CPUE standardization of yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788) from Indonesian tuna longline fishery in the north-eastern Indian Ocean

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Introduction

Yellowfin tuna (*Thunnus albacares*) is one of the most exploited tuna species in all ocean includes Indian Ocean. Annual total catch of yellowfin tuna in Indian Ocean increased significantly since 1980's. The average of annual catch was 404,655 metric ton (t) between 2014 and 2018, in 2018 the total annual catch approximately 423,815 (IOTC, 2019). In the last 4 years (2015-2019), based on 2018 assessment, the IOTC stated that the yellowfin status was in the overfished and became the subject to overfishing (IOTC, 2019).

Abundance indices (e.g. CPUE) convey important information concerning the status of fisheries stocks because it related to the biomass. Furthermore, those indices are necessary to run simple models and they are also used as auxiliary data in more detailed stock assessment models (Maunder & Punt, 2004). The information of standardized CPUE have been presented by a number of scientists in recent years (Matsumoto, 2018; Hoyle et al., 2018; Yeh et al., 2019). Through this paper, we would like to present CPUE standardization for yellowfin from Indonesian tuna longline fleets operated in the Indian Ocean in order to provide stock indicator of this species.

Materials and Methods

Datasets

We used the Indonesian scientific observer data from commercial tuna longline vessels based in Benoa Fishing Port, Bali. The observer program started in 2005 through an Australia-Indonesia collaboration (Project FIS/2002/074 of Australian Centre for International Agricultural Research), and since 2010 it has been conducted by the Research Institute for Tuna Fisheries (RITF Indonesia).

The dataset includes information concerning the number of fishes caught by species, the total number of hooks, the number of Hooks Between Floats (HBF), start time of the set, soak

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time, and geographic position (latitude and longitude) where the longlines deployed into the water. The response variable in the models was nominal catch or CPUE depending on model. Year and quarter were used as a categorical (factor) explanatory variables.

Originally the mean annual proportion of zero catches from the data was quite high (~60%) and likely to be overdispersed. In attempt to reduce it, several ways were conducted as follows:

1. Data from 2005 was excluded from analysis, since it was the beginning of the scientific observer program, since it only conducted for 7 months and high likely contained species misidentification;
2. Data used for analysis limited only from 5N to 20S (north-eastern Indian Ocean) due to low spatial coverage outside the "core area";
3. Excluding sets which doesn't contain yellowfin catch for the whole trip.

CPUE Standardization

Previous analysis showed that delta-lognormal model quite suitable for Indonesian scientific observer data, therefore the same approach was applied in this study. Response variable for DELTA were log (CPUE) for positive sub-model and proportion of positive catch for second sub-model. The final models' construction was listed as follow:

Lognormal model for CPUE of positive catch:

$$\log(CPUE) = \mu + Year + Quarter + HBF + Moon + Lat5x5 + \varepsilon^{lognormal}$$

Delta model for presence and absence of catch:

$$\mathrm{PA} = \mu + Year + Quarter + HBF + Moon + Lat5x5 + \varepsilon^{del}$$

Where:

a. Year: analyzed between 2006 and 2018;
b. A quarter of the year: 4 categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December;
c. Area: treated as a continuous variable, area stratification method was applied using 5 degree block latitude;
d. The number of hooks between floats: it was assigned as 1 if HBF <10 hooks (surface longline), and 2 if HBF $\geq$10 hooks (deep longline) following (Sadiyah et al., 2012) treated as categorical variable;
e. Moon phase: Moon phase information is available as a daily index of moon fraction for all

recorded sets and ranges between 0 and 1 (from new moon to full moon). The moon phase was calculated using lunar package (Lazaridis, 2014). To account for the effect of cyclic behavior, the moon phase was defined by the following function (Sadiyah et al., 2012):

$$Moon = sin(2\pi\ x\ moon\ phase) + cos(2\pi\ x\ moon\ phase)$$

Results and Discussion

Descriptive Catch Statistic

Scientific observers recorded catch and operational data at onboard following Indonesian tuna longline commercial vessels from 2006-2018. The dataset contained 96 trips, 2472 sets, 4,217 days-at-sea, and more than 3.1 million hooks observed, respectively (Table 1).

Table 1. Summary of observed fishing effort from Indonesian tuna longline fishery during 2005– 2016. Results are pooled and presented by year of observation. Operational parameters are means and standard deviations (in parenthesis).

Year	Trips	Sets	Days-at-sea	Total hooks	Hooks per set		Hooks per float	
2006	12	291	559	402,775	1,384.11	(216.60)	11.10	(4.47)
2007	12	197	463	291,362	1,478.99	(347.73)	14.34	(4.76)
2008	14	354	553	458,293	1,294.61	(389.22)	12.84	(4.52)
2009	13	283	451	323,042	1,141.49	(234.67)	12.14	(4.93)
2010	6	165	225	220,394	1,335.72	(457.51)	13.62	(5.16)
2011	3	105	151	110,384	1,051.28	(173.89)	12.00	-
2012	7	116	333	136,311	1,175.09	(426.77)	13.93	(2.86)
2013	7	210	325	231,994	1,104.73	(204.44)	12.51	(2.02)
2014	6	182	282	214,665	1,179.48	(181.34)	14.98	(1.94)
2015	5	148	226	172,463	1,165.29	(145.21)	14.14	(3.20)
2016	3	130	170	175,868	1,352.83	(208.97)	11.31	(3.33)
2017	3	107	183	128,228	1,198.39	(187.31)	15.98	(1.51)
2018	5	184	296	242,966	1,320.47	(196.60)	14.92	(2.54)

Positive catch mainly distributed in north-eastern Indian Ocean between 10^{o}-35^{o} S and 105^{o}-120^{o} E, in the area in between south of Indonesian and Australian waters. The area also known for native fishing ground for southern bluefin tuna (*Thunnus maccoyii*).

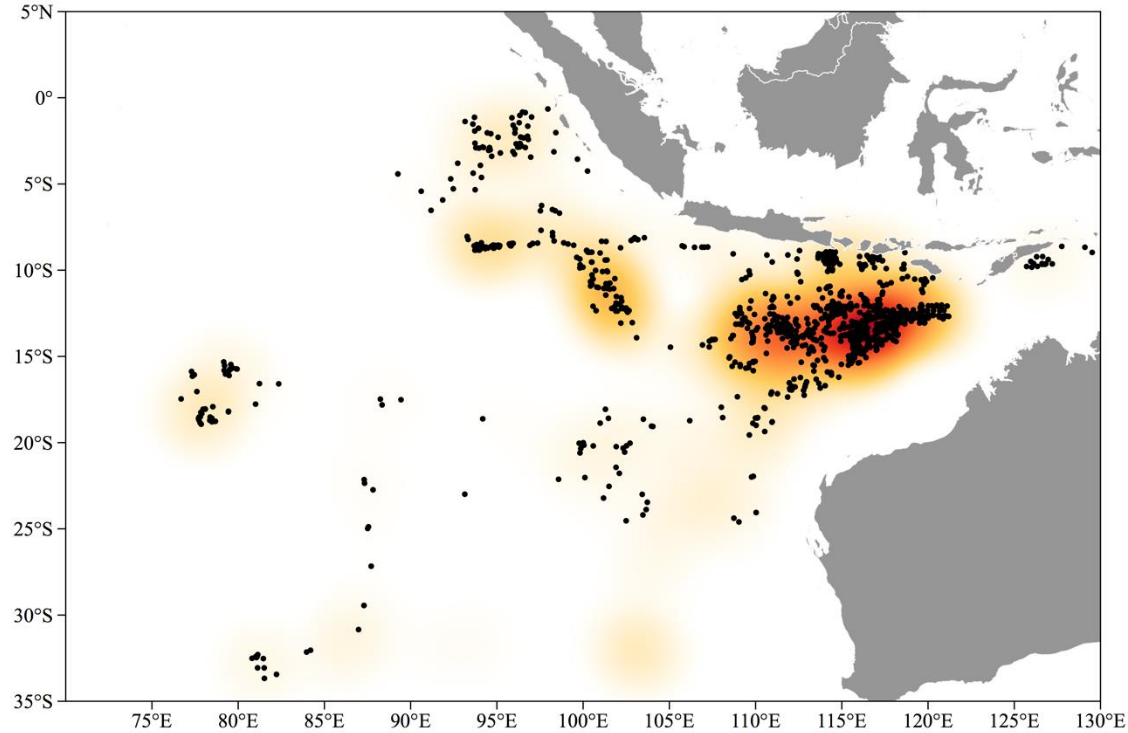

Figure 1. Positive catch (black dots) and effort distribution (heatmap) of yellowfin tuna from scientific observer data 2006-2018.

Catch rates trends

In general, the catch rates of yellowfin tuna during 2006-2018 were consistently dropping regardless subtantial peak in 2012 (0.14±0.03) and then declined sharply to merely just 0.04± 0.01 in 2015. The series later experienced slight increase towards 2018. On the other hand, the proportion of zero catch for yellowfin tuna consistently rasing between a minimum of 0.34±0.03 in 2006 and a maximum of 0.72±0.04 in 2015 with average proportion around 0.59±0.04 per year (Figure 2).

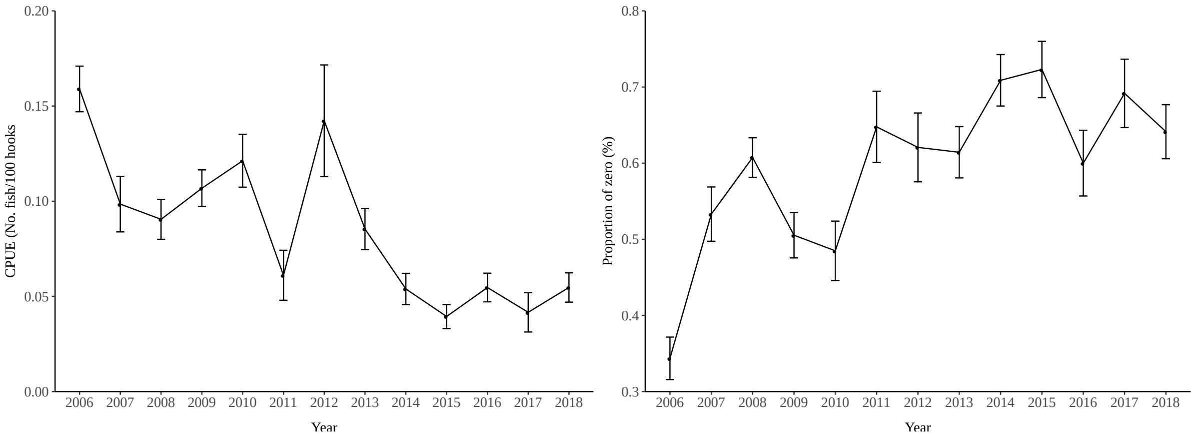

Figure 2. Nominal CPUE series (N/100 hooks) (left panel) and proportion of zero yellowfin tuna catches from 2006 to 2018 (right panel). The error bars refer to the standard errors

CPUE standardization models

On the final model selection, all effects were remained and statistically significant, except for moon phase (Table 2). The lognormal model (positive observation) produced a low AIC and good R^2 value, which 2199.1 and 0.23, respectively. On the other hand, the delta model (proportion of positive catch), although did not perform as good as the previous model but it still gave a reasonable result wherein the both AIC and R^2 value were each 3155 and 0.10.

Tabel 2. Deviance table of the parameters used for delta-gamma approach. Upper panel for positive observation sub-model and lower panel for proportion of positive sub-model. Each parameter indicated the degrees of freedom (Df), the deviance (Dev), the residual degrees of freedom (Resid Df), the residual deviance (Resid. Dev), the F test statistic and the significance (p-value).

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			1053	590.97			
Year	12	32.202	1041	558.77	5.7973	0.00000	***
Quarter	3	30.945	1038	527.82	22.2842	0.00000	***
Cat_HBF	1	36.797	1037	491.02	79.4941	0.00000	***
Lat2	1	11.476	1036	479.55	24.7913	0.00000	***

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	
NULL			2471	3373.10		
Year	12	119.29	2459	3253.80	0.00000	***
Quarter	3	36.09	2456	3217.70	0.00000	***
Cat_HBF	1	66.75	2455	3151.00	0.00000	***
Lat2	1	32.00	2454	3119.00	0.00000	***

In general, the abundance of yellowfin tuna was decreased quite substantially over the years (almost three-fold from the beginning of observation), regardless of the sudden spike in the 2012 (Figure 3). High overdispersion and high zero-catch-per-set remained the ultimate challenge for modelling the abundance for this species in the future. It is likely the main cause for high uncertainties (wide confidence interval), especially in 2012. Low coverage on high latitude, and some missing data (no observation) mainly on first quarter also become the main issue when dealing with scientific observer data.

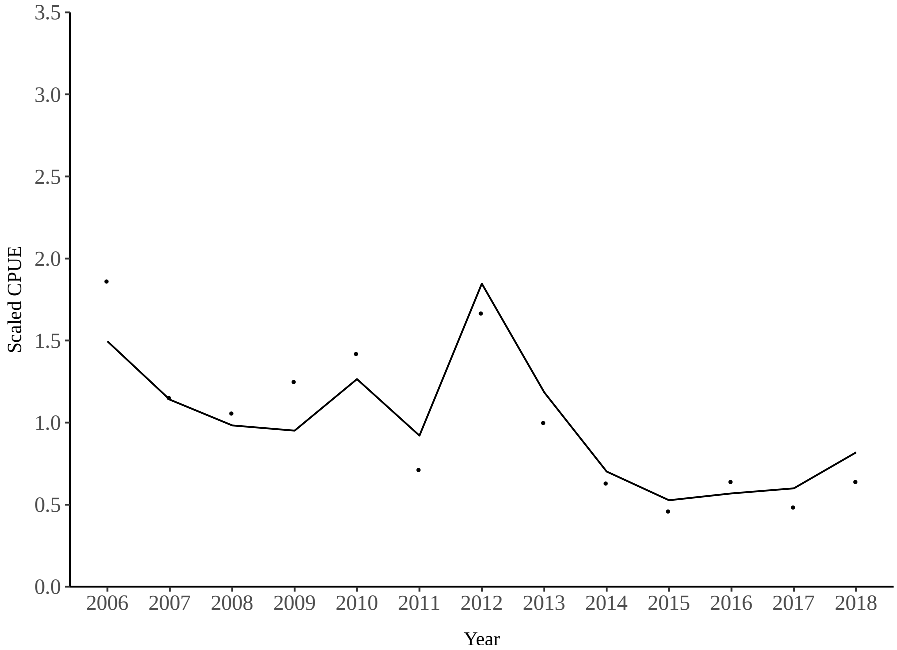

Figure 3. Final graph for standardized catch per unit effort (CPUE) of yellowfin tuna calculated using delta-lognormal model with 95% confidence interval (colored area). Values were scaled by dividing their means.

Acknowledgement

The Authors would like to thank to all scientific observers of Research Institute for Tuna Fisheries (RITF) and national observers of Directorate General of Capture Fisheries (DGCF) for their contribution in collecting data throughout the years. We also would like to extend our gratitude to various organization, namely, Commonwealth Scientific and Industrial Research Organization (CSIRO), the Australian Centre for International Agricultural Research (ACIAR) and the Research Institute for Capture Fisheries (RCCF) for their funding support through research collaboration in the project FIS/2002/074: Capacity Development to Monitor, Analyze and Report on Indonesian Tuna Fisheries. The authors would also like to thank Dr. Humber Andrade, Dr. Rui Coelho and Dr. Sheng-ping Wang for their valuable input on developing the statistical analysis.

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