100 m deep layers which have sufficient oxygen content. In the deeper layers where oxygen levels are low, *T. albacares* individuals are rare, while juvenile *T. albacares* can be found clustered with *K. pelamis* and *T. obesus* in the surface layer. When they are mature, they tend to stay in this water layer. The distribution of *T. albacares* is in the temperature range of 18–31°C (Block & Stevens 2001).

T. maccoyii was caught in a quantity of 7 individuals and all of them was caught on branch line 2, 3, and 4 but mostly found on branch line number 2 amounting to 42.85%. Tuna which has a large body size has a spreading area with temperatures between 5-20ºC and can be found at depths of up to 1,000 m. This high adaptation behavior to extreme temperatures is due to the fact that *T. maccoyii* can raise its blood temperature above water temperature using its muscle activity (Block & Stevens 2001). *T. maccoyii* caught in the present study were suspected to be spawning individuals.

Figure 9 is an illustration of the swimming depth layer of tuna from the results of the present study. It can be seen the difference in the depth of the swimming layer between the four species of tuna captured. The difference in the vertical distribution of tuna is caused by several factors, one of which is temperature (Pranata 2013). According to the results of research by Nugraha & Triharyuni (2009), in the Indian Ocean *T. obesus* was caught in the temperature range of 10.0-13.9ºC, *T. albacares* at 16.0-16.9ºC, and *T. alalunga* at 20.0-20.9ºC. In addition, differences in location or geographic location also affect the habitat of tuna.

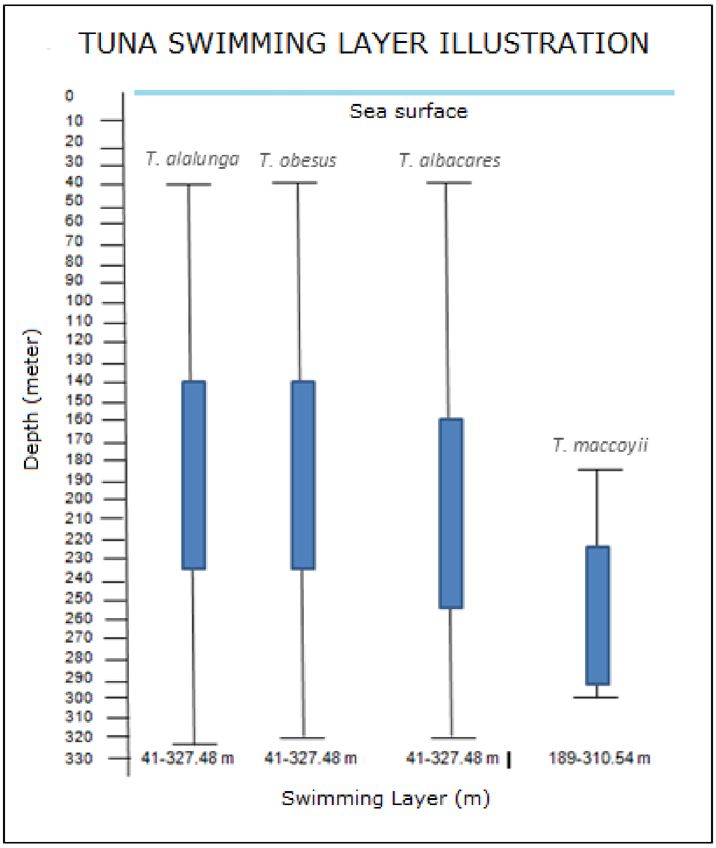

Figure 9. Tuna swimming layer illustration.

Several previous research results also showed differences in the depth of the swimming layer of each type of tuna captured in the Indian Ocean waters. The results of Santoso (1999) research show that *T. obesus* can be found at a depth of 186-285 m, *T. albacares* at 149-185 m, and *T. alalunga* at a depth of 161-220 m. Nugraha & Triharyuni (2009) reported that *T. obesus* was caught at a depth of 300-399.9 m, *T. albacares* at 250.0-299.9 m, and *T. alalunga* at 150.0-199.9 m.

Figure 9 illustrates the overall depth rage of the tuna's swimming layer. *T. alalunga* was caught at a depth range of 41–327.48 m, *T. obesus* was caught at the depth range of 41–327.48 m, *T. albacares* was caught at the depth range of 41–327.48 m and *T. maccoyii* was caught at the depth rage of 189–0 310.54 m.

Conclusions

1. The operation of tuna fishing consists of two processes, namely in setting and hauling. The average setting time was around 5 hours depending on the catch quantity. Hauling was performed from 17.00 until early morning.
2. Overall catches consisted of *T. obesus*, *T. albacares*, *T. alalunga*, and *T. maccoyii*. The average hook rate was 0.18% with the highest hook rate at setting 64, with a hook rate of 0.79%.
3. Concerning the tuna swimming layer, *T. alalunga* was caught at a depth range of 41–327.48 m, *T. obesus* was caught at a depth range of 41–327.48 m, *T. albacares* was caught at a depth range of 41–327.48 m and *T. maccoyii* was caught at a depth range of 189 - 310.54 m.
4. The main catch obtained in the present study consisted of 85 *T. obesus*, 45 *T. alalunga*, 23 *T. albacares* (15%), and 7 (4%) *T. maccoyii*.

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