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Blue sharks (*Prionace glauca*) by-catch in the Indonesian industrial tuna longline fishery in the eastern Indian Ocean

Fathur Rochman, Arief Wujdi, Gussasta Levi Arnenda and Roy Kurniawan

Research Institute for Tuna Fisheries, Bali-Indonesia, Jl. Mertasari No. 140 Br. Suwung Kangin, Sidakarya, Denpasar Selatan, Denpasar-Bali, Indonesia 80224

Email: fathursmasabio1@gmail.com

Abstract. The Indonesian tuna longline fisheries in Indonesia have been targetting four main tuna, including yellowfin tuna, bigeye tuna, albacore, and southern bluefin tuna. In reality, there are many by-catch species, including blue sharks. This study aims to provide integrated information on blue shark species as by-catch species in Indonesian industrial tuna longline fisheries, including nominal and standardized CPUE and biomass of blue shark exploited by Indonesian longliners in the eastern Indian Ocean. This research is expected to become a reference point in shark management in the Indian Ocean. The scientific observer collected 2951 set-by-set longline fishing data based on Research Institute For Tuna Fisheries (RITF) from January 2006 to December 2018, on which the present analysis was made. The result indicated that there were eighteen shark species caught by Indonesian longliner were dominated by a blue shark (*Prionace glauca*) (60%) followed by crocodile shark (*Pseudcarcharias kamoharai*) (23.84%), bigeye thresher shark (*Alopias superciliosus*) (3%) and other species (<3%). Nominal CPUE was fluctuating and needed to be standardized in GLM analysis. The results of CPUE standardization can then be used as a reference in calculating the biomass blue sharks exploited by Indonesian Longliners. By considering several aspects, including the average of hook/set/fleet, an average of size (length and weight), the total number of set/ year, reported the number of vessels, it is obtained that the estimated catch of blue sharks ranges from 366.3-2,616 tons per year with an average of about 1,282 tons.

1. Introduction

Pelagic tuna longline tuna fishery targeting four main large tuna and billfish species typically have a high incidental catch of sharks which are landed in an incomplete form (fins, cutlets) [1] and even discharged while onboard (unwanted species) [2,3]. This makes it challenging to record sharks on tuna longlines fisheries because they are not included in the fisher's logbook. So their number, CPUE, species composition, and fishing mortality are poorly understood [3] and finally are not included in any assessment population status.

Shark is a highly migratory species, swim without acknowledging national boundaries and spending their time in 54-92% in high seas, recognized by tagging methods [2]. Shark was different from other teleosts and relatively closed to mammals, including their longevity, modes of reproduction, low fecundity, and delayed at sex maturity (Table 1).

Table 1. Characteristic comparison of human female and female of porbeagle, blue shark, and bluefin tuna

Characteristic	Human	Porbeagle	Blue Shark	Bluefin Tuna
Adult mean length (cm)	163	220	220	220
Age at sexual maturity (years)	13	13	6	8
Mode of fertilization	Internal	Internal	Internal	External
Gestation period (month)	9	9	12	Indeterminate
Birth	Live	Live	Live	Pelagic eggs
Mean number of young per year	1	4	35	10,000,000
Mean length at birth (cm)	44	65	45	0.3
Longevity (years)	80	40	20	40

Source: [2]

For example, the female porbeagle (*Lamna nasus*) seems like a human female at sexual maturity, fertilization, gestation period, and birth. However, there are differences in the number of birth per year and longevity. Porbeagle has a delayed age at sexual maturity and fecundity than other fish, making low productivity. The porbeagle migration area is a fishing area for tuna longliners, so it is possible to be caught using tuna longlines so that the productivity of the porbeagle is likely to be lower than that of humans [2]. However, the maximum intrinsic rate of population increase for porbeagle (r_{max}) was 0.05 [4] was a little bit higher than human 0.03 [2].

Among the existing shark species, the blue shark (*Prionace glauca*) is one of the most abundant species with (r_{max}) 0.29 and six-time higher than porbeagle closed to bluefin tuna [2]. The productivity level of shark species (class Chondrichthyes, subclass Elasmobranchii) was predictable. However, it will take a long time to recover based on the average age at sexual maturity, significantly when the stock has been degraded [4].

The exploitation of shark resources in Indonesia was high, from 1,000 tons in early 1950 to 95,600 tons in 1997. In 2016, the number of sharks caught in one fishing port (Cilacap-Centra Java) amounted to 533.41 tonnes [5]. We know that Cilacap is the home base of industrial longline tuna operated in the Eastern Indian Ocean. This study aims to provide integrated information on blue shark species as by-catch species in Indonesian industrial tuna longline fisheries, including nominal and standardized CPUE and biomass of blue shark exploited by Indonesian longliners in the eastern Indian Ocean.

2. Materials and method

2.1. Study area

This research is a part of the Research Institute for Tuna Fisheries (RITF) scientific observer program from January 2006 to December 2018. The area study covered 75.00ºE-131ºE and 1.00ºS-35ºS of the Indian Ocean, which stretches from the west coast of Sumatra, south of Java/Bali /Nusa Tenggara, west of Australia, and east of Madagascar (Figure 1). The scientific observation is carried out by participating in fishing activities based in four main ports, including Benoa (Bali), Cilacap (Central Java), Palabuhanratu (West Java), and Muara Baru (Jakarta). There were 154 ships involved with 128 trips and 2,951 fishing sets of tuna longliners operated in the eastern Indian Ocean. The QGIS 3.16.2 Hannover was used for spatial data analysis where base map representation using Environmental Systems Research Institute (ESRI) standard map obtained from https://server.arcgisonline.com/ArcGIS/rest/services/World_Street_Map/MapServer/tile/{z}/{y}/{x} and the maritime boundaries geodatabase: naval boundaries and exclusive economic zone (200 NM) version 7 obtained from https://www.marineregions.org/downloads.php as of 27 January 2021.

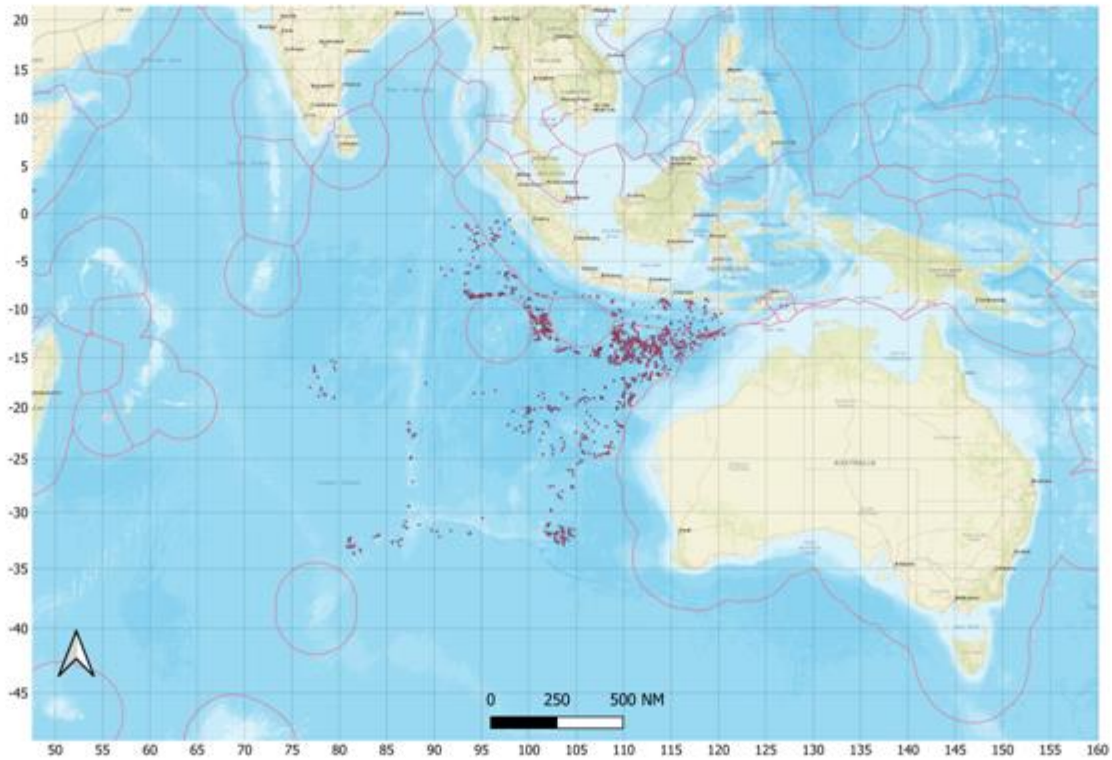

Figure 1. Blue shark (BSH) catches coordinate in RITF scientific observer program 2006-2018 in the Eastern Indian Ocean.

2.2. Data analysis

2.2.1. Nominal catch per unit of effort (CPUE)
This study consists of 2,951 setting data of blue sharks from the onboard scientific observer program 2006-2018, including trip number, setting number, fishing time, fishing coordinate, hook per set, number of catch, and other data related to longline fishing strategy. Nominal Catch per unit of effort (CPUE) was calculated using the number of fish per 100 hooks as the effort [6]. Nominal CPUE is a fluctuating value and is highly dependent on a fishing strategy which includes differences in fishing time, fishing season, fishing area, tuna longline types, and other factors that affect the amount of catch and CPUE. Therefore, an effort to standardize CPUE is needed by involving confounding factors that significantly affect catches.

2.2.2. Standardization of catch per unit of effort (std. CPUE)
The CPUE standardization encloses confounding factors as a covariate in Generalized Linear Model (GLM) analysis. Generalized Linear Model is a flexible general model on linear regression in which response variables have error distribution and normal distribution. Several confounding factors which has the possibility of influencing the catch quantity in a polynomial linear regression model. A one-way ANOVA test was used to see how far these factors significantly affect the catch. The equation model of GLM used in CPUE standardization as follows [7,8]:

$$CPUE = C + \beta_{1j}Cov1_{ij} + \beta_{2j}Cov2_{ij} + \beta_{3j}Cov3_{ij} + \beta_{4j}Cov4_{ij} + e \quad (1)$$

C is Constanta (intercept), *β* is CPUE (no. fish per 100 hooks), *Cov* is covariate from the significant confounding factor, *j* is corresponding to *j*th coefficient, *i* corresponds to an ith data record, and *e* is the error term in a normal distribution.

Tweedie distribution (Poisson and Gamma) was used in this GLM analysis due to the abnormal data distribution with zero CPUE 70.99% of the total data. Tweedie distribution has the power parameter index (*P*) range between 1 to 2, which was suitable for zero CPUE observation data in longline fisheries [7,8]. R version 4.0.3 [9] was used for this statistical analysis. All of the covariates in this GLM analysis were presented in Table 2.

Table 2. All covariate used in GLM analysis.

Covariate	Level	Category	Type
Year	1 to 13	2006-2018	categorical
Quarter	1	January-March	categorical
	2	April-June	
	3	July-September	
	4	October-December	
Season	1	West Monsoon (December-May)	categorical
	2	East Monsoon (June-November)	
Month	1 to 12	January-December	categorical
Area	1 to 40	Area of 5*5 grid Latitude & Longitude	categorical
Hook Between Float (HBF)	1	Surface longline type (1-5 HBF)	categorical
	2	Half-way longline type (6-12 HBF)	
	3	Deep longline type (>12 HBF)	

GLM analysis is performed by determining the *P*-value of randomized quantile residual diagnostic using “Statmod” and “Tweedie” package in R studio. Next, a running model (equation1) is carried out by entering the covariate and the predetermined *P*-value. The ANOVA value is used to determine the covariate that has a significant effect on the CPUE value. The best GLM model is determined by the stepwise AIC (Akaike Information Criterion) value, where the lowest AIC will be selected as the best model.

The CPUE standardization obtained can then be used to calculate the productivity value of the longline fleet for one year using the assumption that the period of fishing per year is nine months with a practical day of 24 days per month. By calculating the average number of hooks per set per day, it can be estimated that the number of hooks used per year per tuna longline fleet can be estimated so that it can be calculated the number of fish per year per fleet. The onboard scientific observer program data set was based on length-frequency data. The fishing productivity was count using length-weight, length-length, and weight-weight relationships as weight-based data for blue shark species [10,11]. Fork length (cmFL) was used in this study, where projected straight from the tip of the upper jaw (snout) to the short caudal ray (fork).

3. Results and discussion

3.1. Catch composition

In this study, 18 species of sharks were identified, including blue shark (*Prionace glauca*), crocodile shark (*Pseudocarcharias kamoharai*), bigeye thresher shark (*Alopias superciliosus*), mako sharks (*Isurus spp*), spinner shark (*Carcharhinus brevipinna*), Oceanic whitetip shark (*Carcharhinus longimanus*), silky shark (*Carcharhinus falciformis*), cookie-cutter shark (*Isistius brasiliensis*), various sharks nei (*Selachimorpha(Pleurotremata)*), hammerhead sharks (*Sphyrna spp*), tiger shark

(*Galeocerdo cuvier*), thresher sharks nei (*Thresher sharks nei*), pelagic thresher (*Pelagic thresher*), whale shark (*Rhincodon typus*), longnose velvet dogfish(*Centroscymnus crepidater*), dusky shark (*Carcharhinus obscurus*), blacktip shark (*Carcharhinus limbatus*) and bull shark (*Carcharhinus leucas*). The shark catches were dominated by blue shark 60.80%, followed by crocodile shark 23.87%, bigeye thresher shark 3.10%, mako shark 2.77%, spinner shark 2.16%, silky shark 1.92%, cookie-cutter shark 1.47%, and other shark species under 1% (Table 3).

Table 3. The composition of shark catches during the RITF scientific observer program 2006-2018.

Species	Code	Number	Percentage (%)
Bull Shark (*Carcharhinus leucas*)	CCE	1	0.030
Blacktip Shark (*Carcharhinus limbatus*)	CCL	2	0.060
Dusky shark (*Carcharhinus obscurus*)	DUS	2	0.060
Longnose velvet dogfish (*Centroscymnus crepidater*)	CYT	2	0.060
Whale shark (*Rhincodon typus*)	RHN	2	0.060
Pelagic thresher (*Pelagic thresher*)	PTH	4	0.120
Thresher sharks nei (*Thresher sharks nei*)	THR	5	0.150
Tiger shark (*Galeocerdo cuvier*)	TIG	11	0.331
Hammerhead sharks (*Sphyrna spp*)	SPN	25	0.751
Various sharks nei (*Selachimorpha(Pleurotremata*))	SKH	28	0.842
Cookie cutter shark (*Isistius brasiliensis*)	ISB	49	1.473
Silky shark (*Carcharhinus falciformis*)	FAL	64	1.924
Oceanic whitetip shark (*Carcharhinus longimanus*)	OCS	72	2.164
Spinner shark (*Carcharhinus brevipinna*)	CCB	72	2.164
Mako sharks (*Isurus spp*)	MAK	92	2.765
Bigeye thresher shark (*Alopias superciliosus*)	BTH	103	3.096
Crocodile shark (*Pseudocarcharias kamoharai*)	PSK	794	23.865
Blue shark (*Prionace glauca*)	BSH	1999	60.084
Total		3327	100

3.2. Nominal and Standardized Catch per Unit of Effort (CPUE)
The nominal CPUE value for blue sharks varies widely and tends to be sharp each year, with the minimum CPUE value achieved in 2011 of 0.001 and a maximum in 2018 of 0.120 with an average CPUE of 0.049 (Figure 2). The significant difference in blue shark CPUE can be caused by several factors, including fishing time (year, quarter, month), fishing area, and changes in fishing strategy.

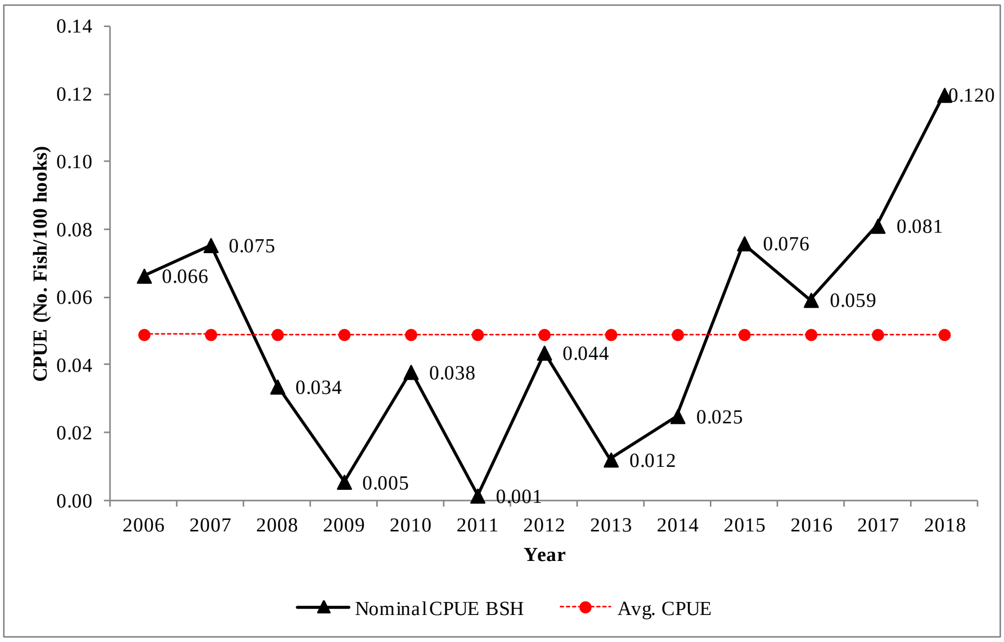

Figure 2. Nominal CPUE of blue shark (BSH) from the scientific observer data 2006-2018 of longliners in the Indian Ocean

There are several models built using the GLM Tweedie distribution, among others presented in Table 4. The significant level of each covariate was summarized in Table 5. The best fit model of GLM CPUE standardization is achieved at the lowest AIC value, but the covariate must significantly affect catch and CPUE.

Table 4. List of model option for blue shark CPUE standardization based on AIC value.

No	Model	AIC
1	CPUE~1	1,959.87
2	CPUE ~ Year	1,604.67
3	CPUE ~ Year + Quarter	1,599.35
4	CPUE ~ Year + Quarter +Season	1,601.28
5	CPUE ~ Year + Quarter + Season + Month	1,598.67
6	CPUE ~ Year + Quarter + Season + Month + Area	1,013.33
7	CPUE ~ Year + Quarter + Season + Month + Area + HBF	1,012.23
8	CPUE ~ Year + Quarter + Month + Area + HBF	1,010.31

Year, Quarter, Month, Area, and HBF significantly affect CPUE except for the season variable (Table 5). So the best model for CPUE standardization is the 8th model with the AIC value 1,010.31 with not enclosed “Season” variable in the model (Table 4). The CPUE standardization using the 8th model results in the CPUE scale was presented in Figure 3. The actual prediction of CPUE standardization results based on the difference in scale is presented in Figure 4.

Table 5. The summary of a significant level of covariate used in blue shark CPUE standardization

Covariate	Df	Deviance Resid.	Df Resid	Dev.	Pr(>Chi)	Sig.
Null			2950	872.16		
Year	12	139.964	2938	732.2	<2.2e-16	***
Quarter	3	4.285	2935	727.91	0.0017	**
Season	1	0.028	2934	727.88	0.75423	
Month	11	1.749	2933	726.13	0.01293	*
Area	39	270.049	2894	456.08	<2.2e-16	***
HBF	2	2.212	2892	453.87	0.02011	*

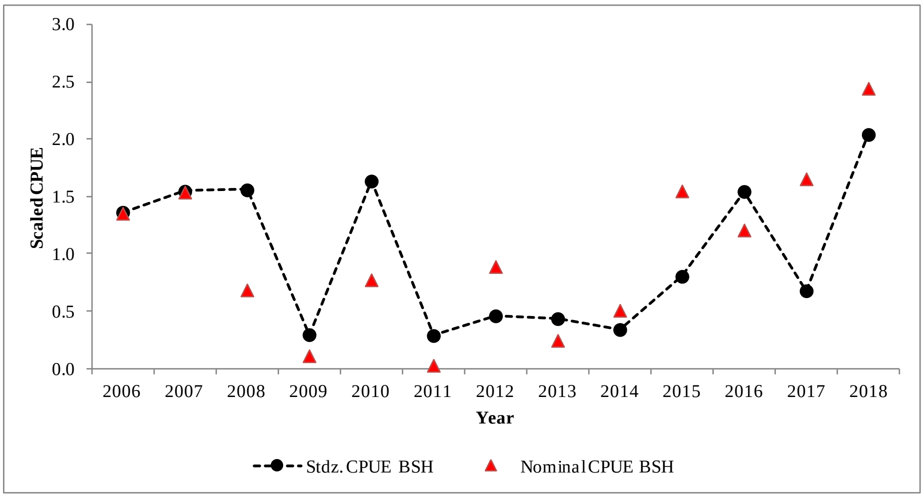

Figure 3. Scaled CPUE of nominal and standardized CPUE of blue shark (BSH) from the scientific observer data 2006-2018 of longliners in the Indian Ocean.

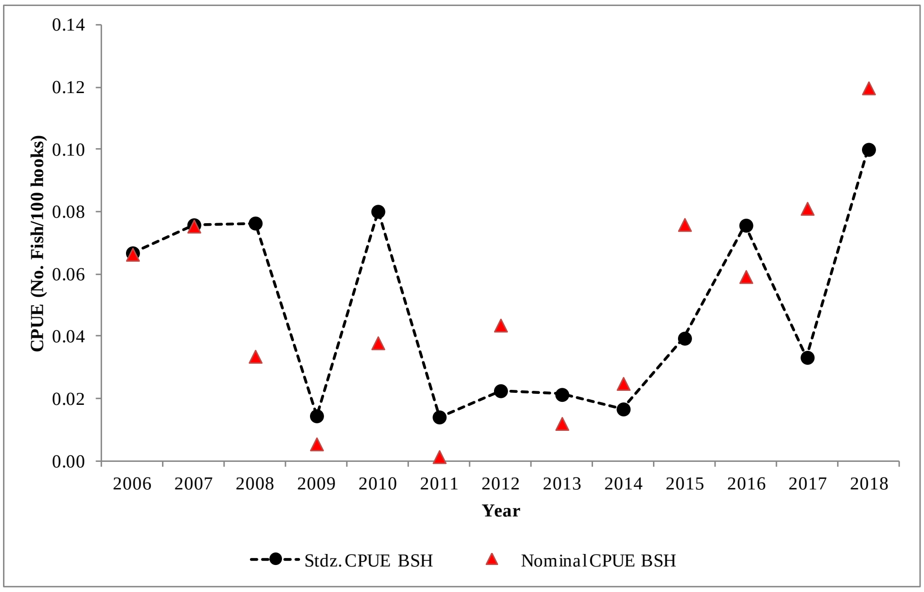

Figure 4. Nominal and standardized CPUE of blue shark (BSH) from the scientific observer data 2006-2018 of longliners in the Indian Ocean.

The minimum value of the CPUE standardization results was in 2011 at 0.014, and the maximum in 2018 was 0.100 with an average standardized CPUE of 0.049. This standardized CPUE value can calculate the biomass of blue sharks per ship per year captured by tuna longlines in the Indian Ocean.
The acquisition of blue sharks nominal and standardized CPUE is primarily influenced by several factors, both environmental factors and fishing strategy [6,8]. So that if the fishing is done at a different time, the fishing area and fishing strategy will produce different catches. The previous research of blue sharks in the North Pacific indicated a similar position where relative abundance trend affected by that variable [12]. The nominal value of CPUE cannot stand alone and must be standardized using the confounding factors that affected the number of blue sharks caught. The increase and decrease in the value of CPUE are not too significantly volatile.

In this study, the increase and decrease in the value of CPUE each year is strongly influenced by several covariates in the GLM analysis, including year, quarter, month, area, and some hooks between float (HBF). The highest catch and CPUE levels are in the second and fourth quarters, namely at the start of the east monsoon (April to June) and the beginning of the west monsoon (October to December).

Blue sharks are not the primary target for tuna longline fishing, but only by-catch species. The main catch targets are four main large tuna, including yellowfin tuna, bigeye tuna, albacore, and southern bluefin tuna. Fishers are operating at high seas with the fishing ground coordinate 12-35ºS aim to catch bigeye tuna, albacore, and southern bluefin tuna. They have a strategy to use deep-sea tuna longlines with a hook between float (HBF) specification of more than 12 hooks between floats with a depth fishing line 75 to 450 m [13,14]. However, in practice, many blue sharks are caught following the main target species where the nominal value of CPUE is higher in high seas areas than areas under the Indonesian exclusive economic zone (EEZ) or areas close to the coast. There is a fact that although fishers use pelagic longlines, 90% blue shark is caught by the surface with an estimated depth of the surface area (homogeneous layer) and the thermocline layer at a depth of 75 to 300 m depth. It can be seen from previous research conducted by [13] on the swimming layer using mini logger data in the Indian Ocean. Statistically, the use of tuna longlines affects ($\rho = 0.02105$), but the strategy for selecting fishing grounds has a more substantial influence on the success of catching blue sharks ($\rho = 2.2e\text{-}16$). This study indicated that fishing areas near the west coast of Sumatra, south Java, Bali, and Nusa Tenggara have an average CPUE of 0.0265.

In contrast, high seas areas between Indonesia and northwest Australia have a higher CPUE value of around 0.0426. Meanwhile, the high seas catchment area in northwest Australia (15-35ºS) has an even higher CPUE value of 0.102. This phenomenon should be studied further by exploring the habitat suitability index and environmental factors in blue shark fishing in the Indian Ocean.

3.3. Biomass

The total biomass of blue sharks per year captured by tuna longliner ships can be calculated by identifying the average number of hooks per year. The average number of hook per set of longliners was 1,394 units with several settings of 24 sets per month. Assuming the day of operation is nine months, the total hooks per year are 301,104 hooks per fleet. The total biomass blue shark per fleet is estimated to be in the range of 1.294-9.245 kg per year, with an average of 5.530 kg per year. Thus, with 283 registered vessels in the Indian Ocean, it is estimated that the total biomass of blue sharks exploited by Indonesian tuna longlines in the Indian Ocean is 366.3-2,616.3 tons per year, with an average of around 1,282 tons per year (Table 5).

Table 6. The estimation of blue shark (BSH) biomass of longliners in the Indian Ocean based on the scientific observer program 2006-2018.

Blue shark (BSH)	Number	Remarks
Avg. Hook per set	1,394.00	
No. set per year	216.00	9 month operation, 24 set/month
Total hook per year	301,104.00	
No. of fish		No. of fish is based on Standardized CPUE (Min, Mean & Max)
1. Min. stdz. CPUE (0.014)	42.15	
2. Mean. Stdz CPUE (0.049)	147.54	
3. Max. Stdz CPUE (0.100)	301.10	
Size (median) (cmFL)	170.00	Based on Box plots size
Avg. Weight (kg)	30.70	
		RND=a*L^b where, a=0.0000031841, b=3.1313 provided by (IOTC, 2005 & IOTC, 2013)
Est. Biomass per Fleet (kg)		
Min.	1,294.30	
Mean.	4,530.06	
Max.	9,245.02	
Reported Fleet	283	Indonesian national report of IOTC, 2020
Estimation of Total Biomass per year (kg)		Longliners operated in the Indian Ocean
Min.	366,287.76	
Mean.	1,282,007.15	
Max.	2,616,341.12	

The estimated value of catching blue sharks by Indonesian tuna longline fishers per year is 366.3-2,616.3 tons, which is 0.66% to 4.75% of the total average estimated catch of blue sharks in the Indian Ocean, where the total average estimated catch of blue sharks in the period of 2011-2015 was 54,993 tons. With an estimated average catch value of 1,282 tonnes per year, it is estimated that the estimated catch of Indonesian blue sharks longliners is 2.33% of the total estimated catch of blue sharks in the Indian Ocean [15]. This study only includes the exploitation value for registered tuna longlines. At the same time, there are also unregistered tuna longlines so that the estimated exploitation of this blue shark can be greater than the estimation of this study. In addition, it is also informed that some fishing gear besides tuna longlines can catch blue sharks, including bottom longline, gillnets, handline, and purse seines [5,15]. In 2017 blue sharks in the Indian Ocean were assessed to be not overfished or subject to overfishing [15], but the current catch is likely to decrease biomass in the future. The mean number of young blue sharks per year, only 35 fish, causes vulnerability compared to teleost species such as tuna [4]. Therefore, the IOTC, as a regional fisheries management organization, recommends reducing blue shark fishing by 20% from what is caught now so that in the next ten years, the biomass of blue sharks (B) can be greater than the Biomass Maximum Sustainable Yield (B_{MSY}) [15].

4. Conclusion

Blue sharks are the most widely caught as by-catch species in tuna longline effort in the Indian Ocean. The calculation of CPUE blue sharks must be standardized to avoid excessive fluctuation in value so that the CPUE standardization can be used as an index of blue shark abundance. With CPUE standardization values ranging from 0.014 to 0.100 with an average of 0.049, it is estimated that the exploitation of blue sharks in tuna longline fisheries in the Indian Ocean ranges from 366.3 to 2,616.3 tons with an average of 1.282 tons per year or 0.66% to 4.75% of all blue sharks catches in the Indian Ocean. Although the blue shark is currently not overfished, care must be taken because the vulnerability of sharks is higher than that of teleost fish.

Suggestion
This research is expected to be improved by adding environmental covariates in CPUE standardization to determine the suitability and quality of habitat for blue sharks (Habitat Suitability Index) in the Indian Ocean.

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