Standardization of Catch per Unit of Effort (CPUE) of Black Marlin (*Makaira Indica*) Caught by Indonesian Tuna Longline Fishery in the Eastern Indian Ocean

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Abstract

Black marlin (*Makaira indica*) is caught as by-catch by Indonesian tuna longline fleet. Approximately 18% (~2,500 tons) of total black marlin caught in Indian Ocean is landed in Indonesia. Relative abundance indices are the input data for several stock assessment analyses that provide 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 and to estimate relative abundance indices based on the Indonesian longline dataset. Data was collected by scientific observers from August 2005 to December 2014. Most of the vessels monitored were based in Benoa Harbour, Bali. We have used conventional models for counting data, but also zero inflated and hurdle models because the catches are often zero. Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) were used to selected the best models among all we have evaluated. If we rely on AIC the negative binomial (NB) and the zero inflated negative binomial (ZINB) models are selected, but if we use BIC the NB model is the best option. Time trends of standardized CPUE as calculated using NB and ZINB models were similar from 2007 to 2011. However, time trends are conflictive in the very beginning and in the very end of the series. At this stage there is not strong motivation to choose one of the two models (NB or ZINB), hence sensitivity analysis concerning the two time series are the alternative when running stock assessment models.

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Introduction

Black marlin (*Makaira indica*) is an apex predator, highly migratory species and considered as a non-target species of industrial and artisanal fisheries in Indonesian tuna longline fishery. It ranked second after swordfish in catch composition (Setyadji *et al.*, 2012). It is also known to have high commercial value in the tropical and subtropical Indian and Pacific Oceans (Nakamura, 1985). In Indian Ocean it has been caught between 20° N and 45° S, but more often off the western coast of India and the Mozambique Channel (IOTC, 2015).

Black marlin was largely caught in Indian Ocean with gillnets (~59%), followed by longlines (~19%), with remaining catches recorded under troll and hand lines (IOTC, 2015). Contribution of black marlin from Indonesian fleet between 2011-2014 was around 18% (~2,500 tons) of total catch in Indian Ocean, ranked fourth after Iran, Sri Lanka and India (IOTC, 2015). Results of latest stock assessment as calculated using Stock Reduction Analysis (SRA), which is a data poor method, suggest that black marlin stock of the Indian Ocean is not overfished but subject to overfishing (IOTC, 2015). Estimations of relative abundance indices can support the use of more detailed models, which can provide important information concerning black marlin status stock.

Statistical models such as Generalized Linear Models (GLM) can be used to "standardize" commercial catch per unit effort (CPUE) in order to calculate relative abundance indices, which are the input data for several stock assessment models. Estimations of standardized CPUE of Indian Ocean black marlin are limited, especially if compared to other billfish species as swordfish (*Xiphias gladius*), blue marlin (*Makaira mazara*), and striped marlin (*Tetrapturus audax*). Lack of detailed data hampers the calculation of standardized CPUE for black marlin. The last estimation was calculated using Japanese longline fishery statistics for 1967-1997 (Uozumi, 1998). However, since 2005, Indonesia through scientific observer program has been providing information concerning black marlin caught by longline boats operating in the east of Indian Ocean (Setyadji *et al*., 2014). In this paper we have used a GLM to calculate standardized CPUE of black marlin caught by Indonesian longline fleet in the Eastern Indian Ocean. Results are useful to assess the status of the stock of black marlin, which is an important fishery resource in the Indian Ocean.

Materials and Methods

Data and Variables

A total of 2,287 set-by-set data span in 1x1 latitude and longitude degrees grid from August 2005 to December 2014 were obtained from Indonesia scientific observer program, which covers commercial tuna longline vessels mostly based in Port of Benoa, Bali. Fishing trips usually last from three weeks to three months. In the Eastern Indian Ocean, the main fishing ground spreads from west of Sumatra to south of Java, Bali and Nusa Tenggara.

Dataset include information concerning catch (number of fish caught), 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 longline was deployed into the water. Follow explanations on how the information was used in the analyses:

a. Fishing area

   Longline sets were classified into two categories (inside or outside) according to the geographical position concerning the Indonesian Economic Exclusive Zone (Figure 1 upper panel). Furthermore, the longline sets were also classified into five different regions as shown in bottom panel of Figure 1.

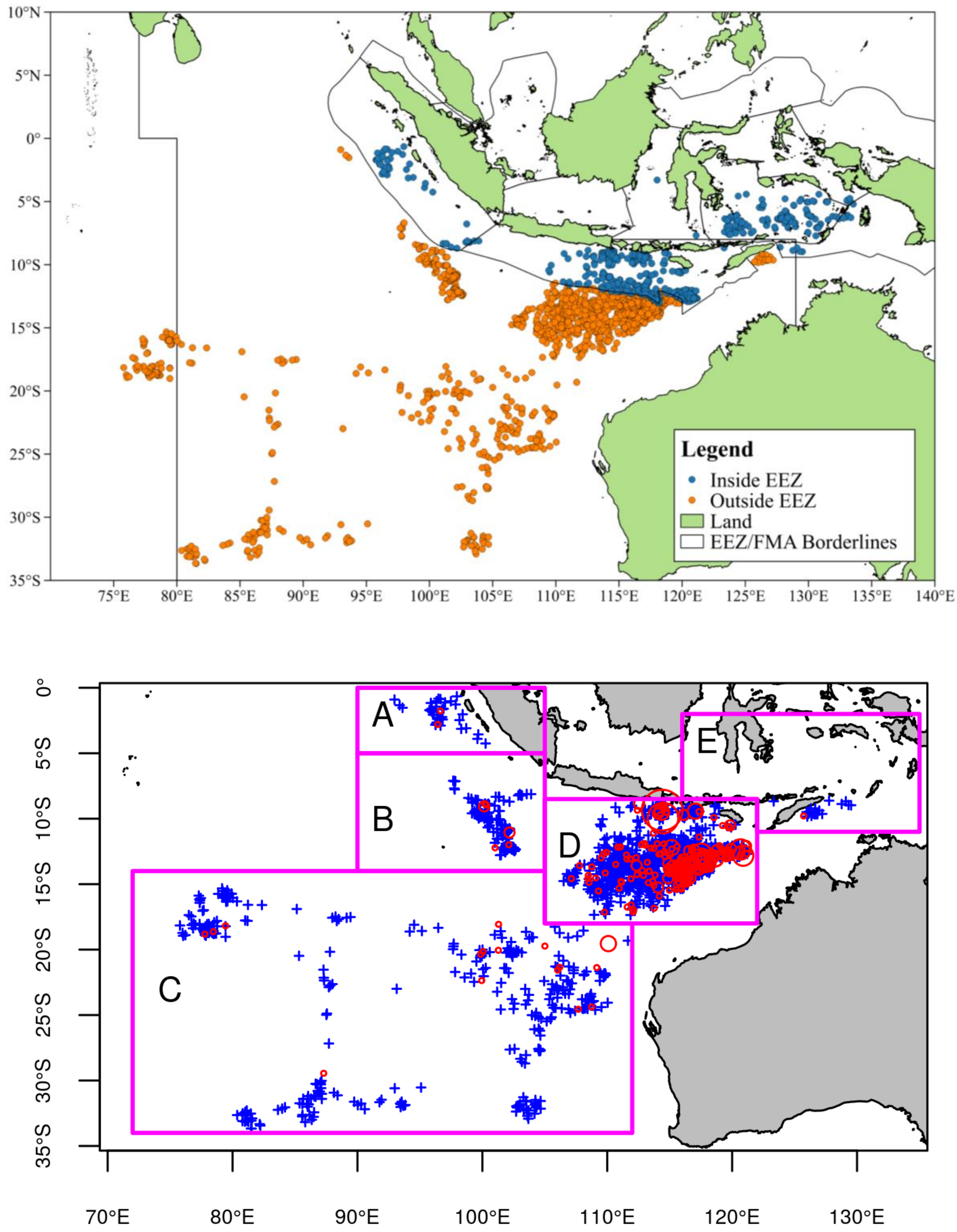

Figure 1. Longline sets distribution classified as within or outside of Economic Exclusive Zone (EEZ) (upper panel), and classified into five fishing regions (bottom panel). In this panel blue crosses stand for zero catch, while red circles indicate the positive catches.

Subareas based on EEZ threshold were included in the model to account for differences concerning if the fishery was (or was not) in high seas open oceanic water. Subareas concerning the five regions include three core fishing grounds (A, B and D), the Banda Sea (E), and fishing sets scattered all over southeast Indian Ocean in open oceanic areas (C) (bottom panel – Figure 1).

b. Number of hooks between floats (HBF)

HBF information available ranged from 4-21. We have tried out to fit models with HBF as continuous variable and also as categorical.

c. Start time of the set (Start_Set)

Similarly to HBF, start time of the set was also considered as continuous or categorical variable.

d. Soak time (Soak_Time)

Soak time was calculated as the time elapsed between the start of setting and the start of hauling of the fleet. Assuming longline retrieval throughout each operation was at constant rate (Chen *et al.*, 2012). Soak time was also included as continuous or categorical variable in the models. In order to deal with the variable as categorical the values were rounded to the nearest integer.

e. Moon phase was the only environmental variable included in the analyses. Moon phase was divided into four equal subsets within the lunar cycle (29.5 days) and using ~5 days for each phase: new moon, first quarter, full moon and third quarter (He *et al.*, 1997; Ponce-Díaz *et al.*, 2003).

Models

Generalized linear models can be written in matrix notation as $g[E(Y)] = X\beta$ where Y is a vector of realizations of the response variable; $E[\,]$ is the expectation function, $g(\,)$ is the link function, β is the vector of parameters and X is the design matrix of the explanatory variables. A probability distribution for Y and a link function need to be selected in advance to calculate estimations of the parameters β, which represent the effects of the explanatory variables (*e.g.* year).

In this study, GLM was used to model the nominal catch (number of fish) as response variable while effort was included in the models as an offset. Poisson and negative binomial distributions were used to model catches. However, black marlin is a by-catch and datasets contain huge quantity of zero catch (~89.4%). Hence poisson model may not fit well the data. Negative binomial model usually can account for large amount of zeros and overdispersion because a dispersion parameter is estimated. However, if the amount of zeros is excessive, even the negative binomial model may not fit the data well. Therefore we also used zero inflated poisson, zero inflated negative binomial, hurdle poisson and hurdle negative binomial models. These four models are alternatives to cope with the excessive zero catches. Logarithmic link functions were used to fit all models.

In order to choose the order the explanatory variables were included in the full model, we have started by fitting simple models with one variable at a time. Then we select first the variable of the model with lowest residual deviance. In the second step we have fitted a model with the selected variable plus one of the other variables each at a time. Again we selected the model with lowest residual deviance. This procedure followed until deviance did not decrease as new variables were added to the previous selected model.

All main effects and first order interactions were included in the models. Akaike Information Criterion (AIC) (Akaike, 1974) and Bayesian Information Criterion (BIC) (Schwarz, 1978) were used to compare and select among the models. In addition, we assessed the quality of the model fittings by comparing the observed frequency distribution of the number of fish caught to the predicted frequency distribution as calculated using the selected models. Kolmogorov-Smirnov test was used to test if the difference of the two distributions (observed and predicted) were significant. All the analyses were carried out using R software functions version 3.2.4 (R Core Team, 2016).

Results and Discussions

Results

Number of black marlin caught per set were very low and there were excessive zero catches per set (89.4%), mostly because it is by-catch (Fig. 2, left panel). The number of hooks used per set ranged from 396-2,700, with mean 1,32±7.4 hooks/set and mode at 960 hooks/set (Fig. 2, right panel).

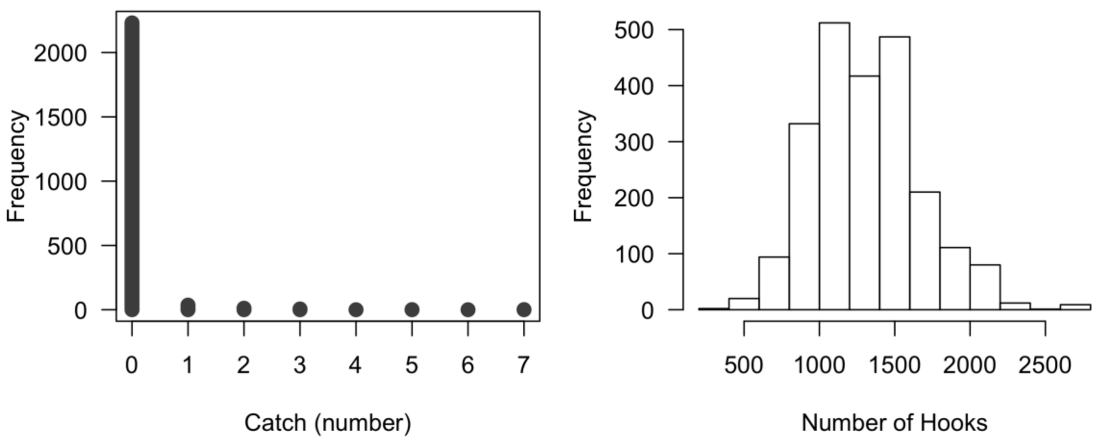

Figure 2. Catch (number of fish) of black marlin and effort (number of hooks) as reported by onboard observers.

Other variables concerning the longline sets are shown in Figure 3. Highest number of sets was in 2006 (401 sets), while the lowest was in 2008 (105 sets), with average of 228 sets/year. Number of sets in first quarter (January-March) were lower than in other quarters. Overall the average was 571 sets/quarter. Most of Indonesia longliners have used 11 and 12 HBF, while 9 or 10 HBF were not reported. Longlines sets usually started in the morning between 6-8 a.m. while haul operations start at 4-8 p.m. in the evening, hence soak time were mostly between 10-12 hours. Data set distribution was balanced with similar number of observations in each moon phase.

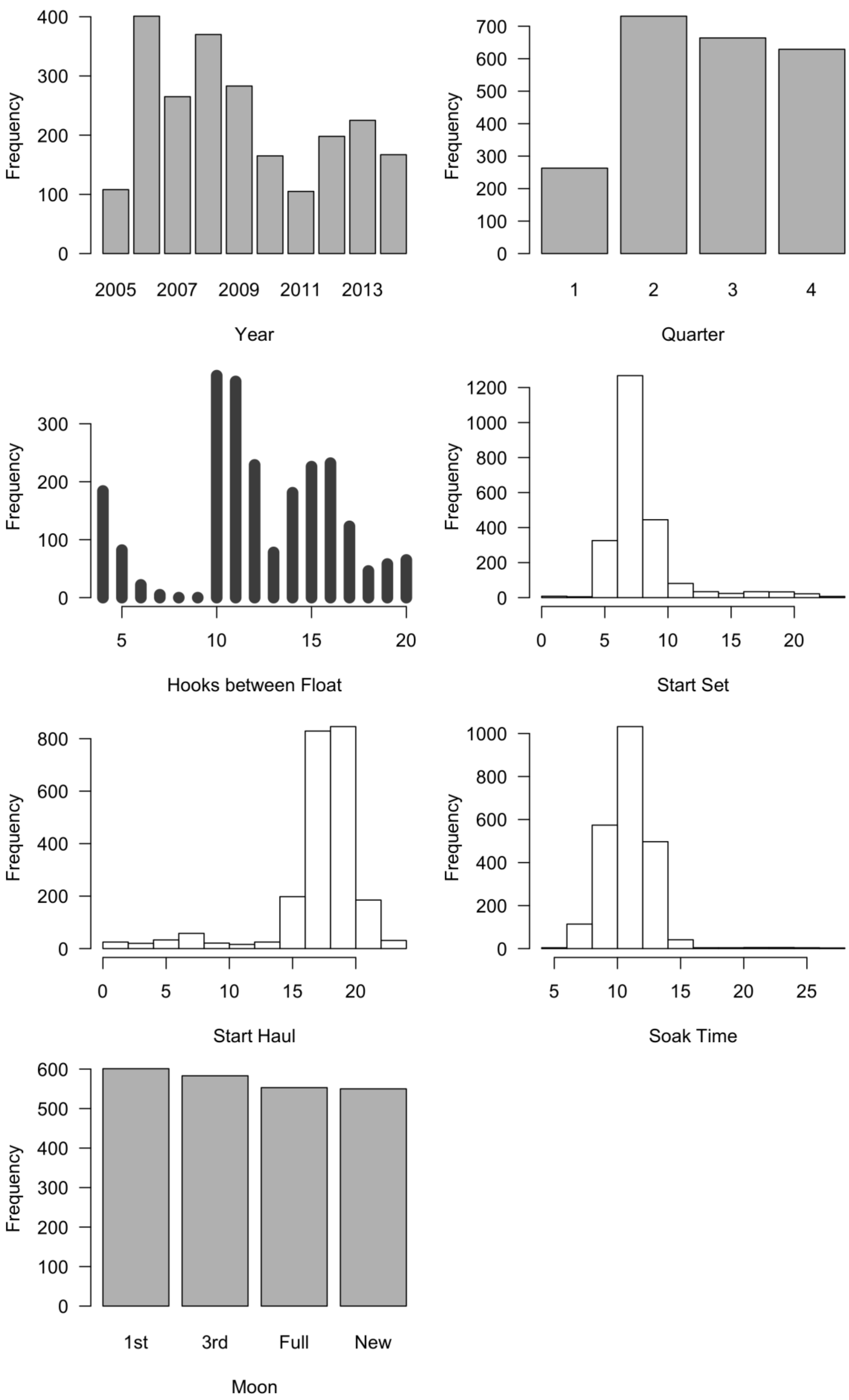
Frequency
Year
Quarter
Hooks between Float
Start Set
Start Haul
Soak Time
Moon
1st
3rd
Full
New

Figure 3. Variables used in the analysis of catch and effort to standardize CPUE of black marlin.

Variables that mostly reduce deviance were in order: number hooks per basket, fishing region, year, quarter, start set, soak time, area concerning ZEE, start haul and moon phase. Hence fishermen strategy concerning the number of hooks per basket and location where they deploy the longline are the variables that explain most of the variability of black marlin catches.

Models did not converge when all main effects and interactions were included in the formulation. Hence simple models with lower number of interactions were fitted to data. Because results (e.g. selection of variables and models, and standardized CPUE) were similar when Start_Set, HBF and Soak_Time were included in models as quantitative (covariate) or as qualitative (factor) variables (e.g. classified in categories), hereafter we show only the solutions calculated using them as covariates. Summary of indicator calculations for the six models selected are showed in Table 1. Notice that hurdle models have more parameters than the others, while poisson (P) and negative binomial (NB) are the smaller models. A difference of 2 units between AIC values is not strong evidence that one of the models is better than the other (Burnham and Anderson, 2002). Hence if we rely in AIC both NB and Zero Inflated Negative Binomial (ZINB) models are selected. However, the simple NB is clearly the selected if we use the BIC to select among the fitted models.

Logarithm of likelihood of ZINB model is higher than that of NB model (Table 1), but remind that ZINB has more parameters. The number of zero catches in the database is 2,044. Hurdle models always predict the correct number of zeros due to its structure, but these models are more complex in the sense there have more parameters. Poisson and NB simple models are more biased than others as indicated by differences between the observed and the predicted number of zero catches. However, biases of all models including the simple ones were not of concern as indicated by the p values calculated using Kolmogorov-Smirnov test to compare the observed and predicted distributions of number of fish.

Table 1. Summary of indicators as calculated using six model structures: Poisson (P), Negative Binomial (NB), Zero Inflated with Poisson (ZIP), Zero Inflated with Negative Binomial (ZINB), Hurdle with Poisson (HP), and Hurdle with Negative Binomial (HNB). The terms in the column at left indicate: number of parameters (k), Akaike (AIC) and Bayesian (BIC) Information Criteria, logarithm of the likelihood (logLik), number of predicted zero catches (zero), and p values as calculated using a Kolmogorov-Smirnov test.

	Model structure					
	P	NB	ZIP	ZINB	HP	HNB
k	21	21	34	34	40	36
AIC	1907.64	1820.55	1836.52	1821.47	1839.95	1845.27
BIC	2028.07	1946.72	2031.51	2016.46	2069.35	2051.73
logLik	-932.82	-888.28	-884.26	-875.74	-879.98	-885.64
Zero	1999	2072	2040	2046	2044	2044
p.value	0.768	0.995	~1	~1	~1	~1

NB and ZINB models were selected to calculate standardized catch rate indices for black marlin as they were the models with lower values of AIC and BIC, and because there are no evidences they are biased if we rely in the Kolmogorov-Smirnov test. Hereafter only the results of NB and ZINB are showed. Summary of parameter estimations of NB and ZINB models are in Tables 2 and 3, respectively. Notice that moon phase and start haul variables were dropped due to the high values of AIC and BIC when they are in the models. None of the interactions were included in the final models.

Table 2. Summary of parameter estimations of Negative Binomial model. Terms: SE – standard error, p – p values as calculated using Z test to assess difference from zero. HBF – Hooks per Basket, FR – Fishing Region.

	Estimate	SE	p
(Intercept)	-8.963	1.186	0.000+
HBF	-0.124	0.022	0.000+
FR_B	-0.494	0.914	0.589
FR_C	-0.709	0.845	0.401
FR_D	0.982	0.803	0.221
FR_E	-0.277	1.349	0.837
Year2006	-0.011	0.455	0.981
Year2007	-0.292	0.489	0.550
Year2008	-0.546	0.457	0.232
Year2009	0.378	0.450	0.401
Year2010	-0.436	0.490	0.374
Year2011	0.260	0.480	0.587
Year2012	0.189	0.486	0.698
Year2013	0.368	0.453	0.417
Year2014	0.428	0.533	0.421
Quarter2	0.307	0.239	0.198
Quarter3	-0.410	0.264	0.121
Quarter4	0.386	0.255	0.129
Start_Set	-0.058	0.023	0.012
Soak_Time	0.092	0.041	0.025
AreaWithin EEZ	-0.305	0.203	0.133

Only estimations of parameters for three quantitative explanatory variables (HBF, Start Set and Soak Time) were significantly different of zero as calculated using the Negative Binomial model (Table 2). However, estimations for explanatory categorical variables were significant as calculated using ZINB model (Table 3). Standardized catch rate calculations are based on estimations of parameters of categorical variable “Year”, hence it is of particular interest. Notice that the standard error calculated for 2011 in the ZINB model were high for zero catches. Standard errors were also high with respect to estimations of parameters of years 2012, 2013 and 2014, hence p values were high, which indicate that estimations for the end of the time series were not significantly different of zero. Estimation of dispersion parameter (e.g. Log(theta)) of the negative binomial model fitted to the counts (excluded the excess of zeros) was not significant. This result indicates that after the excess of zeros was discarded the remaining counting distribution is not overdispersed.

Table 3. Summary of parameter estimations of Zero Inflated Negative Binomial model. Terms: SE – standard error, p – p values as calculated using Z test to assess difference from zero. HBF – Hooks per Basket, FR – Fishing Region.

		Zero	
	Estimate	SE	p
(Intercept)	-11.198	48.300	0.817
HBF	-0.372	0.113	0.001
FR_B	13.758	48.212	0.775
FR_C	12.625	48.208	0.793
FR_D	10.071	48.202	0.834
FR_E	-0.196	NA	NA
Year2006	-6.298	2.070	0.002
Year2007	-5.887	2.095	0.005
Year2008	-6.321	1.993	0.002
Year2009	-8.504	2.393	0.000
Year2010	-5.817	2.019	0.004
Year2011	-11.037	20.339	0.587
Year2012	-5.221	1.761	0.003
Year2013	-3.361	1.517	0.027
Year2014	-5.206	1.812	0.004
Start_Set	-0.070	0.070	0.313
Soak_Time	0.273	0.123	0.027
		Positive	
	Estimate	SE	p
(Intercept)	-9.052	1.738	0.000+
HBF	-0.147	0.030	0.000+
FR_B	1.870	1.263	0.139
FR_C	1.188	1.084	0.273
FR_D	1.857	0.918	0.043
FR_E	-0.503	1.393	0.718
Year2006	-1.659	0.836	0.047
Year2007	-1.591	0.834	0.056
Year2008	-2.200	0.820	0.007
Year2009	-1.600	0.822	0.052
Year2010	-2.014	0.848	0.018
Year2011	-1.565	0.833	0.060
Year2012	-1.244	0.856	0.146
Year2013	-0.604	0.849	0.477
Year2014	-1.338	0.921	0.146
Start_Set	-0.077	0.027	0.005
Soak_Time	0.240	0.062	0.000
Log(theta)	0.074	0.396	0.853

Estimations of standardized catch rates are shown in Figure 4. Time trends of standardized CPUE as calculated using NB and ZINB models were similar from 2007 to 2011. However, time trends are conflictive in the very beginning and in the very end of the time series. Standardized catch rate calculated using NB decreased from 2005 to 2006, but it has increased in the same period if we rely on ZINB results. After 2011, standardized CPUE calculated with ZINB decreased. In opposition, estimations calculated with NB showed an increasing trend from 2011 to 2014. Because there is not motivation to select one of the two standardized series for stock assessment, we suggest that a sensitivity analysis is the alternative. Overall, both standardized CPUE series showed a slight increasing trend across the ten years span we analyzed. If we rely in these calculations as valid indices, there are no clear evidences that abundance of the stock has decreased in the recent years.

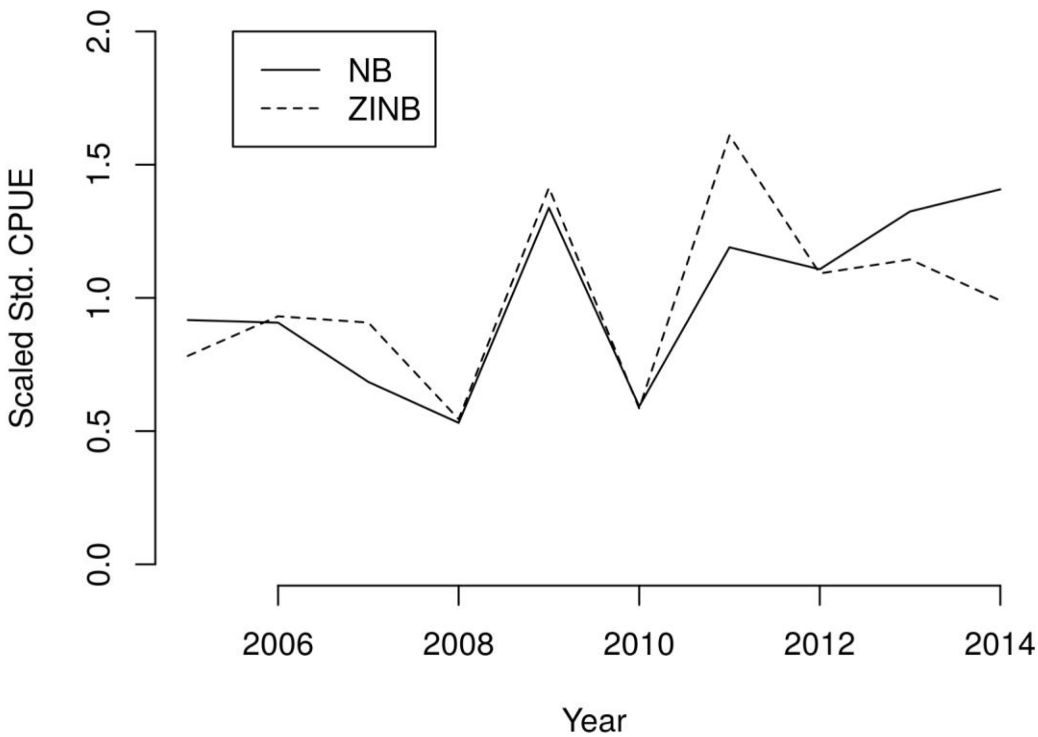

Figure 4. Standardize catch per unit effort (CPUE) calculated using Negative Binomial (NB) and Zero Inflated Negative Binomial (ZINB) models. Values were scaled by dividing them by their means.

Discussions

The configuration of number hooks between float (HBF) during the longline operation was likely the most influential factor as already suggested in other analyses concerning billfish (Sadiyah *et al.*, 2012, Ijima *et al.*, 2015). Models with HBF as factor did not outperform model with HBF as covariate, hence simple linear models represents the relationship between HBF and CPUE of black marlin.

Despite start set and soak time have been also considered as important in CPUE standardization by some authors (e.g. Chen *et al*, 2012, Unwin *et al*., 2005), often those variables are not considered in the analyses of Indonesia fisheries because it can only be obtained from scientific observer data. However, our results suggest that soak time and start set are not as important as HBF and the location (fishing region) where the longline is deployed into the water.

There is not consensus about the relationship between moon phase and CPUE of species caught using tuna pelagic longline. In the present paper the relationship between black marlin catches and moon phase was weak, which is agreement with Ponce-Díaz *et al.* (2003) that reported no significant difference between catches of striped marlin in the four moon phases. However, Poisson *et al*. (2010) found the yield of the albacore tuna (*Thunnus alalunga*) and swordfish (*Xiphias gladius*) caught by the Réunion Island swordfish longline fleets was related to the phases of the moon. The effect of moon phase in CPUE and catches depends on the fish habits and nictmeral movementsm, and on the time of the day the longlines are deployed into the water. Indonesia longlines were mostly deployed into the water during the day. The effect of moon may be stronger when the fisheries take place at night.

Based on the analysis, both negative binomial and zero-inflated negative binomial models fit the catch per set data for black marlin. Estimations of standardized CPUE of black marlin showed a slight increasing trend during recent years, similarly to blue marlin CPUE time trend as calculated by Wang *et al*. (2012). In opposition striped marlin (*Tetrapturus audax*) (Wang, 2015; Ijima *et al.*, 2015), Indo Pacific Sailfish (*Istiophorus platypterus*) (Andrade, 2015) and swordfish (Nishida and Wang, 2014) showed a declining trend.

The peak of standardized CPUE values in 2009 appeared in both CPUE series (NB and ZINB). It may be related to a strong *El Niño* phenomenon, which affected bigeye tuna (*Thunnus obesus*) in eastern Indian Ocean off Java (Syamsuddin *et al.*, 2013; Setiawati *et al.*, 2015). In order to investigate this hypothesis further analysis concerning fishery data and environmental variables such as sea surface temperature (SST), sea surface height (SSH), surface winds, and sea surface chlorophyll (SSC) are encouraged in the future.

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