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# DELTA MODEL APPROACH FOR CPUE STANDARDIZATION OF SWORDFISH (*Xiphias gladius* Linnaeus, 1978) CAUGHT BY INDONESIAN LONGLINE FLEET IN THE EASTERN INDIAN OCEAN

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**ABSTRACT**

Relative abundance indices as calculated based on commercial catches are the input data to run stock assessment models to gather useful information for decision making in fishery management. A Generalized Linear Model (GLM) was used to calculate relative abundance indices and effect of longline fishing gear configuration. Data were collected by a scientific observer program from August 2005 to November 2013. Most of the boats monitored were based in the Benoa Port, Bali. Catches are often equal to zero because swordfish is a bycatch for Indonesian longline fleets. Therefore, a hurdle model and a binomial distribution was used to model the proportion of positive catch rates, while a gamma distribution were used to model the positive longline sets. Correlations between the proportion of positive sets and year ($0.109$; $p = 0.781$) and quarter ($0.492$; $p = 0.507$) were weak. However, linear correlation between the proportion of positive sets and the length of branch lines ($r = -0.628$; $p = 0.029$) and number of hooks between floats ($-0.446$; $p = 0.084$) were negative and significant. The probability of success is higher for surface longline with small number of hooks and short branch lines. Models with year in interactions as random effects did not converge. Models with year in interactions as fixed effects did converge, but the estimation of standard errors of year coefficients were high. Meaningful estimations were obtained only when using the simplest model, in which year is not in interactions. The low proportional decrease of deviance indicates that most of the variability of catch rates of swordfish caught by Indonesian longline boats are not related to year, quarter, number of hooks between floats and the length of branch lines. Other variables and information, like the daytime while the longlines deployed in the water (day or night), type of bait, size and type of hooks, and if the fishermen use light-sticks to attract the fish, are necessary to better understand the catch rate, and improve the estimations of the relative abundance indices.

**Keywords: Swordfish; standardized CPUE; GLM; GLMM**

## INTRODUCTION

Swordfish is a highly migratory species (Neilson *et al*., 2015) to wide speading in the Indian Ocean where the stock, hence, is exploited by several countries. This species is economically important for tuna longline industries. About half of billfish caught by Indonesian tuna longline is swordfish (Jatmiko, *et al*., 2015) The countries concerned are deal to the Indian Ocean Tuna Commission (IOTC) as the international agency in charge to carry out data analyses and stock assessment. The estimation of relative abundances indices is necessary in most of the stock assessment models. In the tuna fisheries catch-per-unit-effort (CPUE) as calculated based on commercial data is assumed to be proportional to the abundance but also to the catchability coefficient (Quinn & Deriso, 1999).

Therefore changes of nominal CPUE over the years may reflect both, changes in abundance or in catchability. Changes in catchability could be affected by several factor, such as changes in fishing technology and fishing ground. If data regarding the factors that affect catchability area available, statistical models could be used to calculate “standardized” CPUE, that reflect changes in abundance only. If standardized CPUE is reliable

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enough to figure out the relative indice of abundance. It can be used straight forward to evaluate fish stock status, or as an input data in stock assessment analysis (Squires & Vestergaard, 2015).

In the GLM the response variable is assumed to follow a probability distribution of the exponential family. A normal and a gamma distribution are often the alternative for continuous variables (catch or CPUE calculated in weight), while Poisson and negative binomial are often as an alternative for discrete variables (*e.g.* catch or CPUE calculated in number of fish). Some distributions do not appropriate to model catches (or CPUEs) that equal to zero (gamma) (Vaz *et al*., 2008). However zero catches are often found in longline fisheries data sets. When the amount of zeros is very large most of the probability distributions are inadequate to model the catches. Hence zero-inflated, mixture and hurdle models (sometimes also denominated as delta models) are the alternative to cope with the excess of zeros (Hall, 2000).

In this paper both GLM and GLMM are used to calculate standardized CPUE of swordfish caught by Indonesian longline fleets in the Eastern Indian Ocean. There are three alternatives factors to consider: (i) year as fixed main effect; (ii) year as main effect and also in interactions as fixed effect; and (iii) year as fixed main effect and also in interactions but as random effect. In order to cope with the excess of zeros it was used a hurdle model. The results are useful to assess the status of the stock of swordfish, which is an important fishery resource in the Indian Ocean.

## MATERIALS AND METHODS

### Data and Exploratory Analysis

A tuna longline consists of a main line and several float lines and branch lines with hooks in the end. Tuna longlines used in Indonesia are belonging to the group of drifting longlines. Data collection was done by a scientific onboard observer program from August 2005 to November 2013 in the tuna longline vessels mostly based in Benoa Port, Bali. Duration of fishing trips is extended 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. Data collections included the number of swordfish caught, the total number of hooks and the setting location. In addition, scientific observers also recorded characteristics of the longline such as the number of hooks between floats, length of float lines, length of branch lines, and the length between branch lines. Catch per unit effort was calculated as $U = (C/f) \times 100$ (Klawe, 1980), in which $C$ is the number of fish caught in the fishing set, $f$ is the number of hooks, and $U$ is the CPUE in number of fish caught per 100 hooks.

The number of fishing sets was mapped in a regular grid (1º latitude x 1º longitude) in order to evaluate spatial distribution of fishing operations. Basic statistics summaries concerning central trend (*e.g.* mean and median) and dispersion (*e.g.* variance) were calculated for all the variables. Contingency tables and mosaic plots were used to evaluated the balance of database entries in the crossing levels of the factors (*e.g.* year x quarter). Histograms and dispersion diagrams were used to assess the relationship between variables. Correlation coefficients between continuous variables were also calculated in order to identify redundant variables.

### Models

Generalized linear models (GLM) can be written in matrix notation as:

ln (CPUE+c) = (mean) + YR + MO + A + A10 + TAR + (interaction) + (error)

where;

| | | |
|---|---|---|
| *Mean* | : | mean STD_CPUE; |
| *CPUE* | : | CPUE of swordfish (catch in number/ 100 hooks); |
| *C* | : | constant value (i.e. 10% of the average nominal CPUE); |
| *YR* | : | the effect of year; |
| *MO* | : | the effect of month; |
| *A* | : | the effect of area; |
| *A10* | : | the effect of 10ox10o area; |
| *TAR* | : | the effect of targeting (NHBF or cluster related to fishing types:1 and 3); |
| *NHBF* | : | class of number of hooks between floats (Class 1 (shallow): 4 7; Class 2 (regular): 8 10; Class 3 (deep):11 13; Class 4 (deep): 14 16; Class 5 (ultra deep): 17 19; Class 6 (ultra deep): 20>); |
| *Interactions* | : | the interaction between effects; |
| *Error* | : | the error term, *å~N(0, ó2)*. |

Explanatory variables considered in the models to standardize CPUE were the number of hooks between floats (nhbf), length of float lines (lfl), length of branch lines (lbl) and length between branch lines (lbbl), quarter and year. These variables have an effect on the depth of the line into shallow, medium and deep. Selected these variables were considered as factors affecting the catchability rate in longline fleets. The formers are continuous variables (quantitative), while the latter two were considered as factors (qualitative). There was no separation between inside and outside Indonesian Exclusive Economic Zone (EEZ) since the fishing grounds have been still in the same area of Eastern Indian Ocean.

In the hurdle models the approach to cope with zero catches is to model positive observations and the proportion of positive separated (Mullahy, 1986). In this paper the binomial distribution was used to model the proportion of positive CPUE, and the performance of three link functions, namely logit, probit and complementary log-log to found the best function, was evaluated. Positive CPUE were modeled using gamma and normal. Identity, inverse and log link functions were evaluated for both distributions. The normal distribution was also used to model the logarithm transformation of the CPUE using an identity link function.

Akaike Information Criterion (AIC) (Akaike, 1974) was used to compare and select the models calculated using different density distributions (gamma and gaussian) and link functions (*e.g.* logarithm and identity). When comparing models for different response variables (catch rate and logarithm of catch rate), the variables were laid in the proportional reduction of deviance (pseudo-$R^2$). Standard diagnostic plots were used to assess the fitting of the selected model. All the analyses were carried out using R software functions.

## RESULTS AND DISCUSSION

### Results

#### *Exploratory Analysis*

Indonesian fleets have been fishing from 2005 to 2013 between 0° to 35° S and between 75°E and 125°E, but most of the longlines were deployed in the east of Indian Ocean southwest of Indonesia (7°S to 18°S, and 106°W to 122°W). Hereafter that area is denominated the "core" fishing ground. Because the sample size is small in other areas, the calculations were based on the core dataset only.

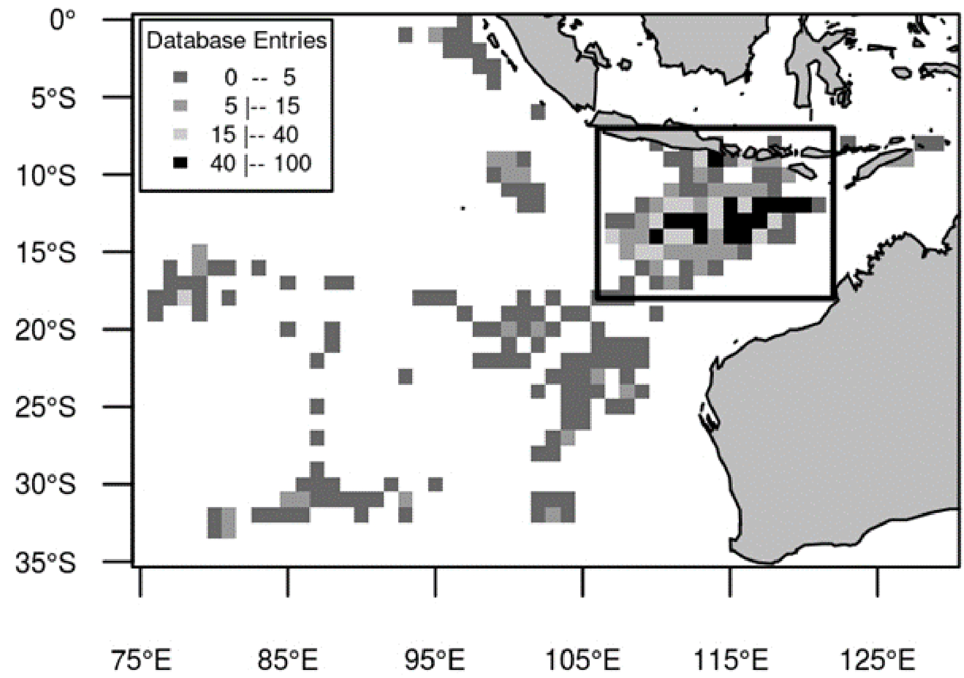


Figure 1. Distribution of the fishing sets. Rectangle indicates the main fishing ground.

The number of fishing sets in the first quarter is smaller than in the other periods of the year (Figure 2). Indonesian fleets used 4, 11, 12 13 or 17 hooks between floats in most of the fishing sets. Often the lengths of branch lines were between 22 and 27 meters. Regarding the balance of observations notice that fishing sets in first quarter were only recorded 2,007 onwards. Notice also that in beginning of the time series (2005) only large number of hooks between floats were used ($p \geq 17$), and that very short ($< 20$) or very long ($> 28$) branch lines were rare. There were not fishing sets with very large number of hooks between floats in the first quarter. Also, very short branch lines were not used in the first quarter. In summary, the balance of design matrix is not ideal. Moreover, the lack of balance between year and quarter can be a problem if interaction between these two factors is included in the models.

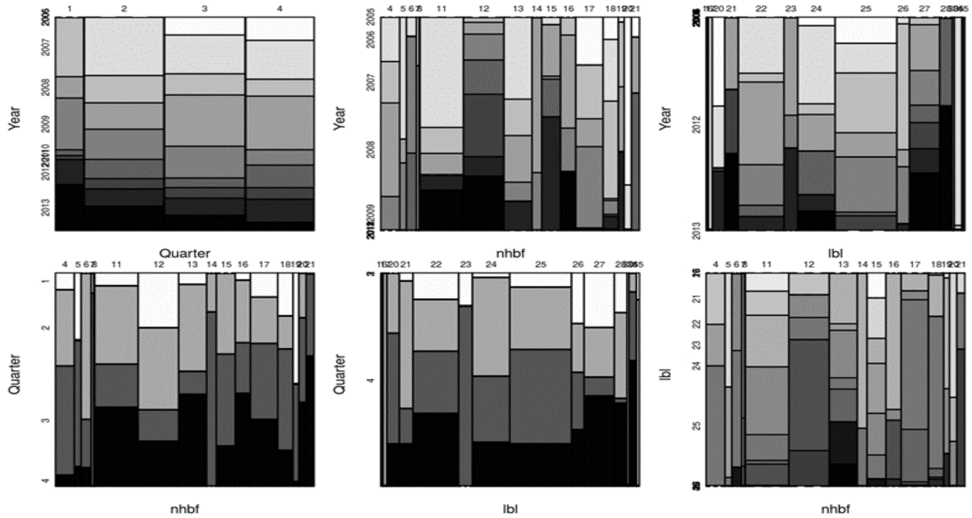


Figure 2. Balance of the number of fishing sets by year, quarter, number of hooks between floats (nhbf), and length of branch lines (lbl).

The relationships between the proportion of positive sets and potential explanatory variables are shown in Figure 3. The correlations between the proportion of positive sets and year ($0.109$; $p = 0.781$) and quarter ($0.492$; $p = 0.507$) are weak. However, linear correlations between the proportion of positive sets and the length of branch lines ($r = -0.628$; $p = 0.029$), and between the proportion of positive and the number of hooks between floats ($-0.446$; $p = 0.084$) are negative and cannot be neglected. This result indicates that the probability of success is higher for a surface longline with small number of hooks and short branch lines.

Relationships between catch rate of positive sets and potential explanatory variables are in Figure 4. Catch distributions are strongly positive skewed, hence the logarithm is shown for sake of clarity. Nominal catch rates of positive sets increased from 2005 to 2008, but there is not a clear time trend 2009 onwards. Overall catch rates were slightly higher in the second and third quarters. The relationship between positive catch rates and the length of branch lines are not clear. On the other hand, the relationship between catch rates of positive sets and the number of hooks between floats is strong and negative.

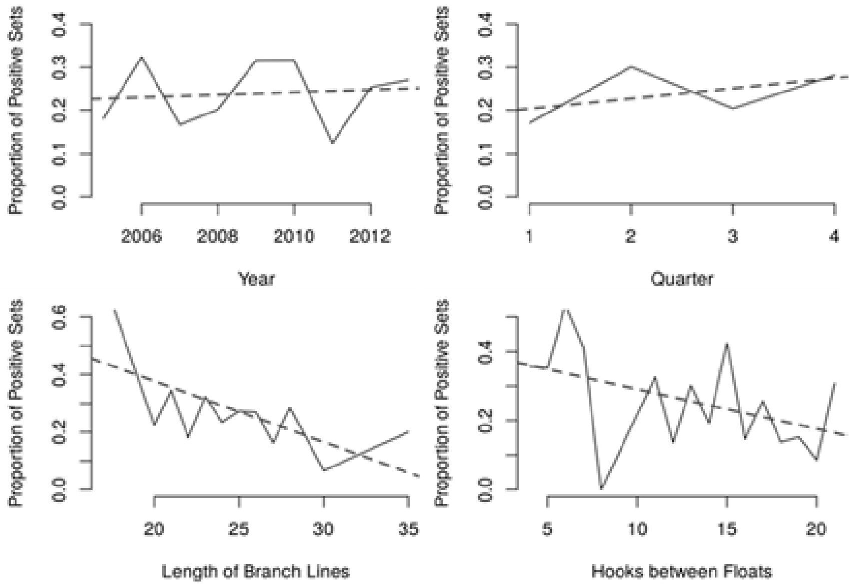


Figure 3. Relationship between the proportion of positive sets and the explanatory variables.

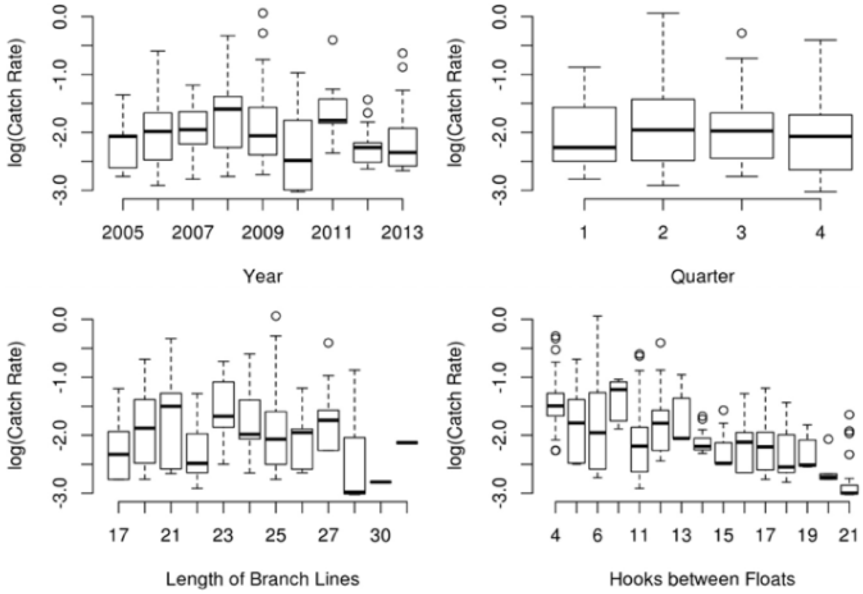


Figure 4. Relationship between logarithm of catch rate (fish/100 hooks) and the explanatory variables.

## Selected Models

Selected models for the proportional of positive sets were binomial with complementary log-log as link function. Deviances of the selected model are in Table 1. All explanatory variables included in the model were significant as indicated by the *p* values calculated in the chi-square test. The exception was the interaction between the number of hooks between floats and quarter. That interaction was not dropped because it was selected based on the AIC. Residual degree of freedom of the full model (1,604) is close to the residual deviance (1,713.881), which suggests the model is not biased. However, the performance of the model and variables selected is low. The proportional reduction of the deviance after all the variables were included in the model was low [(1,829.235 – 1,686.300)/1,829.235 = 0.078]. Therefore the variables year, quarter, number of hooks between floats and length of branch lines do not explain much of the variability concerning the proportion of positive sets.

Table 1. Deviance table of the model fitted to the proportion of positive sets. nhbf – number of hooks between floats; lbl – length of branch lines; Resid. Df – Residual degrees of freedom; Resid. Dev – Residual deviance.

| | Df | Deviance | Resid. Df | Resid. Dev | Pr(>Chi) |
|---|---|---|---|---|---|
| NULL | | | 1624 | 1829.235 | |
| Year | 8 | 40.64075 | 1616 | 1788.595 | 2.43E-06 |
| Nhbf | 1 | 25.98674 | 1615 | 1762.608 | 3.44E-07 |
| Lbl | 1 | 9.803611 | 1614 | 1752.804 | 0.001742 |
| Quarter | 3 | 25.22289 | 1611 | 1727.581 | 1.39E-05 |
| nhbf:lbl | 1 | 8.648659 | 1610 | 1718.933 | 0.003273 |
| nhbf:quarter | 3 | 5.052048 | 1607 | 1713.881 | 0.168025 |
| lbl:quarter | 3 | 27.58069 | 1604 | 1686.300 | 4.45E-06 |

Estimations of the coefficients of the model fitted to the proportion of positive sets are shown in Table 2. Most of the estimations were significantly different of zero. Because the scope of this paper is the standardization of the CPUE only the estimations of coefficients for year are explored here. The estimations of the coefficients of years 2006, 2007, 2009, 2010 are not significantly different of zero, hence the expectation of the proportion of positive sets for those years are close to the expectation for 2005, which is reference level. However, the estimations for 2008, 2011 and 2012 are negative and significant. This result suggests that the proportion of positive sets in these three years were lower than in the 2005 (reference year).

Table 2. Estimations of parameters of the model fitted to the proportion of positive sets. nbfl – number of hooks between float lines; lbl – length of branch lines.

| | Estimate | Std. Error | z value | Pr(>\|z\|) |
|---|---|---|---|---|
| (Intercept) | 13.48102 | 2.773716 | 4.860276 | 1.17E-06 |
| year2006 | -0.18961 | 0.30361 | -0.62453 | 0.53228 |
| year2007 | -0.21345 | 0.316721 | -0.67393 | 0.500354 |
| year2008 | -0.59376 | 0.28819 | -2.06029 | 0.03937 |
| year2009 | 0.199892 | 0.27239 | 0.733845 | 0.463043 |
| year2010 | -0.03103 | 0.297159 | -0.10442 | 0.916836 |
| year2011 | -1.259 | 0.396572 | -3.17471 | 0.0015 |
| year2012 | -0.75332 | 0.399443 | -1.88592 | 0.059305 |
| year2013 | 0.304192 | 0.301941 | 1.007457 | 0.313715 |
| Nhbf | -0.3329 | 0.129199 | -2.57662 | 0.009977 |
| Lbl | -0.63271 | 0.112958 | -5.60123 | 2.13E-08 |
| quarter2 | -6.3306 | 2.276554 | -2.78078 | 0.005423 |
| quarter3 | -10.8209 | 2.552249 | -4.23976 | 2.24E-05 |
| quarter4 | -8.13582 | 2.562521 | -3.17493 | 0.001499 |
| nhbf:lbl | 0.016032 | 0.005277 | 3.038231 | 0.00238 |
| nhbf:quarter2 | -0.10616 | 0.04355 | -2.43758 | 0.014786 |
| nhbf:quarter3 | -0.1419 | 0.04303 | -3.29767 | 0.000975 |
| nhbf:quarter4 | -0.14642 | 0.049993 | -2.92887 | 0.003402 |
| lbl:quarter2 | 0.320977 | 0.092308 | 3.477249 | 0.000507 |
| lbl:quarter3 | 0.512028 | 0.104922 | 4.880065 | 1.06E-06 |
| lbl:quarter4 | 0.429836 | 0.106135 | 4.049887 | 5.12E-05 |

Gamma distribution and identity link function were selected to model positive catch rates. Calculations of deviance of the model fitted to positive data are shown in Table 3. Almost all explanatory variables resulted in significant reduction of the deviance. The exception is the main effect of quarter. However it was kept in the model because it is in interactions that proved to be important if it is dependent on AIC. Overall proportional reduction of deviance was low ($0.367$), which means that only a part of the variability of positive catch rate is explained by the variables year, quarter, length of branch lines and number of hooks between floats. The later is the more important explanatory variable.

Table 3. Deviance table of the model fitted to the positive catch rates. nhbf – number of hooks between floats; lbl – length of branch lines; Resid. Df – Residual degrees of freedom; Resid. Dev – Residual deviance.

| | Df | Deviance | Resid. Df | Resid. Dev | F | Pr(>F) |
|---|---|---|---|---|---|---|
| NULL | | | 406 | 153.411 | | |
| Year | 8 | 18.40879 | 398 | 135.0022 | 7.324624 | 4.45E-09 |
| Nhbf | 1 | 28.90563 | 397 | 106.0966 | 92.00945 | 1.09E-19 |
| Lbl | 1 | 1.18715 | 396 | 104.9095 | 3.778841 | 0.052629 |
| Quarter | 3 | 1.440867 | 393 | 103.4686 | 1.528807 | 0.206536 |
| nhbf:quarter | 3 | 3.777385 | 390 | 99.69121 | 4.007928 | 0.007893 |
| lbl:quarter | 3 | 2.588964 | 387 | 97.10224 | 2.746975 | 0.042724 |

Coefficients of the model fitted to positive catch rates are in Table 4. Significant differences between year effect estimation and zero were found only for 2011 and 2012. Both coefficients were negative, which suggests that the expectations of positive catch rates in the very end of the time series are lower than the expectations in the beginning of the time series.

Table 4. Estimations of parameters of the model fitted to the proportion of positive sets. nbfl – number of hooks between float lines; lbl – length of branch lines.

| | Estimate | Std. Error | t value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -0.19216 | 0.2068 | -0.92918 | 0.353373 |
| yearf2006 | -0.0292 | 0.022659 | -1.28875 | 0.198256 |
| yearf2007 | 0.00174 | 0.024182 | 0.071937 | 0.942689 |
| yearf2008 | -0.00234 | 0.021194 | -0.11054 | 0.912037 |
| yearf2009 | -0.0176 | 0.021348 | -0.82426 | 0.410301 |
| yearf2010 | -0.03353 | 0.021164 | -1.58417 | 0.113972 |
| yearf2011 | 0.011083 | 0.041879 | 0.264644 | 0.791424 |
| yearf2012 | -0.0953 | 0.034999 | -2.72302 | 0.006762 |
| yearf2013 | -0.07817 | 0.020891 | -3.74179 | 0.00021 |
| Nhbf | 0.004234 | 0.003266 | 1.29617 | 0.195689 |
| Lbl | 0.014255 | 0.008239 | 1.730263 | 0.084381 |
| quarter2 | 0.347953 | 0.210019 | 1.656771 | 0.098376 |
| quarter3 | 0.642935 | 0.242051 | 2.656197 | 0.00823 |
| quarter4 | 0.478308 | 0.225471 | 2.121372 | 0.034526 |
| nhbf:quarter2 | -0.01447 | 0.003719 | -3.88972 | 0.000118 |
| nhbf:quarter3 | -0.01307 | 0.003652 | -3.57979 | 0.000388 |
| nhbf:quarter4 | -0.0185 | 0.0045 | -4.11146 | 4.80E-05 |
| lbl:quarter2 | -0.00773 | 0.008474 | -0.91242 | 0.362117 |
| lbl:quarter3 | -0.02166 | 0.009834 | -2.20223 | 0.028239 |
| lbl:quarter4 | -0.01055 | 0.009515 | -1.1086 | 0.268293 |

**Standardized Catch Rates**

Nominal and standardized CPUE with 95% confidence intervals are in Figure 5. Overall catch rates were below 0.06 fish/100 hooks, which indicate that the catch rate of swordfish is low for Indonesian boats. Nominal catch rates showed an instable pattern in the beginning of the time series. However, nominal values increased from 2007 to 2009, then dropped until 2011, and showed a slight increasing trend until 2013. Standardized catch rates oscillated from 2005 to 2009, then it dropped quickly until 2012, but it increased in 2013. Confidence intervals were wide in the beginning of the time series, but they shrank after 2010.

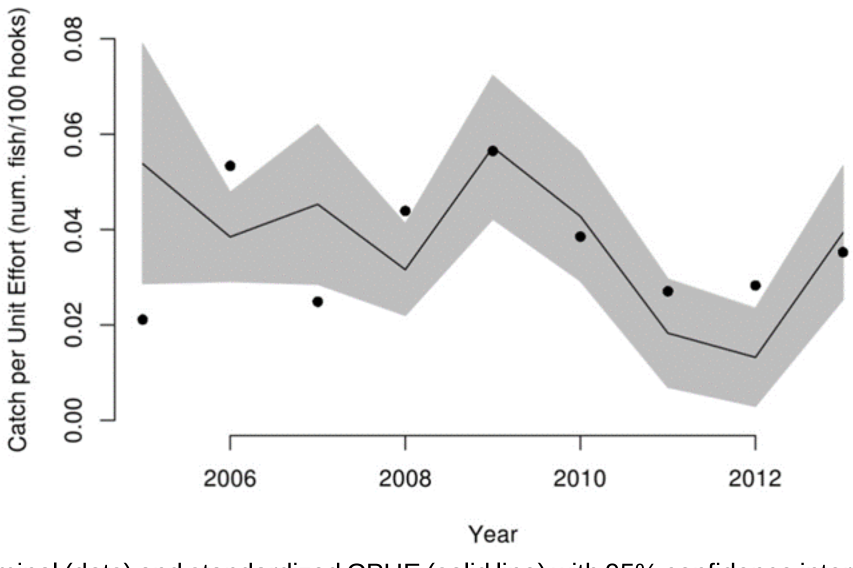


Figure 5. Nominal (dots) and standardized CPUE (solid line) with 95% confidence interval shaded gray.

**Discussion**

Swordfish is known to inhabit the surface layer of the ocean, especially at night (*e.g.* Carey & Robison, 1981; Sepulveda *et al.*, 2010). Hence the negative relationship found between the proportion of positive sets and the length of branch lines, the proportion of positive sets and the numbers of hooks between floats, and also between the CPUE in positive sets and the number of hooks between floats, were all an ordinary results.

Despite the Indonesian boats eventually endeavor fishing trips to far distances in the Indian Ocean, the majority of fishing sets were concentrated in the southeast of Indian Ocean, southwest of Indonesia and northwest of Australia. Therefore the dataset analyzed cover a fraction of the Indian Ocean stock. Hence, the standardized catches might be interpreted as a local proxy. However, the analyses of the calculations presented in this paper and the all the previous calculations based on other databases concerning fleets operating in another location of the Indian Ocean can help to better understand the status of the swordfish stock.

Four documents were presented in the 12th Working Party on Billfish regarding standardized catch rates of swordfish. Calculations based on Portuguese (Santos *et al.*, 2014), Spanish (Fernandéz-Costa *et al.*, 2014), Japanese and Taiwanese (Nishida & Wang, 2014; Wang & Nishida, 2014) datasets cover a long period, while calculations showed here for Indonesia dataset cover a short period. The five fleets have different characteristics. While the Portuguese and Spanish fleets aim at swordfish at the surface layer in the southwestern Indian Oceans, swordfish is a bycatch to the other three fleets that often operate with deep longline and large number of hooks between floats. However, the Japanese and the Taiwanese fleet's fishes in wide area all over the tropical Indian Ocean, operations of Indonesia fleet are concentrated in the southeast of the Indian Ocean. Despite the operational differences of the fleets, all the standardized CPUE calculations showed similar oscillatory pattern (2005-2012). The catch of swordfish from Japanese and Taiwanese fleet tend to decrease while from Indonesian fleet tend to increase.

Moreover, if those standardized calculations are counted on as relative abundance indices, the conclusion is that the biomass of Indian Ocean stock of swordfish did not change much in the last decade. As matter of fact, current status of swordfish stocks in the Indian Ocean is good, in the sense there is no evidence of overfishing (IOTC, 2014). The fisheries manager and authorities in regional countries need to maintain the production of swordfish in sustainable level. However, the increasing demands for fish products in the world in recent years resulting in a growing number of fishing fleet could threaten the sustainability of sword fish resources. Moreover, swordfish is one of the targets of an increasing recreational fishery. Therefore, management is necessary (FAO, 2012).

Finally, it is important to highlight that the results gathered after fitting the generalized linear models indicate that more information are necessary to improve our knowledge concerning swordfish catch rates variations of the Indonesian longline fishery. The models did not converge whenever we tried out to fit them using more parameters concerning interaction between year and the other variables. The lack of convergence often arises when the model is over parameterized, when the data does not convey enough information allowing the estimation of all the parameters (McCullagh & Nelder, 1989).

## CONCLUSION

The low proportional decrease of deviance indicates that most of the variability of catch rates of swordfish caught by Indonesian longline boats are not related to year, quarter, number of hooks between floats and the length of branch lines. The catch rates and distribution of swordfish in the Indian Ocean were sensitive to climatic and environmental variation, therefore proper management strategies need to implement to maintain their sustainability. Other variables and information, like the daytime when the longlines are deployed in the water (day or night), type of bait, size and type of hooks, and if the fishermen use light-sticks to attract the fish, are necessary to better understand the catch rate, and improve the estimations of the relative abundance indices. Therefore, the Indonesian onboard observers are encouraged to collect more detailed data, which are of major importance to assess the status of the fishery in the southeast area, and of the Indian Ocean swordfish stock.

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