STANDARDIZED CPUE INDICES FOR BLUE MARLIN (*Makaira nigricans*) CAUGHT BY INDONESIAN TUNA LONGLINE FISHERY IN NORTH EASTERN INDIAN OCEAN

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ABSTRACT

Blue marlin (*Makaira nigricans*) is usually caught as frozen by-catch in by Indonesian tuna longline fleets. Its contribution estimated around 31% (~4,000 tons) from of total catch in Indian Ocean. Relative abundance indices as calculated based on commercial catches are the input data for several to run stock assessment analyses that provide models to gather information useful information for decision making and fishery management. In this paper a Generalized Linear Model (GLM) was used to standardize the catch per unit effort (CPUE) and to calculate estimate relative abundance indices based on the Indonesian longline dataset. Data was collected from January 2006 to December 2018 through scientific observer program (2005-2018). Most of the vessels monitored were based in Benoa Port, Bali. On overall, the Delta-gamma performs better on data with high proportion of zeros compared to other traditional models. CPUE trend relatively stable, despite the fluctuation over the years of estimation. Catch rates are likely affected by temporal trend rather than operational or environmental effects. However, the final model also leaves high range of uncertainty, which leave room for further improvement in the future.

KEYWORDS: Blue marlin, abundance indices, GLM, eastern Indian Ocean.

Introduction

Blue marlin *Makaira nigricans* (Lacépède, 1802) is an apex predator, highly migratory species and considered as a non-target species of industrial and artisanal fisheries (Setyadji, Jumariadi, & Nugraha, 2012; Widodo, Prisantoso, & Suprapto, 2016). It is a solitary species, prefers the warm offshore surface waters above 24°C and known to have high commercial value in the tropical and subtropical Indian and Ocean Pacific (Nakamura, 1985). However, due to its characteristics, blue marlin is threatened by over-exploitation (Collette et al., 2011).

In Indian Ocean, black marlin was largely caught by longline (70%), followed by gillnets (24%), with remaining catches recorded under troll and hand lines (IOTC-WPB16, 2018). Contribution of black marlin from Indonesian fleet between 2013-2017 was around 31% (~3,900 tons) of total catch in Indian Ocean, ranked second after Taiwan, China (IOTC-WPB16, 2018). Results of latest stock assessment undertaken in 2016, as calculated three different approach, namely: BSP-SS (Bayesian state space surplus production), ASPIC (A Stock–Production model Incorporating Covariates) and SS3 (Stock Synthesis model), together indicated that, blue marlin stock of the Indian Ocean is overfishing but not overfished (IOTC-WPB16, 2018), with a high chance (70-80%) of exceeding the MSY-based reference points in next 10 years if the catch level at the time of the assessment is maintained. However, there were some uncertainties in the robustness of the data available (nominal catch) and the CPUE series, especially in the north eastern Indian Ocean which may hampers the assessment.

Through this paper we attempt to bridge the research's gap in term blue marlin abundance in the north eastern Indian Ocean. Hopefully, the results will be useful for assessing the status of the stock of blue marlin, which is an important fishery resource in the Indian Ocean.

Materials and Methods

Fishery and Environmental Data

A total of 2,984 set-by-set data span in detail 1x1 degree latitude and longitude grid from January 2006 to December 2018 were obtained from Indonesia scientific observer (2006-2018) and national observer program (2016-2017), which covers commercial tuna longline vessels mostly based in Port of Benoa, Bali. Fishing trips usually last from three weeks to three months. Main fishing grounds cover from west to southern part of Indonesian waters, stretched from 75 ˚E to 35 ˚S (Figure 1). It also informed concerning the number of fish caught by species, total number of hooks, number of hooks between floats (HBF), start time of the set, start time of haul, soak time, and geographic position where the longlines were deployed into the water. The response variable in the models was the catch of blue marlin in number of fish. Year and quarter were used as categorical (factor) explanatory variables. Additional information was used as explanatory variables as follows:

a. Number of hooks between floats (HBF)

   Number of hooks between floats was set as a continuous variable in the model. It was varied from 4-27 hooks between floats;

b. Soak time

   Soak time was calculated as the time elapsed between the start of the fishing setting and the start of hauling of the longline. Soak time in the model was treated as continuous variable, thus the values were rounded to the nearest integer;

c. Start Set

The time at which the set commenced was employed to represent fishing time. In the model, it was treated as continuous variable, thus the values were converted into decimal and rounded to the nearest integer;

d. Moon

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, Dowling, & Prisantoso, 2012):

$Moon = sin(2\pi\ x\ moon\ phase) + cos(2\pi\ x\ moon\ phase)$ .... 1)

Data filtering

The major issue for modelling the abundance for billfishes from Indonesian tuna longline fishery was the high proportion number of zero-catch-per-set (Setyadji, Wibawa, & Fahmi, 2018). It was acknowledged that predominance of zero catches could be driving the model outputs as the CPUE trends do not appear to be biologically plausible (IOTC-WPB16, 2018). Originally the mean annual proportion of zero catches from the data was really high, around 91%. 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, therefore it might contain species misidentification;
2. Spatial coverage of the scientific observer data covers from north eastern to south eastern Indian Ocean, ranged from 0-33S and 75-129E (Figure 1). However, it lacks temporal coverage, moreover, the positive sets are concentrated in the north eastern area. Therefore, the data used for analysis limited to 0-17.5S and 75-129E;
3. Excluding sets which doesn’t contain blue marlin for the whole trip.

As a result of the application of the procedures and criteria above, total number of set used in the analysis is 1,752 and zero catch ratio is down to 84%.

CPUE Standardization

A delta-gamma GLM was applied to standardize the CPUE. As the approach of Wang (2018) with some modifications, the models were simply conducted with the main effects considered in this analysis were Year, Quarter, HBF, Moon, Soak Time and Start Set, whereas the interactions between main effects were not incorporated into the models. The gamma and delta models were conducted as follows:

Gamma model for CPUE of positive catch:

$$\log(CPUE) = \mu + Year + Quarter + HBF + Moon + Soak\ Time + Start\ Set + \varepsilon^{gamma} \quad \text{................ 2)}$$

Delta model for presence and absence of catch:

$$\text{PA} = \mu + Year + Quarter + HBF + Moon + Soak\ Time + Start\ Set + \varepsilon^{del} \quad \text{.......................................3)}$$

We used a forward approach to select the explanatory variables and the order they were included in the full model. The first step was to fit simple models with one variable at a time. The variable included in the model with lowest residual deviance was selected first. As second step the model with the selected variable then received other variables one at a time, and the model with lowest residual deviance was again selected. This procedure continued until residual deviance did not decrease as new variables were added to the previous selected model. Finally, all main effects and first order interactions were considered and a backward procedure based on Akaike Information Criterion (AIC) (Akaike, 1974), Bayesian Information Criterion (BIC) (Schwarz, 1978) and the values of the coefficient of determination (R^2) were used to select the final models.

The area-specific standardized CPUE trends were estimated based on the exponentiations of the adjust means (least square means) of the year effects (Butterworth, 1996; Maunder & Punt, 2004). The standardized relative abundance index was calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

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

where:

$CPUE$: is the adjust means (least square means) of the year effect of the gamma model;

$\tilde{P}$: is the adjust means (least square means) of the year effect of the delta model.

Result from other models, such as: negative binomial (NB), zero-inflated negative binomial (ZINB), and tweedie (TWEEDIE) also included for comparisons. Maps were produced using QGIS version 2.14 (Butterworth, 1996; Maunder & Punt, 2004) and the statistical analyses were carried out using R software version 3.6.0 (R Core Team, 2019), particularly the package *pscl* (Jackman, 2017; Zeileis, Kleiber, & Jackman, 2008), *emmeans* (Lenth, 2018), *MASS* (Venables & Ripley, 2002), *Hmisc* (Harrell Jr., Dupont, & Others, 2018), *nlme* (Pinheiro, Bates, DebRoy, Sarkar, & R Core Team, 2019) and *statmod* (Giner & Smyth, 2016).

Results and Discussions

Results

Descriptive Catch Statistic

Scientific observers and national observers recorded catch and operational data at sea following Indonesian tuna longline commercial vessels from 2006-2018 and 2016-2017, respectively. The combined dataset contained 112 trips, 2984 sets, 3,703 days-at-sea, and more than 3.9 million hooks deployed, respectively (Table 1). The spatial data distributed mainly in eastern Indian Ocean with most of the positive catches occurred in the area south of Indonesian waters, between 0^{o}-17.5^{o} S and 75^{o}-125^{o} E (Figure 1).

CPUE data characteristics

BUM nominal CPUE series is presented in Figure 2. In general, the catches of BUM during the last decade were relatively stable, except in 2012. The lowest CPUE recorded was in 2007 (0.042$\pm$0.02), as the highest was in 2012 (0.44$\pm$0.09). On the other hand, the proportion of zero catch for BUM was also very high, varying annually between a minimum of 0.71$\pm$0.05 in 2012 and a maximum of 0.95$\pm$0.23 in 2017 with average value 0.94$\pm$0.02 (Figure 3).

CPUE standardization

Based on model selection, all effects were remained and statistically significant, except moon phase. The deviance tables for selected gamma models are shown in the Table 2. The result indicated that the positive catch of blue marlin strongly influenced by year effect rather than targeting (HBF) or operational factors (i.e. soak time or start set). On the other hand, the environmental variable (moon phase) play less significant effect. For the delta model, soak time was excluded from the model and all effects were statistically significant except moon phase. The deviance tables for selected delta models are shown in the Table 3. Similar with gamma model, the catch probability of blue marlin was probably be affected more by temporal trend rather than operational or environmental effects. In addition, despite of the significances from the main effects it didn’t contribute a lot on reducing the deviance.

Estimations of standardized catch rates from several models are shown in Figure 4. Time trends of standardized CPUE as calculated using NB, ZINB and TWEEDIE models were similar from 2006 to 2018, however, time trend for ZINB was conflictive at the very end (2018). Moreover, DELTA model gave smoother trend, balanced trade-off and responded better to high proportion of zero catches (Figure 5). However, further analysis is required for handling the high value of confidence interval on the final model.

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References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control*, *19*(6), 716–723.

Butterworth, D. S. (1996). A possible alternative approach for generalised linear model analysis of tuna CPUE data. *Collective Volume of Scientific Papers*, *45*, 123–124.

Collette, B. B., Carpenter, K. E., Polidoro, B. A., Juan-Jordá, M. J., Boustany, A., Die, D. J., … Harrison, L. R. (2011). High value and long life—Double jeopardy for tunas and billfishes. *Science*, *333*(6040), 291–292.

Giner, G., & Smyth, G. K. (2016). statmod: Probability calculations for the inverse Gaussian distribution. *ArXiv Preprint ArXiv:1603.06687*.

Harrell Jr., F. E., Dupont, C., & Others. (2018). *Hmisc: Harrell Miscellaneous*. Retrieved from https://CRAN.R-project.org/package=Hmisc

IOTC-WPB16. (2018). *Report of the 16th Session of the IOTC Working Party on Billfish* (Working Party Report No. IOTC–2018–WPB16–R[E]; p. 97 pp). Retrieved from Indian Ocean tuna Commission (IOTC) website: http://iotc.org/sites/default/files/documents/2018/11/IOTC-2018-WPB16-RE_FINAL_-_DO_NOT_MODIFY.pdf

Jackman, S. (2017). *pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory*. Retrieved from https://github.com/atahk/pscl/

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

Lenth, R. (2018). *emmeans: Estimated Marginal Means, aka Least-Squares Means*. Retrieved from https://CRAN.R-project.org/package=emmeans

Maunder, M. N., & Punt, A. E. (2004). Standardizing catch and effort data: A review of recent approaches. *Fisheries Research*, *70*, 141–159. https://doi.org/10.1016/j.fishres.2004.08.002

Nakamura, I. (1985). Billfishes of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes and swordfishes known to date. *FAO Species Catalogue; FAO Fisheries Synopsis*, *5*(125), 65.

Nishida, T., & Wang, S.-P. (2006). *Standardization of swordfish (Xiphias gladius) CPUE of the Japanese tuna longline fisheries in the Indian Ocean*. IOTC-WPB-2006.

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., & R Core Team. (2019). *nlme: Linear and Nonlinear Mixed Effects Models*. Retrieved from https://CRAN.R-project.org/package=nlme

QGIS Developer Team. (2018). *QGIS Geographic Information System*. Retrieved from Open Source Geospatial Foundation Project website: http://qgis.osgeo.org/

R Core Team. (2019). *R: A Language and Environment for Statistical Computing*. Retrieved from https://www.R-project.org/

Sadiyah, L., Dowling, N., & Prisantoso, B. I. (2012). Developing recommendations for undertaking CPUE standardisation using observer program data. *Indonesian Fisheries Research Journal*, *18*(1), 19–33.

Schwarz, G. (1978). Estimating the dimension of a model. *The Annals of Statistics*, *6*(2), 461–464.

Setyadji, B., Jumariadi, J., & Nugraha, B. (2012). Catch estimation and size distribution of billfishes landed in Port of Benoa, Bali. *Indonesian Fisheries Research Journal*, *18*(1), 35–40.

Setyadji, B., Wibawa, T. A., & Fahmi, Z. (2018). Catch per Unit of Effort (CPUE) Standardization of Black Marlin (Makaira Indica) Caught by Indonesian Tuna Longline Fishery in the Eastern Indian Ocean. *Paper Presented on 16th Working Party on Billfish, Cape Town, South Africa, 4-8 September 2018, IOTC-2018-WPB16-12*, 14.

Venables, W. N., & Ripley, B. D. (2002). *Modern Applied Statistics with S* (Fourth). Retrieved from http://www.stats.ox.ac.uk/pub/MASS4

Wang, S.-P. (2018). CPUE standardization of striped marlin (Tetrapturus audax) caught by Taiwanese large scale longline fishery in the Indian Ocean. *Paper Presented on 16th Working Party on Billfish, Cape Town, South Africa, 4-8 September 2018, IOTC–2018–WPB16–18*, 31.

Widodo, A. A., Prisantoso, B. I., & Suprapto, S. (2016). Perikanan pancing ulur di Samudera Hindia: Hasil tangkapan ikan berparuh yang di daratkan di Sendangbiru, Malang, Jawa Timur. *Jurnal Penelitian Perikanan Indonesia*, *18*(3), 167–173. http://dx.doi.org/10.15578/jppi.18.3.2012.167-173

Zeileis, A., Kleiber, C., & Jackman, S. (2008). Regression models for count data in R. *Journal of Statistical Software*, *27*(8), 1–25.

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

Year	Trips	Sets	Days at Sea	Total Hooks	Hooks per Set		Hooks per Float	
2006	13	401	401	577,243	1,439.51	(214.9)	11.2	(3.9)
2007	13	265	258	406,135	1,532.58	(326.5)	14.0	(4.4)
2008	15	370	404	483,662	1,307.19	(385.9)	13.0	(4.5)
2009	13	283	288	323,042	1,141.49	(234.7)	12.1	(4.9)
2010	6	165	152	220,394	1,335.72	(457.5)	13.6	(5.2)
2011	3	105	111	110,384	1,051.28	(173.9)	12.0	-
2012	8	198	192	290,265	1,465.98	(559.1)	14.1	(2.3)
2013	7	225	198	252,919	1,124.08	(210.4)	12.7	(2.1)
2014	5	167	265	193,740	1,160.12	(176.9)	15.0	(2.0)
2015	5	148	241	172,463	1,165.29	(145.2)	14.1	(3.2)
2016	8	244	383	324,068	1,314.89	(146.4)	15.2	(6.4)
2017	10	218	489	279,204	1,214.04	(395.3)	17.2	(4.8)
2018	6	195	321	262,856	1,349.98	(242.9)	14.8	(4.5)

Table 2. The deviance table for selected gamma models.

Variable	Df	Deviance Resid.	Df. Resid.	Deviance	F	Pr(>F)	
NULL			230	35.4			
Year	12	5.247	218	30.2	3.5367	0.000084	***
Quarter	3	1.429	215	28.8	3.8552	0.010275	*
HBF	1	1.190	214	27.6	9.6287	0.002178	**
Moon	1	0.346	213	27.2	2.8006	0.095710	.
Soak_Time	1	0.601	212	26.6	4.8656	0.028477	*
Start_Set	1	0.549	211	26.1	4.4411	0.036265	*

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

Table 3. The deviance table for selected delta models.

Variable	Df	Deviance Resid.	Df. Resid.	Deviance	Pr(>F)	
NULL			1571	1312.2		
Year	12	46.328	1559	1265.9	6.09E-06	***
Quarter	3	8.774	1556	1257.1	0.03245	*
HBF	1	5.542	1555	1251.6	0.01857	*
Moon	1	2.247	1554	1249.3	0.13388	
Start_Set	1	4.235	1553	1245.1	0.0396	*

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

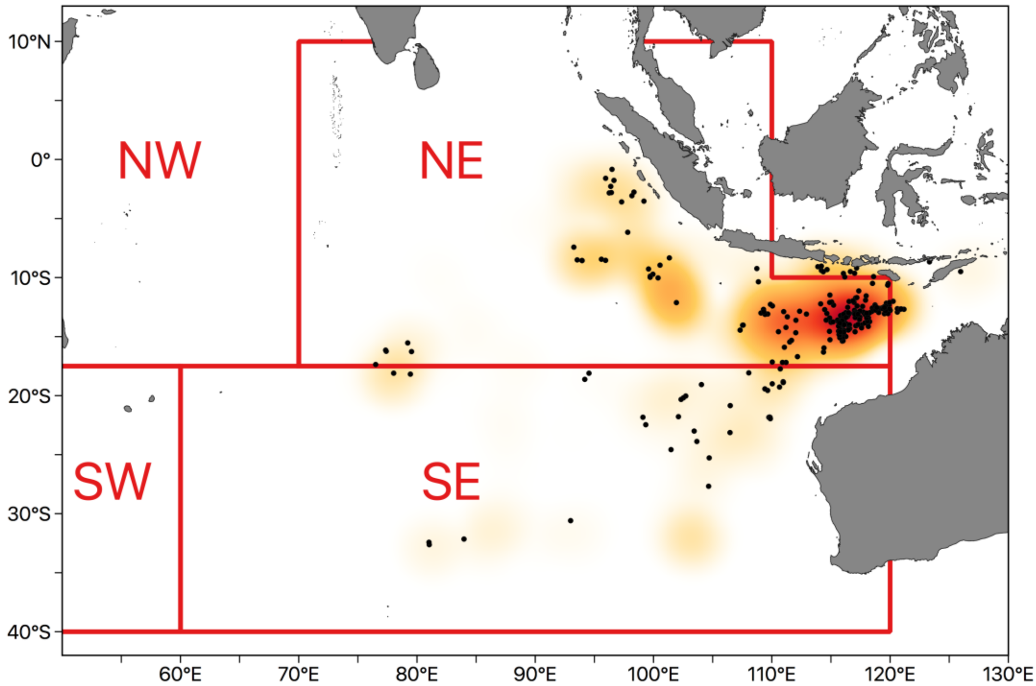

Figure 1. Area stratification used in the analysis (Wang, 2018) based on the aggregation of the relative sizes from nine IOTC statistics areas for swordfish in the Indian Ocean (Nishida & Wang, 2006)

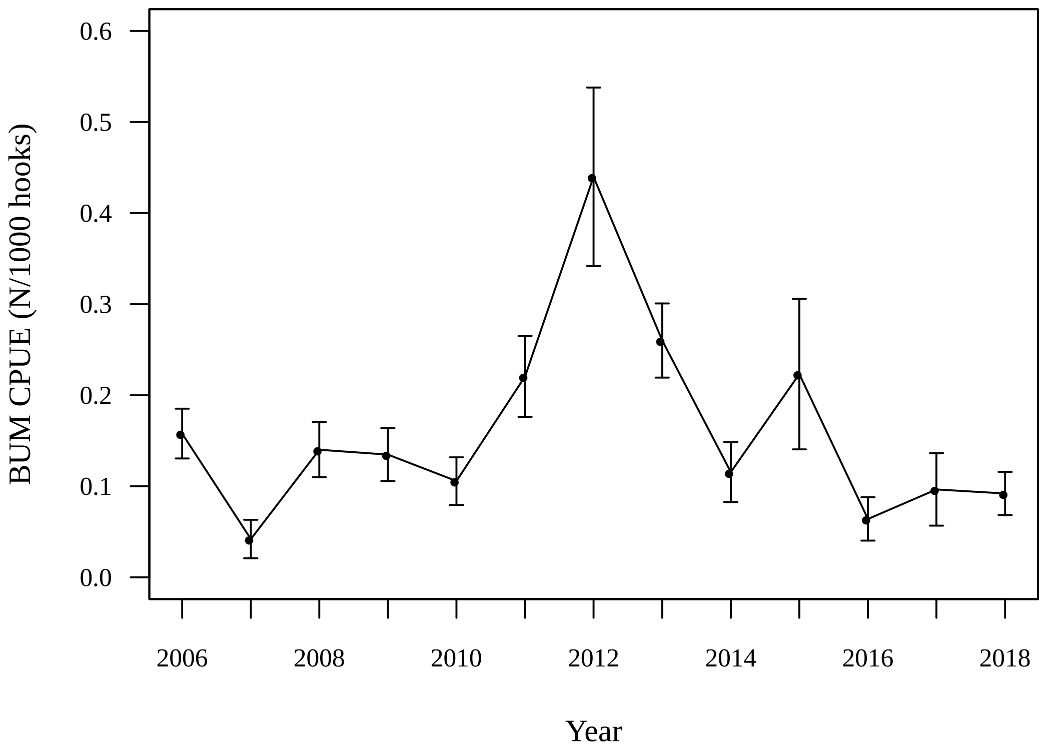

Figure 2. Nominal CPUE series (N/1000 hooks) for BUM from 2006 to 2018. The error bars refer to the standard errors.

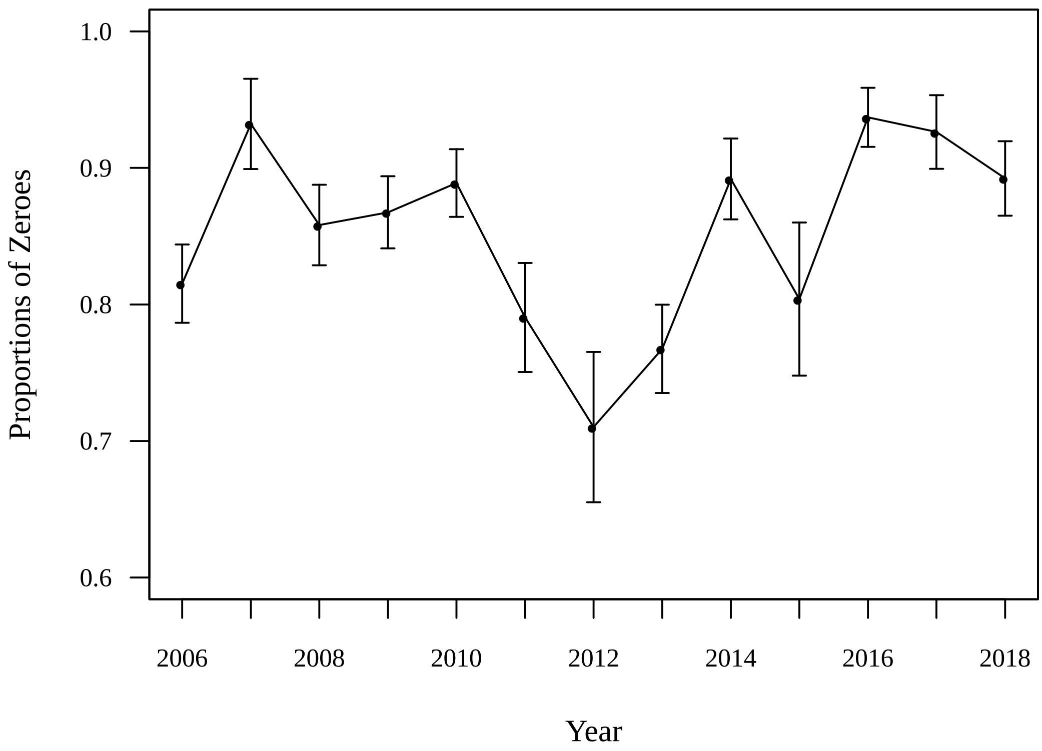

Figure 3. Proportion of zero BUM catches from 2005 to 2017. The error bars refer to the standard errors.

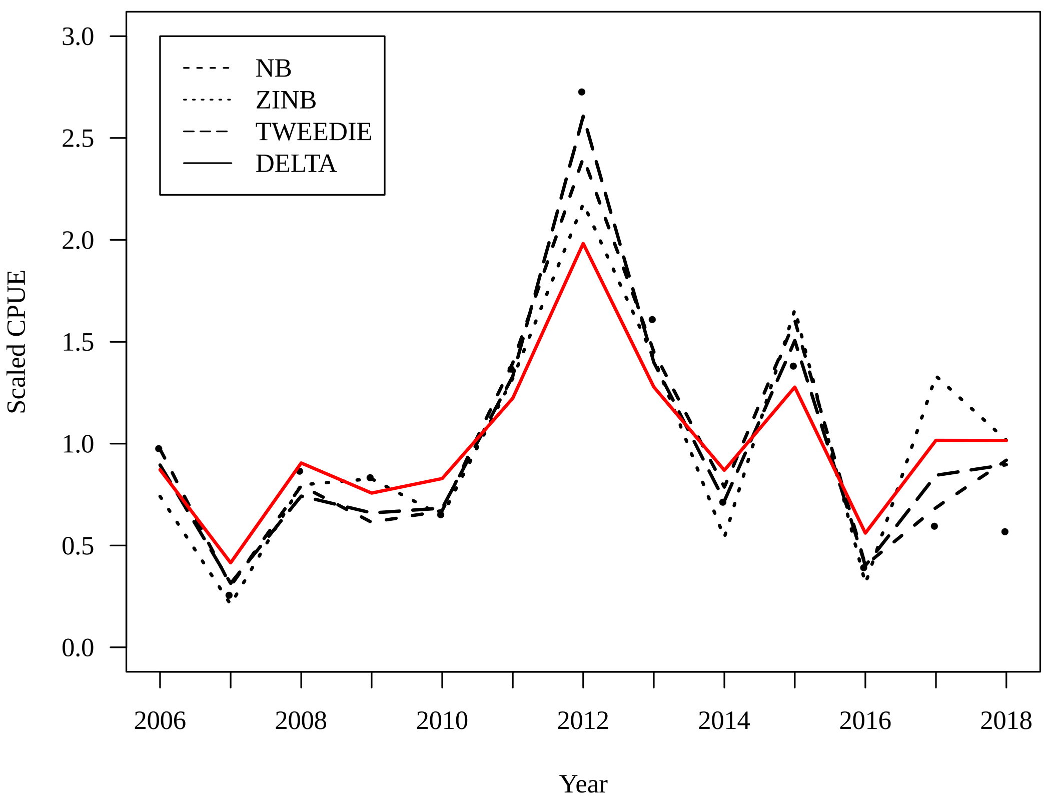

Figure 4. Standardize catch per unit effort (CPUE) calculated using various models. Values were scaled by dividing them by their means.

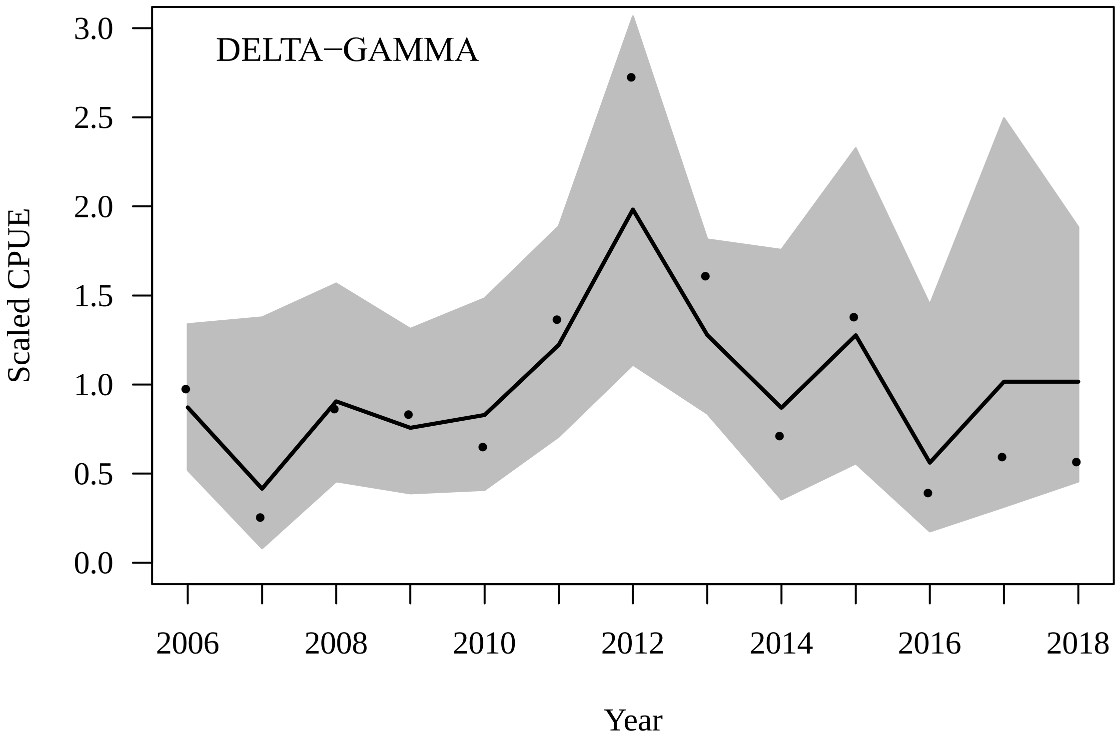

Figure 5. Final graph for standardized catch per unit effort (CPUE) of BUM calculated using delta-gamma model with 95% confidence interval (greyed area). Values were scaled by dividing them by their means.