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Relative abundance of yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) in the tropical area of the north-eastern Indian Ocean

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ABSTRACT

The tropical area of the north-eastern Indian Ocean has historically been a prominent fishing ground for yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788). However, low effort from either Japanese or Taiwanese fleet in the last two decades has driven some uncertainties in relative abundance estimates of yellowfin tuna, which affects the robustness of the current stock analysis for an already declined population. Hence this study was carried out to bridge the research gap by utilising the Indonesian scientific observer data from 2006-2021, which covers the north-eastern Indian Ocean. A delta-lognormal model was adopted to fit the data, with the catch per unit effort as the response variable and year, quarter, moon phase, latitude and longitude as known covariates. The optimal model was chosen using a backward method based on Akaike Information Criterion (AIC) (Akaike, 1974), Bayesian Information Criterion (BIC) (Schwarz, 1978) and the values of the coefficient of determination (R2). In general, the relative abundance of yellowfin tuna remained at a very low level, with an apparent declining trend in the first decade, followed by a slight sign of recovery in the past three years. However, the increasing trend was overshadowed by uncertainties, likely caused due to natural variation and low coverage in some years. Although the series was considered short, it managed to picture the dynamics of the abundance of yellowfin tuna in the tropical area of the north-eastern Indian Ocean, which is essential for conducting a more robust harvest strategy evaluation.

Keywords: Declining stock, Fisheries-independent data, Highly migratory, Relative abundance, Scientific observer

Introduction

Yellowfin tuna *Thunnus albacares* (Bonnaterre, 1788) is the most exploited tuna species in the world (Dortel *et al.*, 2015; Zhang *et al.*, 2017; Nimit *et al.*, 2020), including the Indian Ocean. Historically, it has been the primary target for Japanese longline fleets since the 1950s, followed by Taiwanese, Korean and Indonesian fleets two decades later (Sadiyah *et al.*, 2011; Hoyle *et al.*, 2018; Yeh *et al.*, 2018). Since the species is distributed in tropical and subtropical waters throughout the world's major oceans (Fonteneau, 2010), it has also been targeted by artisanal fleets (Lan *et al.*, 2013) and industrial European purse seiners for the past 50 years (Baez *et al.*, 2020).

The annual total catch of yellowfin tuna in the Indian Ocean has increased significantly since the 1980s. The average annual catch between 2014 and 2018 was 404,655 t, with the total yearly catch approximately 423,815 t (IOTC, 2019) and the Indonesian fleet contributed at least 10% (~40,000 t) (Fahmi *et al.*, 2020). Based on the 2021 assessment, the IOTC stated that the yellowfin stock was overfished (IOTC-WPTT23, 2021), which lasted for five years. However, the result was overshadowed by uncertainties, especially when most indicators (*e.g.* relative abundance) only refer to the western part of the Indian Ocean, where high fishing pressure occurred since the 1980s [IOTC-WPTT22(AS), 2020]. Meanwhile, the condition in the north-eastern area, particularly of Indonesian fleets, remained questionable since it was not included in the analysis (Fu *et al.*, 2021).

As it is related to biomass, abundance indices (*e.g.,* catch per unit effort, CPUE) communicate crucial information about the state of fish stocks. Additionally, these indices are required to run simple models and are beneficial as supplementary data in more complex stock assessment models (Maunder and Punt, 2004). Usually, it needs to be presented in the standardised form (*i.e.* divided by the overall mean) to be compatible with other countries' datasets. Though several studies have been published recently (Hoyle *et al.*, 2018; Matsumoto, 2018; Yeh *et al.*, 2018), the calculation of standardised CPUE has been impeded by a lack of precise data caught by other fleets or in places where the Japanese/Taiwanese longline fleet is absent (*i.e.*, north-eastern Indian Ocean).

This paper hopes to resolve this issue by creating a sub-regional yellowfin tuna abundance indicator based on fishery-independent data from the Indonesian scientific observer program. Such an indicator would help fill the research gap of the yellowfin tuna abundance in the north-eastern Indian Ocean.

Materials and methods

Data origin and scrutiny

We used the Indonesian scientific observer data from commercial tuna longline vessels based in Benoa Port, Bali. The observer program began in 2005 as a result of a collaboration between Australia and Indonesia [Project FIS/2002/074 of the Australian Centre for International Agricultural Research (ACIAR)]. From 2010 onwards, it was continued by the Research Institute for Tuna Fisheries (RITF).

The dataset provides the number of fishes caught by species, the start time of the set, soak duration, overall number of hooks, hooks between floats (HBF) and the geographic location (latitude and longitude) where the longlines were deployed. The mean annual fraction of zero captures in the data was initially fairly high (60%) and presumably overdispersed. Several methods were used in an attempt to decrease overdispersion, such as:

- Data from 2005 was removed from the study because it was the start of the scientific observer program, which lasted only seven months and was highly likely to contain species misidentification;
- Data from Tropical Indian Ocean (TIO) (Wu *et al.,* 2010) limited to 5°N to 20°S (north-eastern Indian Ocean) only were used, due to low spatial and temporal coverage outside the "core area" or main fishing ground;
- Excluded sets which did not contain yellowfin catch for the whole trip, assuming no targeting.

Standardisation of catch per unit of effort

The number of yellowfin tuna caught per 100 hooks was used to calculate the catch per unit of effort (CPUE). Each daily record comprised temporal (year and month) and spatial information (latitude and longitude) based on where the set began, in addition to catch and effort data. Previous analysis showed that the delta-lognormal model is quite suitable for Indonesian scientific observer data (Setyadji *et al.*, 2021; Wujdi *et al.*, 2021). Therefore, a similar approach was applied in this study also. The response variables for delta were *log (CPUE)* for the positive sub-model and the proportion of positive catch for the second sub-model. The final models used were:

Lognormal model for CPUE of positive catch: $\log(\text{CPUE}) = \mu + \text{Year} + \text{Quarter} + \text{HBF} + \text{Moon} + \text{Lat5} + \text{Lon5} + \varepsilon^{\text{lognormal}}$ ....(1)

Delta model for presence and absence of catch: $\text{PA} = \mu + \text{Year} + \text{Quarter} + \text{HBF} + \text{Moon} + \text{Lat5} + \text{Lon5} + \varepsilon^{\text{de}}$ ......(2)

where: *Year* : Available from 2006 to 2018, assigned as a categorical variable;

Quarter : Falls into four categories: 1 = January to March, 2 = April to June, 3 = July to September, 4 = October to December, assigned as categorical variable;

Area : Defined as a continuous variable, area stratification method was applied using 5x5 degree blocks latitude (*Lat5*) and longitude (*Lon5*), assuming north-south and east-west movement (Lan *et al.*, 2020);

HBF : Number of hooks between floats. Assigned as 1 when HBF <10 hooks (surface longline) and 2 when HBF $\geq$10 hooks (deep longline) following Sadiyah *et al.* (2012), treated as a categorical variable;

Moon : Moon phase, accessible as a daily moon fraction index for all recorded sets, with a range of 0 to 1 (from new moon to full moon). The moon phase was calculated using lunar package (Lazaridis, 2014). To account for the effect of cyclic behaviour, the moon phase was defined by the following function (Sadiyah *et al.*, 2012):

$$\text{Moon} = \sin(2\pi \text{ x Moon phase}) + \cos(2\pi \text{ x Moon phase}) \text{....(3)}$$

For model selection, we used a stepwise method, starting with a null model and introducing variables one after one, choosing only the variable that resulted in the lowest residual sum of squares. This procedure was repeated until the residual sum of squares of the model did not decrease as new variables were introduced. Finally, explanatory variables were chosen using a backward process based on Akaike Information Criterion (AIC) (Akaike, 1974), Bayesian Information Criterion (BIC) (Schwarz, 1978) and the values of the coefficient of determination (R^2).

The exponent of the adjusted means (least-square means) of the year effects was used to estimate the area specific standardised CPUE trends (Butterworth, 1996; Maunder and Punt, 2004). The product of the standardised CPUE of positive captures and the standardised probability of positive catches gave the standardised relative abundance index:

$$\text{Relative abundance index} = e^{\log(\text{CPUE})}\left(\frac{e^{\tilde{P}}}{1+e^{\tilde{P}}}\right) \text{.............(4)}$$

where *CPUE* is the adjusted means (least-square means) of the year effect for the lognormal model and $\tilde{P}$ is the adjusted means of the year effect for the delta model. All maps and statistical analyses were carried out using R software version 3.6.0 (R Core Team, 2021).

Results and discussion

Between 2006 and 2021, scientific observers documented catch and operational data of tuna longline commercial vessels from Indonesia. Post-cleaning, the dataset contained 109 trips, 2735 sets, with nearly 3.5 million hooks (Table 1). Scrutineering process successfully reduced the proportion of zero catch per set by approximately 4%, from 60.03 to 56.30%. Positive catch in the north-eastern Indian Ocean was mainly distributed around 10°-20°S and 105°-120°E (Fig. 1), in the area between south of Indonesian and Australian waters, which is notably known for native fishing grounds for southern bluefin tuna *Thunnus maccoyii* (Castelnau, 1872) (Farley *et al.*, 2014).

The nominal catch rates of yellowfin tuna fluctuated across the years. The series started strongly in 2006 (0.16±0.01) but dropped by half in 2007. Afterwards, it recovered steadily for the next five years until it reached its peak in 2012 (0.14±0.03). The trend relapsed negatively until 2018, followed by a sign of recovery in the last three years. High spike in 2019 (0.25±0.05) was caused by an anomaly (sudden high catch in several sets), while low values in 2011 (0.06±0.01) and 2020 (0.03±0.01) were likely due to low deployment. The proportion of zero capture for yellowfin tuna, on the other hand, has steadily increased from a low of 0.34±0.03 in 2006 to a high of 0.72±0.04 in 2015, with an average of roughly 0.59±0.04 per year (Fig. 2).

Table 1. Summary of observed fishing effort from Indonesian tuna longline fishery during 2006-2021. Results are pooled and presented by year of observation. Operational parameters are means±standard deviations

Year	Trips	Sets	Total Hooks	Mean Hooks	Mean HBF
2006	11	289	399,871	1,383.64±12.77	11.10±0.26
2007	12	194	288,560	1,487.42±24.77	14.41±0.34
2008	14	380	485,333	1,277.19±19.81	12.55±0.23
2009	13	288	328,718	1,141.38±13.82	12.18±0.29
2010	6	166	221,274	1,332.98±35.51	13.61±0.40
2011	3	105	110,384	1,051.28±16.97	12.00±0.00
2012	7	116	136,311	1,175.09±39.62	13.93±0.27
2013	7	210	231,990	1,104.71±14.11	12.40±0.15
2014	6	184	216,705	1,177.74±13.35	15.01±0.14
2015	5	150	174,655	1,164.37±11.81	14.15±0.26
2016	3	130	175,868	1,352.83±18.33	11.31±0.29
2017	3	107	128,228	1,198.39±18.11	15.98±0.15
2018	5	184	242,966	1,320.47±14.49	14.92±0.19
2019	8	109	137,611	1,262.49±16.39	8.72±0.41
2020	2	48	65,915	1,373.23±17.80	13.62±0.14
2021	4	75	102,979	1,373.05±31.51	10.12±0.45

On the final model selection, all effects remained and were statistically significant, except for the moon phase (Table 2). The step-wise procedure for the lognormal model (positive observation) produced the best AIC, BIC and good R^2 value, which were 2563.6, 2680.5 and 0.20, respectively. On the contrary, although the delta model (proportion of positive catch) did not perform as well as the previous model, it still gave a reasonable result wherein the best combination of AIC, BIC and R^2 values were 3445.4, 3575.5 and 0.08, respectively.

The relative abundance of yellowfin tuna between 2006-2021 revealed a repetitive pattern every 5-6 years (Fig. 3). The series went down immediately after reaching its first peak in 2006; however, it quickly recovered until it attained the second highest in 2012. The trend repeated from 2013 to 2019, in which, after recording its highest value, it dropped down for two consecutive years. However, the abundance seemed to show a positive trend in the last seven years, a contrasting phenomenon when the global stock is declining (IOTC-WPTT23, 2021). It is to be noted that, high uncertainties remained a challenging aspect when dealing with scientific observer data, especially in 2012 and during the last three years. Low spatial coverage, absence of deployment in some months and financial constraint due to the Covid-19 outbreak are touted to be the main culprits.

One drawback from utilising fisheries independent data, such as scientific observers, is probably its lack of temporal and spatial coverage. The excessive cost of deployment (Maunder and Punt, 2004) and dependencies on the government budget was likely the main reason. With at least six to seven trips a year and around 200,000 hooks observed, it was far below (0.6%) the minimum of 5% from total effort (*i.e.*, total hooks deployed)

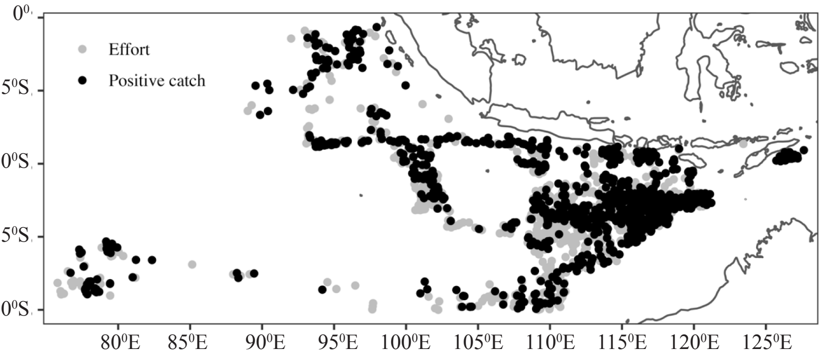

Fig. 1. Positive catch (black dots) and effort distribution (heatmap) of yellowfin tuna from scientific observer data 2006-2021

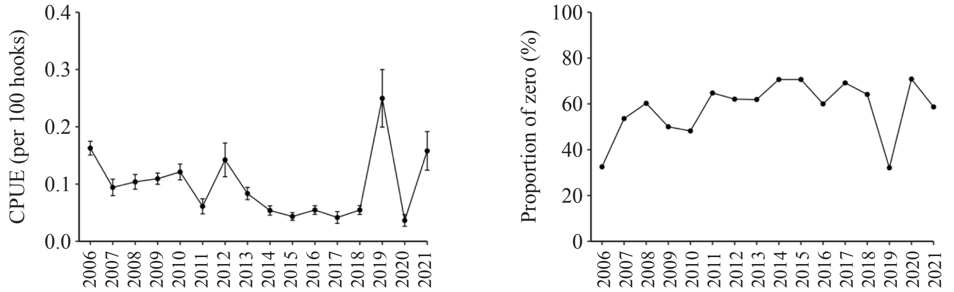

Fig. 2. Nominal CPUE series (N/100 hooks) (left panel) and proportion of zero catch per set (right panel) of yellowfin tuna catch from 2006 to 2019. Error bars refer to standard errors

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

	Df	Deviance	Resid. Df	Resid. Dev	F	p(>F)	
NULL			1194	729.4586			
Year	15	45.5997	1179	683.8588	6.1990	0.0000	***
Quarter	3	28.7570	1176	655.1018	19.5468	0.0000	***
Cat_HBF	1	59.7603	1175	595.3415	121.8612	0.0000	***
Lat2	1	15.4346	1174	579.9069	31.4738	0.0000	***
Lon2	1	4.6724	1173	575.2345	9.5277	0.0021	**

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

	Df	Deviance	Resid. Df	Resid. Dev	p(>Chi)	
NULL			2734	3747.880		
Year	15	158.0479	2719	3589.832	0.000	***
Quarter	3	38.5992	2716	3551.233	0.000	***
Cat_HBF	1	104.8540	2715	3446.379	0.000	***
Lat2	1	36.6931	2714	3409.686	0.000	***
Lon2	1	8.2633	2713	3401.422	0.004	**

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

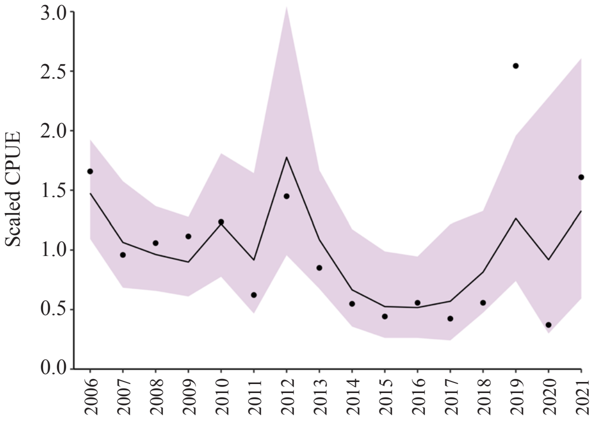

Fig. 3. Standardised CPUE of yellowfin tuna calculated using the delta-lognormal model with 95% confidence interval (coloured area). Values were scaled by dividing their means

required by the Indian Ocean Tuna Commission (IOTC) and Commission on Conservation of Southern Bluefin Tuna (CCSBT). However, due to rebuilding the fisheries logbook program since 2018, which still resulted in fairly low coverage (<10%) (Geehan, 2018), the scientific observer data would still be a key instrument in conducting assessment in the future, particularly for tunas, billfishes and some sharks species.

Earlier findings revealed that Indonesian tuna longliners tend to make yellowfin the second main target after bigeye tuna *Thunnus obesus*, especially for areas above 20^{o}S (Sadiyah *et al.,* 2011; Sadiyah and Prisantoso, 2011). Therefore, it vindicated the moderately low level of zero catch per set (56.30%) shown in this study compared to other bycatch, such as sharks (Shono, 2008; Wu *et al.,* 2021) and billfishes (Punt *et al.,* 2015). On the other hand, the nominal CPUE was relatively low (0.03-0.25 per 100 hooks) compared to other distant fishing nation’ fleets, *e.g.* Taiwan (Yeh *et al.,* 2018) and Japan (Matsumoto and Hoyle, 2019) on a relatively similar scaling. The primary cause might be driven by low primary productivity in the north-eastern part of the Indian Ocean (Tripathy *et al.,* 2014) in particular, further challenged by the decreasing trend of marine phytoplankton for the last 16 years up to a third due to apparent global warming (Roxy *et al.,* 2016). The conventional fishing practices which were "inherited" from Taiwanese vessels since the 1990's (Yang *et al.,* 2008), added with the preference of using laminated wooden-based vessels (Suryanto and Wudianto, 2017), also increased the inability of Indonesian fishers to compete with other foreign fleets, especially in the area below 20^{o}S which are known to have better abundance (Michael *et al.,* 2017).

All covariates have been influential in building the final model, except the moon phase. It is understandable because most of the sets were conducted in the early morning (Setyadji *et al.*, 2018), unlike the Turkish gillnetters that started fishing at dawn and paused at full moon period (Akyol, 2013). Further, previous studies from Sadiyah *et al.* (2012) and Yeh and Chang (2011) confirmed that the periodical movement of the moon did not influence the relative abundance of yellowfin tuna. Rather, it was more likely impacted by the hook's depth, spatial movement and temporal dynamics. Since the average number of hooks between floats configuration throughout the series was more than ten, which indicated deep longline type (Yokawa *et al.*, 2006; Sadiyah *et al.*, 2011), it was assumed that yellowfin tuna was caught alongside bigeye tuna at the upper layers because the probability of a fish being caught was inversely proportional to increasing depth (Setyadji *et al.*, 2016) and also influenced by a combination of warmer waters with higher sea surface height and lower eddy kinetic energy values (Orue *et al.*, 2020). On the other hand, the north-south movement, which also plays a pivotal role, was likely encouraged by the lower rate of dissolved oxygen in the north during June-October due to the rainy season (Mohri and Nishida, 2000). Thus high catch was slightly diverted southward (Lee *et al.*, 1999). In addition, a west-east movement was also detected by a large-scale tagging program, which in some cases indicated a frequent trans-Atlantic movement (Fonteneau and Hallier, 2015). This movement was incorporated in the last stock assessment conducted by the IOTC Secretariat (Fu *et al.*, 2021).

Although the series was considered short, it managed to capture the dynamics of the abundance of yellowfin tuna in the tropical waters of the north-eastern Indian Ocean, whereas other fleets' coverage was relatively low in the last two decades (Kitakado *et al.*, 2021). The apparent trend has not deviated much with other studies from Japan (Matsumoto, 2018) and Taiwan (Yeh *et al.*, 2019) within the similar area of interest, whereas it was relatively stable at a very low level. Exception for the last three years, when high fluctuations occurred, was possibly triggered by several factors, including a very high catch in some sets in 2019 and very low deployment in the next year due to Covid-19 restriction. However, a relatively high catch in 2020 has signified a possible early sign of recovery, which is in line with aggregated CPUE from the Japanese fleet in the Indian Ocean (Matsumoto, 2018). Local depletion allegedly occurred within the European industrial purse seine in the western part of the Indian Ocean (Guery *et al.*, 2021) which is alarming since they mainly target small bigeye and yellowfin tuna. Thus growth overfishing is likely to occur, with the fish never having had an opportunity to mature and expand before being caught (Diekert, 2012).

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References

Akaike, H. 1974. A new look at the statistical model identification. *IEEE Trans. Automat. Contr.*, 19: 716-723. https://doi.org/10.1109/TAC.1974.1100705.

Akyol, O. 2013. The influence of the moon phase on the CPUEs of swordfish gillnet fishery in the Aegean Sea, Turkey. *Turk. J. Fish Aquat. Sci.*, 13(2): 355-358. https://doi.org/10.4194/1303-2712-v13_2_18.

Baez, J. C., Ramos, M. L., Herrera, M., Murua, H., Cort, J. L., Deniz, S., Rojo, V., Ruiz, J., Pascual-Alayon, P. J. and Muniategi, A. 2020. Monitoring of Spanish flagged purse seine fishery targeting tropical tuna in the Indian ocean: Timeline and history. *Mar. Policy*, 119: 104094. https://doi.org/10.1016/j.marpol.2020.104094.

Butterworth, D. S. 1996. A possible alternative approach for generalised linear model analysis of tuna CPUE data. *ICCAT Col. Vol. Sci. Pap.*, 45: 123-124.

Diekert, F. K. 2012. Growth overfishing: The race to fish extends to the dimension of size. *Environ. Resour. Econ.*, 52: 549-572. https://doi.org/10.1007/s10640-012-9542-x.

Dortel, E., Sardenne, F., Bousquet, N., Rivot, E., Million, J., Le Croizier, G. and Chassot, E. 2015. An integrated Bayesian modeling approach for the growth of Indian

Ocean yellowfin tuna. *Fish Res*., 163: 69-84. https://doi.org/10.1016/j.fishres.2014.07.006.

Fahmi, Z., Hikmayani, Y., Yunanda, T., Yudiarso, P., Wudianto, W. and Setyadji, B. 2020. *Indonesia national report to the Scientific Committee of the Indian Ocean Tuna Commission 2020, National Report No. IOTC-2020-SC23-NR07*, Indian Ocean Tuna Commission (IOTC), Victoria, Seychelles.

Farley, J. H., Eveson, J. P., Davis, T. L., Andamari, R., Proctor, C. H., Nugraha, B. and Davies, C. R. 2014. Demographic structure, sex ratio and growth rates of southern bluefin tuna (*Thunnus maccoyii*) on the spawning ground. *PloS One*., 9: e96392. https://doi.org/10.1371/journal.pone.0096392.

Fonteneau, A. 2010. *Atlas of Indian Ocean tuna fisheries*. Research Institute for Development, Marseille, France, 190 pp.

Fonteneau, A. and Hallier, J. P. 2015. Fifty years of dart tag recoveries for tropical tuna: A global comparison of results for the Western Pacific, Eastern Pacific, Atlantic and Indian Oceans. *Fish. Res*., 163: 7-22. https://doi.org/10.1016/j.fishres.2014.03.022.

Fu, D., Urtizberea, A., Cardinale, M., Methot, R., Hoyle, S. and Merino, G. 2021. Preliminary indian ocean yellowfin tuna stock assessment 1950-2020 (stock synthesis). *Paper presented at the 23rd Working Party on Tropical Tunas (WPTT23),* 25-30 October 2021 (Online). Indian Ocean Tuna Commission (IOTC), 98 pp.

Geehan, J. 2018. Revision to the IOTC scientific estimates of Indonesia's fresh longline catches. *Paper presented at 14th Working Party on Data Collection and Statistics,* 29 November-01 December 2018, Indian Ocean Tuna Commission (IOTC), Seychelles, 14 pp.

Guery, L., Kaplan, D., Grande, M., Merino, G., Marsac, F., Abascal, F., Baez, J. C. and Gaertner, D. 2021. European purse seine CPUE standardization: Methodology and framework for the YFT stock assessment. *Paper presented at 23rd Working Party on Tropical Tuna (WPTT23): Data Preparatory Meeting,* 10-14 May 2021 (Online), Indian Ocean Tuna Commission (IOTC), 34 pp.

Hoyle, S. D., Chassot, E., Fu, D., Kim, D. N., Lee, S. I., Matsumoto, T., Satoh, K., Wang, S. P., Yeh, Y. M. and Kitakado, T. 2018. Collaborative study of yellowfin tuna CPUE from multiple Indian Ocean longline fleets in 2018. *Paper presented at 9th Working Party on Methods,* 25-27 October 2018, Mahe, Seychelles, Indian Ocean Tuna Commission (IOTC), 50 pp.

IOTC 2019. *Report of the 22nd Session of the IOTC Scientific Committee*, Karachi, Pakistan, Indian Ocean Tuna Commission (IOTC), 204 pp.

IOTC-WPTT22(AS) 2020. *Report of the 22nd Session of the IOTC Working Party on Tropical Tunas, Stock Assessment Meeting* (Online), Indian Ocean Tuna Commission (IOTC), 106 pp.

IOTC-WPTT23. 2021. *Report of the 23rd Session of the IOTC Working Party on Tropical Tunas* (Online). Indian Ocean Tuna Commission (IOTC), 59 pp.

Kitakado, T., Wang, S. P., Satoh, K., Lee, S. I., Tsai, W. P., Matsumoto, T., Yokoi, H., Okamoto, H., Lee, K. L., Lim, J. H., Kwon, Y., Su, N. J., Chang, S. T. and Chang, F. C. 2021. Report of trilateral collaborative study among Japan, Korea and Taiwan for producing joint abundance indices for the yellowfin tunas in the Indian Ocean using longline fisheries data up to 2019. *Paper presented at 23rd Working Party on Tropical Tuna* (*WPTT23*): *Data Preparatory Meeting* (Online), 10-14 May 2021, Indian Ocean Tuna Commission (IOTC), 27 pp.

Lan, K. W., Evans, K. and Lee, M. A. 2013. Effects of climate variability on the distribution and fishing conditions of yellowfin tuna (*Thunnus albacares*) in the western Indian Ocean. *Clim. Change*, 119: 63-77. https://doi.org/10.1007/s10584-012-0637-8.

Lan, K. W., Chang, Y. J. and Wu, Y. L. 2020. Influence of oceanographic and climatic variability on the catch rate of yellowfin tuna (*Thunnus albacares*) cohorts in the Indian Ocean. *Deep Sea Res. Pt. II* 175: 104681. https://doi.org/10.1016/j.dsr2.2019.104681.

Lazaridis, E. 2014. *lunar: Lunar Phase & Distance, Seasons and Other Environmental Factors* (Version 0.1-04). http://statistics.lazaridis.eu.

Lee, P. F., Chen, I. C. and Tseng, W. N. 1999. Distribution patterns of three dominant tuna species in the Indian Ocean. in: *Proceedings of 19th International ESRI Users Conference*, San Diego, California, USA, 10 pp.

Matsumoto, T. 2018. Japanese longline CPUE for yellowfin tuna in the Indian Ocean standardized by generalised linear model. *Paper presented at 20th Working Party on Tropical Tuna,* 29 October-03 November 2018, Seychelles, Indian Ocean Tuna Commission (IOTC), 19 pp.

Matsumoto, T. and Hoyle, S. D. 2019. Standardization of bigeye and yellowfin tuna CPUE by Japanese longline in the Indian Ocean which includes cluster analysis. *Paper presented at 21st Working Party on Tropical Tuna,* 21-26 October 2019, San Sebastian, Spain, Indian Ocean Tuna Commission (IOTC), 37 pp.

Maunder, M. N. and Punt, A. E. 2004. Standardizing catch and effort data: A review of recent approaches. *Fish. Res*., 70: 141-159. https://doi.org/10.1016/j.fishres.2004.08.002.

Michael, P. E., Wilcox, C., Tuck, G. N., Hobday, A. J. and Strutton, P. G. 2017. Japanese and Taiwanese pelagic longline fleet dynamics and the impacts of climate change in the southern Indian Ocean. *Deep Sea Res. II*, 140: 242-250. https://doi.org/10.1016/j.dsr2.2016.12.003.

Mohri, M. and Nishida, T. 2000. Consideration of distribution of adult yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on Japanese tuna longline fisheries and survey information. *Journal of National Fisheries University*, 49: 1-11.

Nimit, K., Masuluri, N. K., Berger, A. M., Bright, R. P., Prakash, S., Udayabhaskar, T. V. S., Srinivasa Kumar, T., Rohit, P., Tiburtius, A., Ghosh, S. and Varghese, S. P. 2020. Oceanographic preferences of yellowfin tuna (*Thunnus albacares*) in warm stratified oceans: A remote sensing approach. *Int. J. Remote Sens*., 41: 5785-5805. https://doi.org/10.1080/01431161.2019.1707903.

Orue, B., Pennino, M. G., Lopez, J., Moreno, G., Santiago, J., Ramos, L. and 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. https://doi.org/10.3389/fmars.2020.00441.

Punt, A. E., Su, N. J. and Sun, C. L. 2015. Assessing billfish stocks: A review of current methods and some future directions. *Fish. Res*., 166: 103-118. https://doi.org/10.1016/j.fishres.2014.07.016.

R Core Team 2021. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna. https://www.R-project.org

Roxy, M. K., Modi, A., Murtugudde, R., Valsala, V., Panickal, S., Prasanna Kumar, S., Ravichandran, M., Vichi, M. and Levy, M. 2016. A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. *Geophys. Res. Lett*., 43: 826-833. https://doi.org/10.1002/2015GL066979.

Sadiyah, L., Dowling, N. and Prisantoso, B. I. 2011. Changes in fishing pattern from surface to deep longline fishing by the Indonesian vessels operating in the Indian Ocean. *Indones. Fish. Res. J*., 17: 87-99. https://doi.org/10.15578/ifrj.17.2.2011.87-99.

Sadiyah, L. and Prisantoso, B. I. 2011. Fishing strategy of the indonesian tuna longliners in Indian Ocean. *Indones. Fish. Res. J*., 17: 29-35. http://dx.doi.org/10.15578/ifrj.17.1.2011.29-35.

Sadiyah, L., Dowling, N. and Prisantoso, B. I. 2012. Developing recommendations for undertaking CPUE standardisation using observer program data. *Indones. Fish. Res. J*., 18: 19-33. https://doi.org/10.15578/ifrj.18.1.2012.19-33.

Schwarz, G. 1978. Estimating the dimension of a model. *The Annals of Statistics*, 6: 461-464.

Setyadji, B., Nugraha, B. and Sadiyah, L. 2016. The effect of depth of hooks, set and soak time to the catch-per-unit-of-effort of tuna in the Eastern Indian Ocean. *Indones. Fish. Res. J*., 22: 61-68. http://dx.doi.org/10.15578/ifrj.22.2. 2016.61-68.

Setyadji, B., Andrade, H. A. and Proctor, C. H. 2018. Standardisation of catch per unit effort with high proportion of zero catches: An application to black marlin *Istiompax indica* (Cuvier, 1832) caught by the Indonesian tuna longline fleet in the eastern Indian Ocean. *Turk. J. Fish. Aquat. Sci*., 19: 119-129. https://doi.org/10.4194/1303-2712- v19_ 2_04.

Setyadji, B., Parker, D., Wang, S. P. and Sulistyaningsih, R. K. 2021. Update on CPUE standardisation of black marlin (*Makaira indica*) from Indonesian tuna longline fleets 2006-2020. *Paper presented at 19th session of Working Party on Billfish (WPB19)* (Online), 13-16 September 2021, Indian Ocean Tuna Commission (IOTC), 9 pp.

Shono, H. 2008. Application of the tweedie distribution to zero-catch data in CPUE analysis. *Fish. Res*., 93: 154-162. https://doi.org/10.1016/j.fishres.2008.03.006.

Suryanto, S. and Wudianto, W. 2017. Model for estimating fuel consumption for pole and longline tuna fishing vessels *Jurnal Penelitian Perikanan Indonesia*, 23: 99-110. http://dx.doi.org/10.15578/jppi.23.2.2017.99-110 (In Indonesian).

Tripathy, S. C., Pavithran, S., Sabu, P., Naik, R. K., Noronha, S. B., Bhaskar, P. V. and Anilkumar, N. 2014. Is primary productivity in the Indian Ocean sector of Southern Ocean affected by pigment packaging effect? *Curr. Sci.*, 107: 1019-1026.

Wu, B., Li, T. and Zhou, T. 2010. Relative contributions of the Indian Ocean and local SST anomalies to the maintenance of the western north Pacific anomalous anticyclone during the El Niño decaying summer. *J. Clim*., 23: 2974-2986. https://doi.org/10.1175/2010JCLI3300.1.

Wu, X. H., Liu, S. Y. V., Wang, S. P. and Tsai, W. P. 2021. Distribution patterns and relative abundance of shortfin mako shark caught by the Taiwanese large-scale longline fishery in the Indian Ocean. *Reg. Stud. Mar. Sci*., 44: 101691. https://doi.org/10.1016/j.rsma.2021.101691.

Wujdi, A., Setyadji, B. and Fahmi, Z. 2021. Update on the CPUE standardization of the blue shark (*Prionace glauca*) caught by Indonesian tuna longline in the eastern Indian Ocean. *Paper presented at 17th Working Party on Ecosystems and Bycatch (WPEB17 (DP)) Data Preparatory Meeting* (Online), Indian Ocean Tuna Commission (IOTC), 12-14 April 2021, 13 pp.

Yang, C. M., Li, J. J. and Miyazawa, H. 2008. The overseas expansion of Taiwanese small-scale tuna longliners and the development of the Indonesia tuna fishery policy. *J. Reg. Fish.,* 49: 43-62. https://doi.org/10.34510/jrfs.49.1_43.

Yeh, Y. M. and Chang, S. T. 2011. Updated CPUE standardisations for yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. *Paper presented at 8th session of the Working Party on Data Collection and Statistics (WPDCS).* 8-10 December 2011, Victoria, Seychelles, Indian Ocean Tuna Commission (IOTC), 13 pp.

Yeh, Y. M., Hoyle, S. D. and Chang, S. T. 2018. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean using generalized linear model. *Paper presented at 20th Working Party on Tropical Tuna,* 29 October-03 November 2018, Victoria, Seychelles, Indian Ocean Tuna Commission (IOTC), 73 pp.

Yeh, Y. M., Tsai, W. P., Chang, S. T. and Hoyle, S. D. 2019. Updated CPUE standardizations for bigeye and yellowfin tuna caught by Taiwanese longline fishery in the Indian Ocean. *Paper presented at 21st Working Party on Tropical Tuna,* 21-26 October 2019, San Sebastian, Spain, Indian Ocean Tuna Commission (IOTC), 80 pp.

Yokawa, K., Saito, H., Kanaiwa, M. and Takeuchi, Y. 2006. Vertical distribution pattern of CPUE of Atlantic billfishes and associated species estimated using longline research data. *Bull. Mar. Sci.*, 79: 623-634.

Zhang, Y., Chen, Y., Zhu, J., Tian, S. and Chen, X. 2017. Evaluating effectiveness of biological reference points for bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) fisheries in the Indian Ocean. *Aquac. Fish.*, 2: 84-93. https://doi.org/10.1016/j.aaf.2017.01.004.

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