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Standardized catch rates of blue sharks caught by the Taiwanese longline fishery in the Indian Ocean

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SUMMARY

The blue shark catch and effort data from observers' records of Taiwanese large longline fishing vessels operating in the Indian Ocean from 2004-2012 were analyzed. Based on the fishing grounds of the target species, three areas, namely, A (north of 10ºN), B (10ºN-10ºS), and C (south of 10ºS), were categorized. To cope with the large percentage of zero shark catch, the catch per unit effort (CPUE) of blue shark, as the number of fish caught per 1,000 hooks, was standardized using a two-step delta-lognormal model that treats the proportion of positive sets and the CPUE of positive catches separately. Standardized indices with 95% bootstrapping confidence intervals are reported. The standardized CPUE showed a stable trend for blue sharks from 2004 to 2008 and increased steadily thereafter with a peak in 2012. The results obtained in this study can be improved if longer time series observers' data are available.

KEYWORDS

Blue sharks, Taiwanese longline fishery, standardized CPUE, by-catch, observer programs, delta-lognormal model

1. Introduction

The Taiwanese longline fishery has operated in the Indian Ocean since the late 1970s. However, the shark by-catch of Taiwanese tuna longline fleets was never reported until 1981 because of its low economic value compared with tunas. During the period from 1981 to 2002, only one category "sharks" was recorded in the logbook. The category "sharks" on the logbook has been further separated into four sub-categories namely the blue shark, *Prionace glauca*, mako shark, *Isurus spp*., silky shark, *Carcharihnus falciformis*, and others since 2003. As the Taiwanese longline fishery has widely covered the Indian Ocean, our fishery statistics must be one of the most valuable information that can be used to describe the population status of pelagic sharks.

Blue shark is the major shark by-catch species of Taiwanese large longline fishery. Since FAO and international environmental groups has concerned on the conservation of elasmobranchs in recent years, it is necessary to examine the recent trend of sharks by examining the logbook of tuna fisheries. However, standardization of Taiwanese catch rate on sharks is not straightforward because the logbook data have been confounded with many factors, such as under-reporting, no-recording of sharks and target-shifting effects. Consequently, the observer program for the large longline fishery was conducted to obtain detailed and reliable data for more comprehensive stock assessment and management studies. Recently, the increase of coverage rate of observations enabled us to get a better estimation of shark by-catch. Therefore, it is useful to examine recent trends in relative abundance of the blue sharks using the most recent observer data in the Indian Ocean.

A large proportion of zero values is commonly found in by-catch data obtained from fisheries studies involving counts of abundance or CPUE standardization. The delta-lognormal modeling, which can account for a large proportion of zero values, is an appropriate approach to model zero-heavy data (Lo *et al*., 1992). As sharks are common by-catch species in the tuna longline fishery, the delta lognormal model (DLN) is commonly used in CPUE standardization to address these excessive zero catch of sharks. In this study, the CPUEs of blue sharks in the Indian Ocean were standardized using delta-lognormal model based on observers' records data and hopefully these CPUE series can be used in the blue shark stock assessment in 2015.

2. Material and methods

2.1. Source of data

The species-specific catch data including tunas, billfishes, and sharks from observers' records in 2004-2012 were used to standardize CPUE of blue shark of Taiwanese longline fishery in the Indian Ocean. The summary of these data were shown in **Table 1**. The discard rate might be affected by spatial and temporal factors. We used the following stratification to test for homogeneity. For temporal factors, we separated the data into 4 periods: the 1st season (January to March), 2nd season (April to June), 3rd season (July to September), and 4th season (October to December). For spatial stratification, based on the fishing grounds of the target species (Huang and Liu, 2010)(Fig. 1), we stratified the area into 3 areas as shown in Fig. 2, among which A (north of 10ºN) is the major fishing ground for the yellowfin tuna fleet: B (between10ºN and 10ºS) is the major ground for the bigeye tuna fleet; and C (south of 10ºS) is the major grounds for albacore and southern bluefin tuna fleets. In the area C, most vessels target on albacore from October to March and switch to southern bluefin tuna in May. For standardization, CPUE was calculated by set of operations based on observers' records during the period of 2004-2012.

2.2. CPUE standardization

A large proportion of sets with zero catch of blue sharks (about 60%) in the Indian Ocean was found in observers' records. Hence, to address these excessive zero catches, the delta-lognormal model (DLN) (Lo *et al*., 1992) was applied to the standardization of blue shark CPUE. The DLN is a mixture of two models, one model is used to estimate the proportion of positive catches (GLM) and a separate model is to estimate the positive catch rate (Delta model, PA). The model was fit using glm function of statistical computing language R (R Development Core and Team, 2013) to eliminate some biases by change of targeting species, fishing ground and fishing seasons.

Standardized CPUE series for the blue shark was constructed including main effects and interaction terms. The main effects chosen as input into the DLN analyses were year (Y), quarter (Q), area (A), and number of hooks per basket (HPB). The following multiplicative model was applied to the data in this study:

For the GLM modeling, the catch rates of the positive catch events (sets with positive blue shark catch) were modeled assuming a lognormal error distribution:

$$\ln(CPUE) = \mu + Y + Q + A + HPB + Q*A + Q*HPB + A*HPB + \varepsilon_1 \quad (1)$$

where μ is the mean, Q*A, Q*HPB, A*HPB are interaction terms, ε_1 is a normal random error term. To calculate the proportion of positive records we used a model assuming a binomial error distribution (ε_2):

$$PA = \mu + Y + Q + A + HPB + Q*A + Q*HPB + A*HPB + \varepsilon 2 \quad (2)$$

The effect of gear configuration of HPB was categorized into two classes: shallow set (HPB $\leqq$ 15), and deep set (HPB > 15), and quarter was categorized into 4 classes: the 1st quarter (Jan-Mar), the 2nd quarter (Apr-Jun), the 3rd quarter (Jul-Sep), and the 4th quarter (Oct-Dec). The area strata used for the analysis were shown in Figure 2. The best model for both GLM and PA models were selected using the stepwise AIC method (Venables and Ripley, 2002). For model diagnostics, Cook's distance (Cook and

Weisberg, 1982) was used to assess the influence of observations that exert on the model. The final estimate of annual abundance index was obtained by the product of the marginal year means (Lo et al., 1992).

$$\text{Standardized CPUE} = \text{GLM} * \text{PA} \quad (3)$$

Empirical confidence interval of standardized CPUE was estimated by using bootstrap resampling method. The number of bootstrap sub-samples were generated based on the sample size of CPUE in each year. The 95% confidence intervals were then constructed based on bias corrected percentile method with 1,000 replicates (Efron and Tibshirani, 1993).

3. Results and discussion

The blue shark bycatch data are characterized by many zero values and a long right tail (**Figs. 3 and 4**). Overall, 56.48% of the total sets in the Indian Ocean had zero bycatch of blue sharks (**Table 2**). As a result, the following models with many explanatory variables were finally selected. The best models for GLM and Delta models chosen by AIC values in the Indian Ocean were "ln(CPUE) =μ+Y+Q+A+HPB+Q*A+Q*HPB" and "PA=μ+Y+Q+A+HPB+Q*A+Q*HPB+A*HPB", respectively. The best models were then used in the later analyses.

Standardized CPUE series of the blue shark in the Indian Ocean using the DLN model were shown in **Figure 5**. Standardized CPUE trend contains the combined effects from two models, one that calculates the probability of a zero observation and another one that estimates the count per year. The nominal CPUE of blue shark in the Indian Ocean showed a strong inter-annual fluctuation, particularly in year 2012. This high CPUE might be because that the high blue shark catch rate occurred in area C (**Fig. 3**) where most observers were assigned to that area in recent two years. The obvious lower zero percentage of blue shark catch (**Table 2)** can be found in this year. However, this high variability was slightly smoothed in the standardized CPUE series. In general, the standardized CPUE series of the blue sharks caught by Taiwanese large-scale longline fishery showed a stable increasing trend (**Fig. 5**). These stable trends suggested that the blue shark stock in the Indian Ocean seems at the level of optimum utilization during the period of 2004-2012.

The diagnostic results from the DLN model do not indicate severe departure from model assumptions (**Figs. 6-7**). The additional residual plots and ANOVA tables for each models are given in **Appendix Figs. 1-2 and Table 1**. Most main effects and interaction terms tested were significant (mostly $P < 0.01$) and have been included in the final model. However, other factors may affect the standardization of CPUE trend. In addition to the temporal and spatial effects, environmental factors are important which may affect the representation of standardized CPUE of pelagic fish i.e., swordfish and blue shark in the North Pacific Ocean (Bigelow *et al.,* 1999), and big-eye tuna in the Indian Ocean (Okamoto *et al.,* 2001). In this report, environmental effects were not included in the model for standardization. The results obtained in this study can be improved if longer time series of observers' data are available and environmental factors were included in the model.

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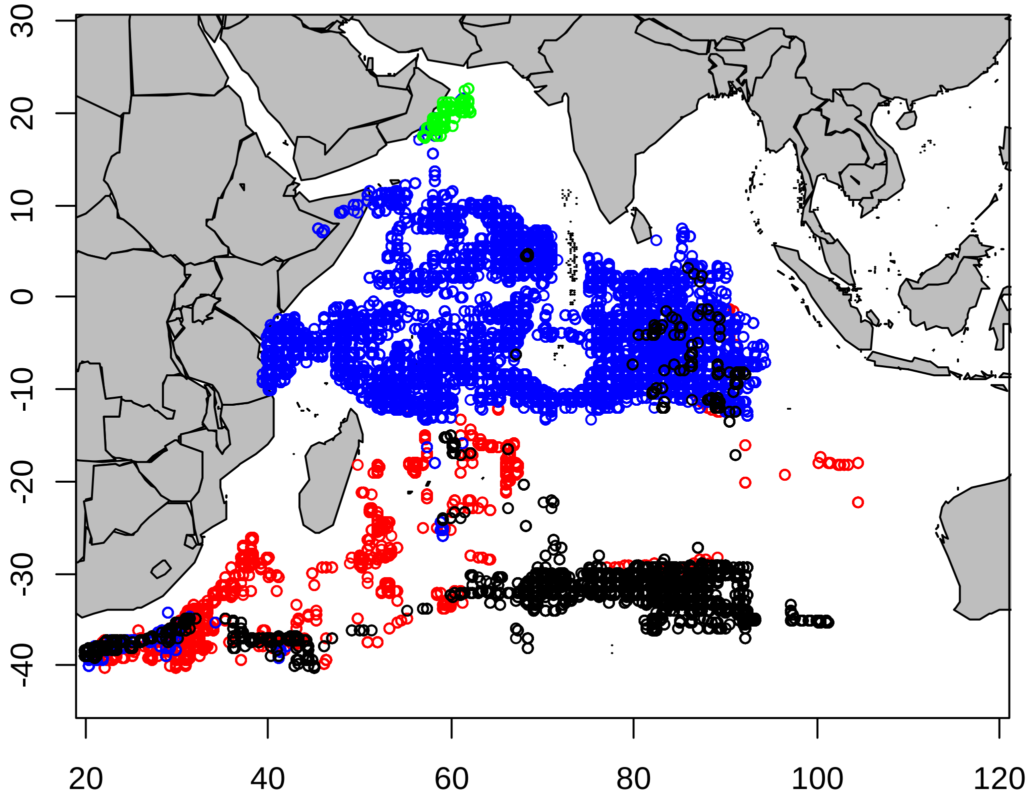


Figure 1. Observed effort distributions in the Indian Ocean from 2004 to 2012. Green circles, yellowfin tuna fleet; blue circles, bigeye fleet; red circles, albacore fleet; black circles, bluefin tuna fleet.

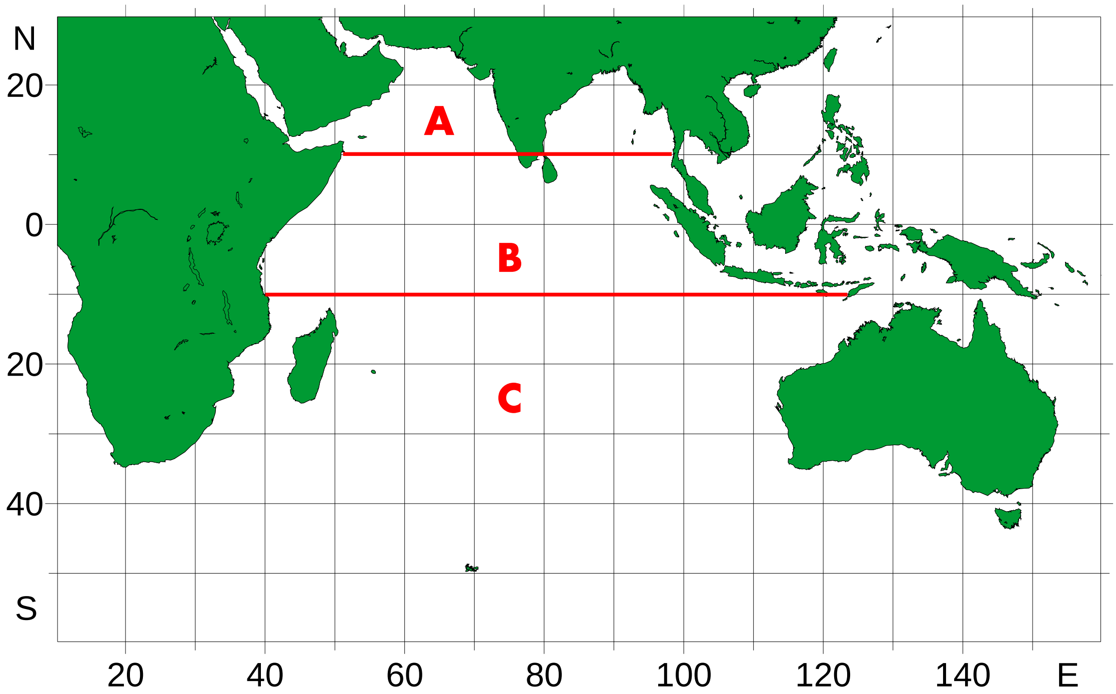


Figure 2. Area stratification based on targging species in this study.

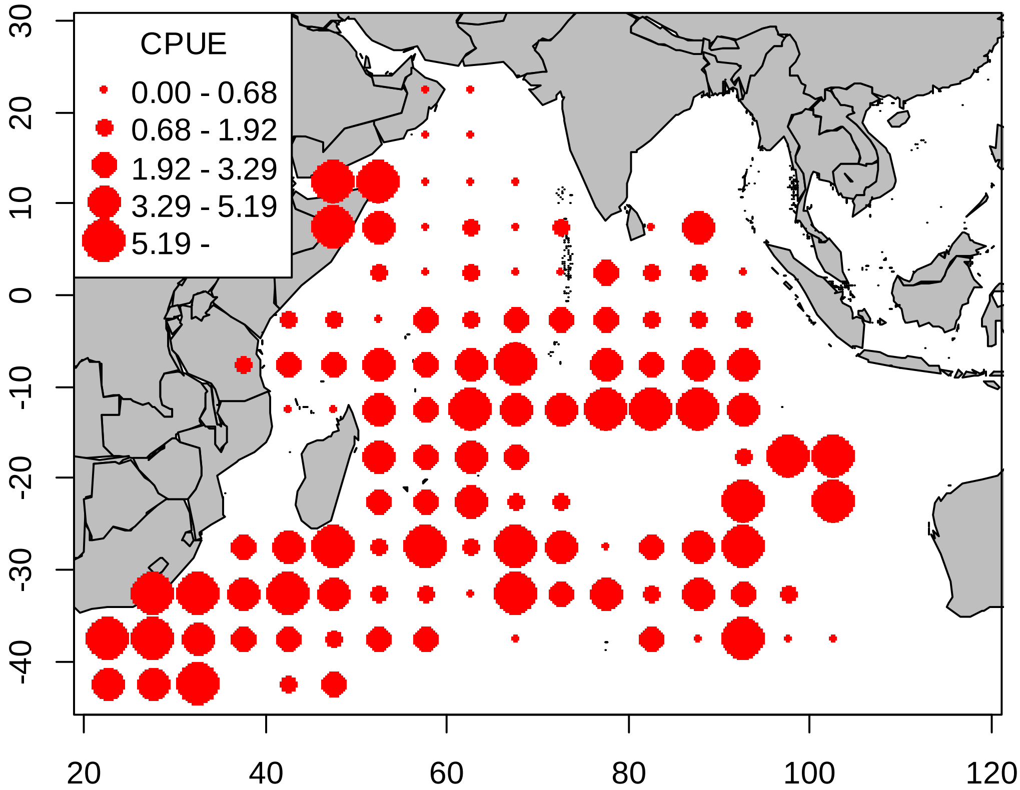


Figure 3. Observed distribution of blue shark CPUE of Taiwanese tuna longline vessels in the Indian Ocean from 2004 to 2012.

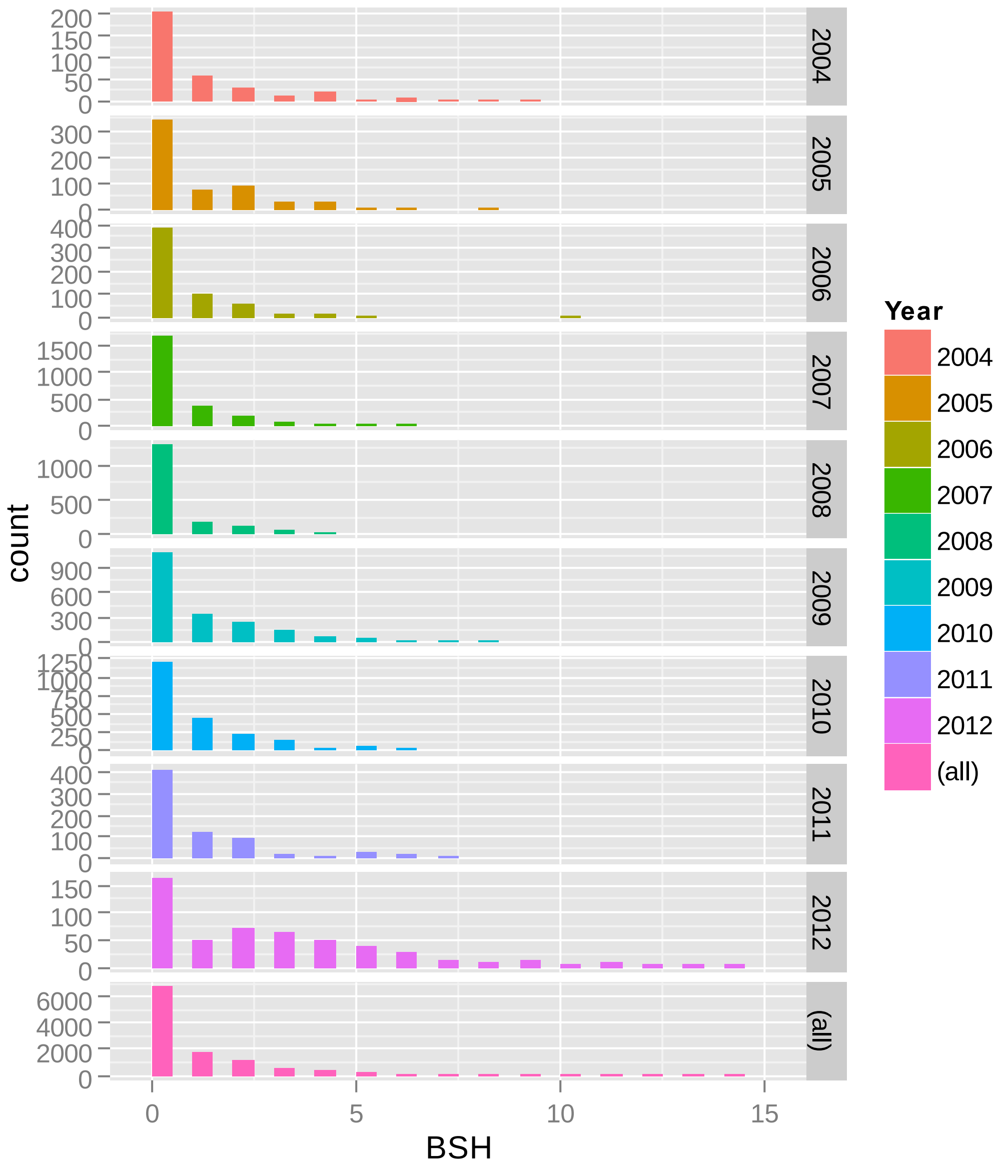


Figure 4. Annual frequency distribution of blue shark bycatch per set in the Indian Ocean, 2004–2012.

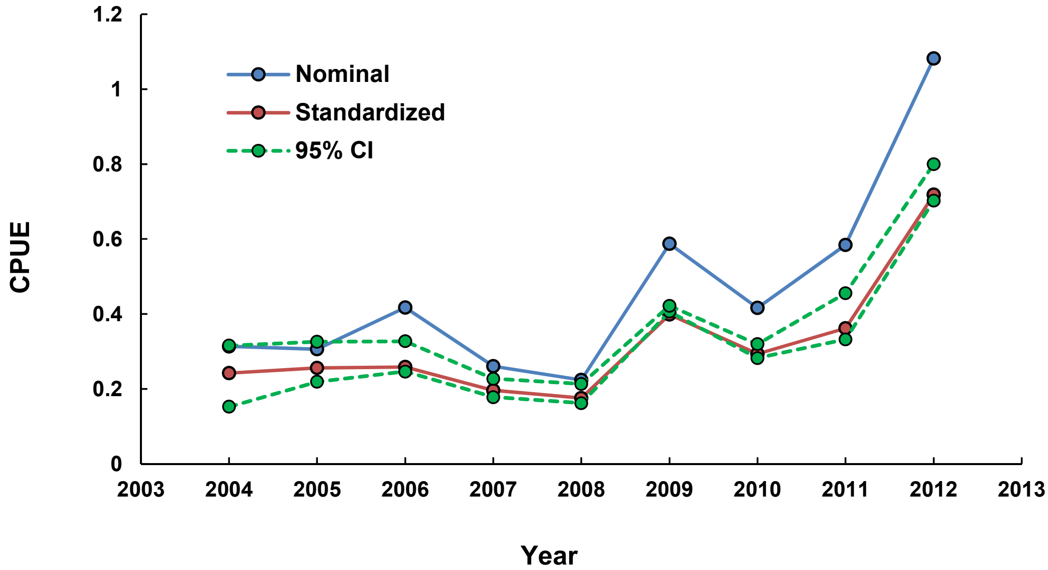


Figure 5. Observed nominal and standardized CPUE with 95% CI of blue shark by Taiwanese longline vessels in the Indian Ocean from 2004 to 2012.

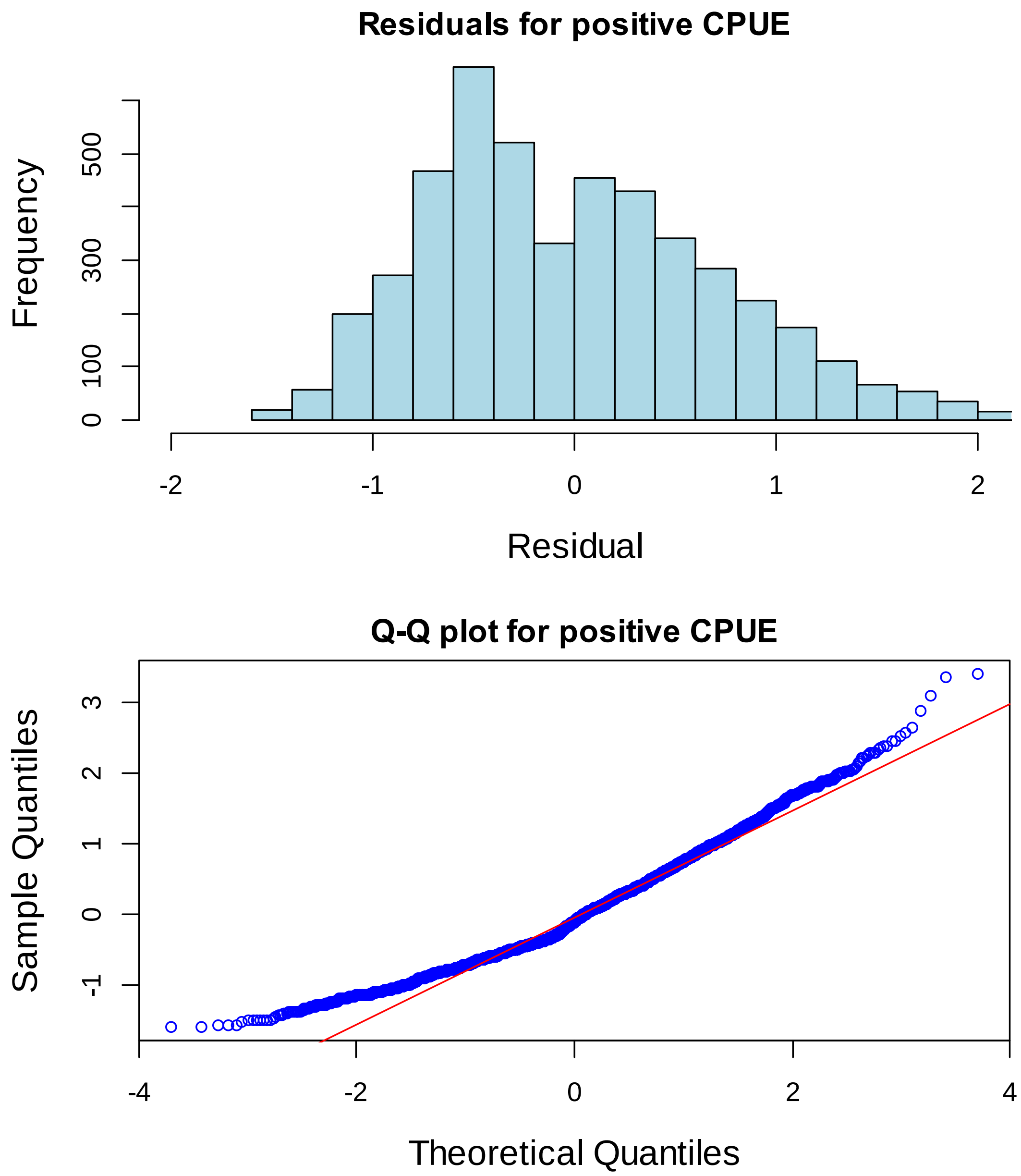


Figure 6. Diagnostic results from the GLM model fit to the Indian Ocean longline blue shark bycatch data.

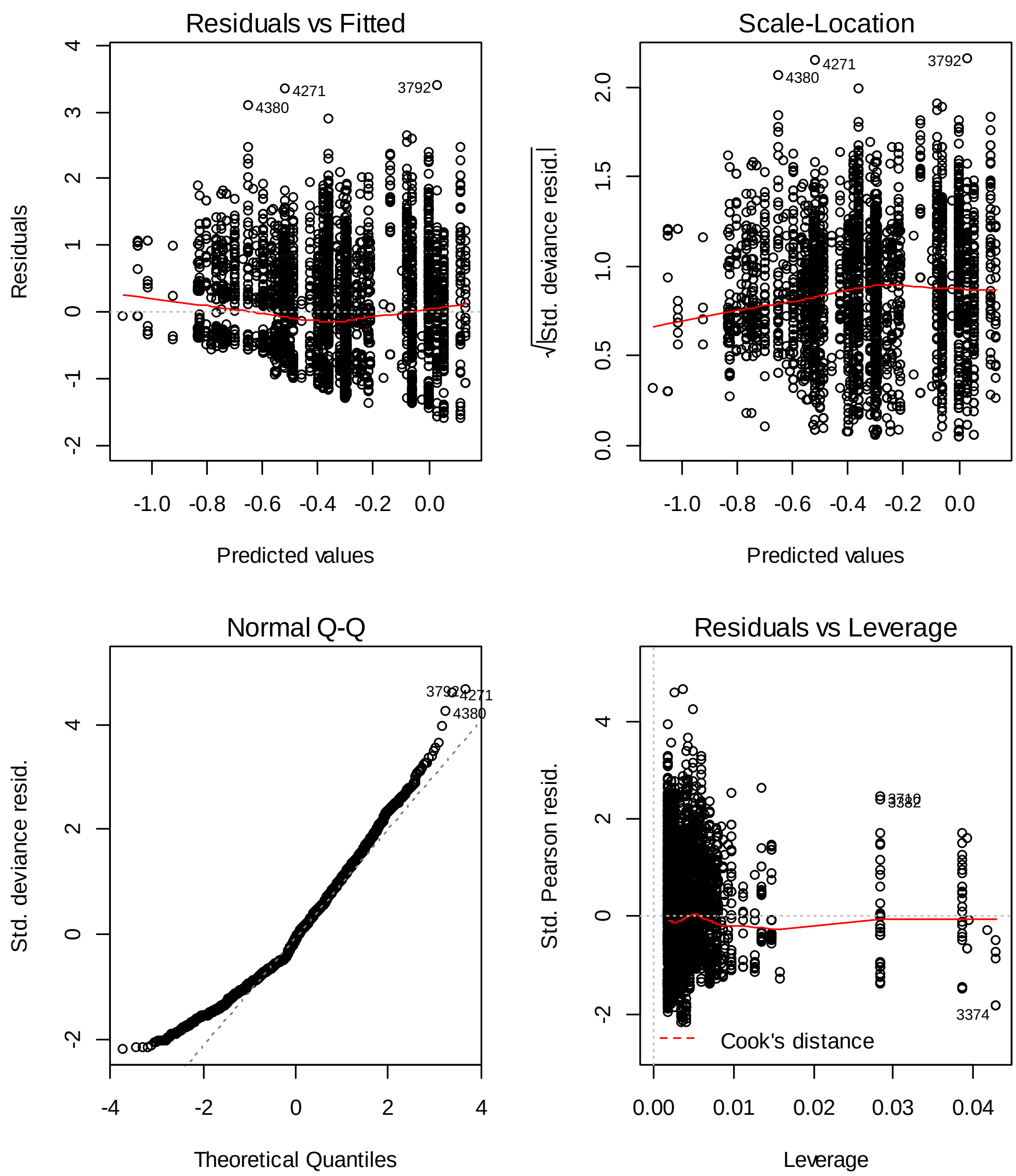


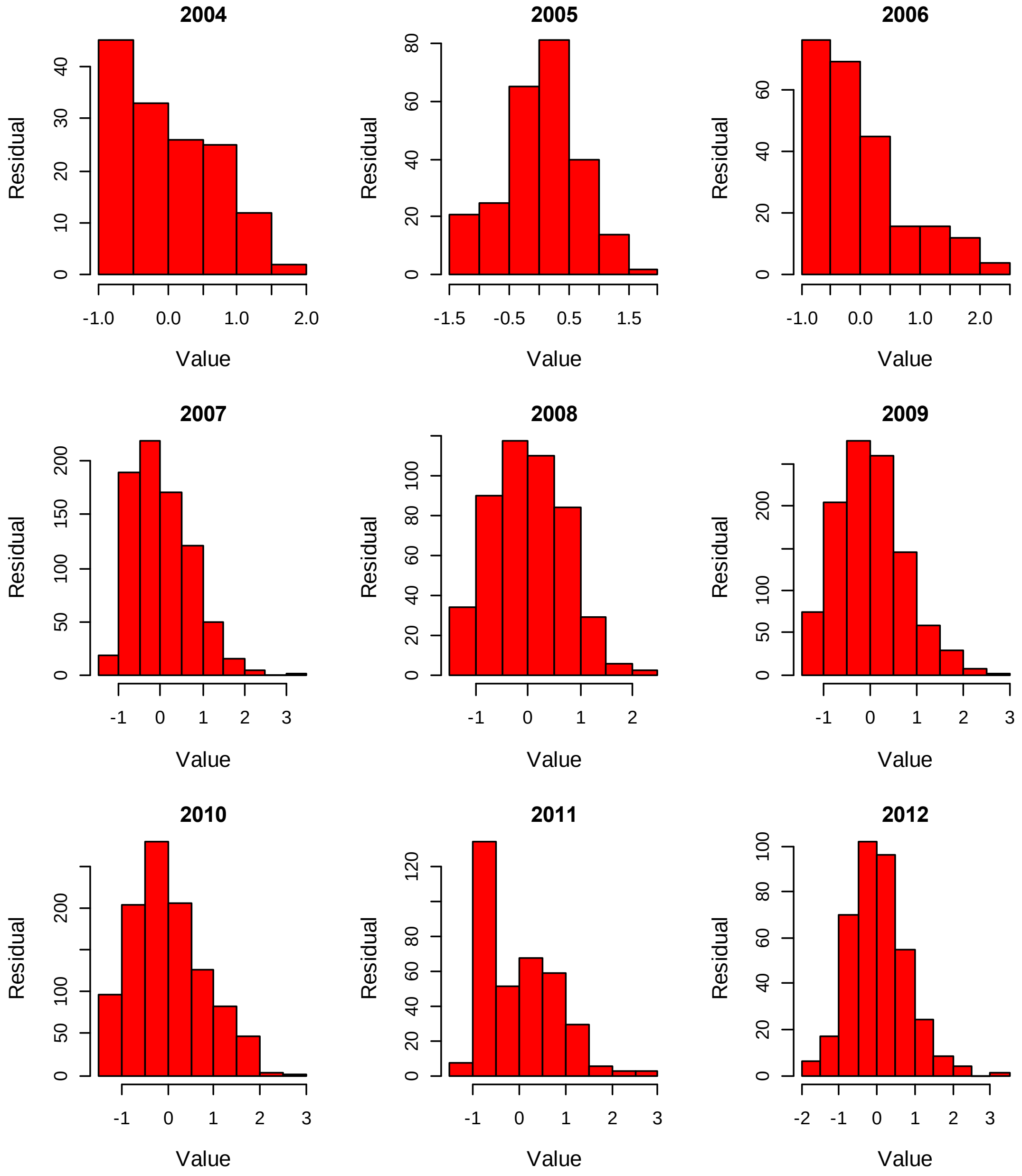
Figure 7. Residual plots for the GLM model fit to the Indian Ocean longline blue shark bycatch data.

Table 1. Summary of the observers' data used in this study.

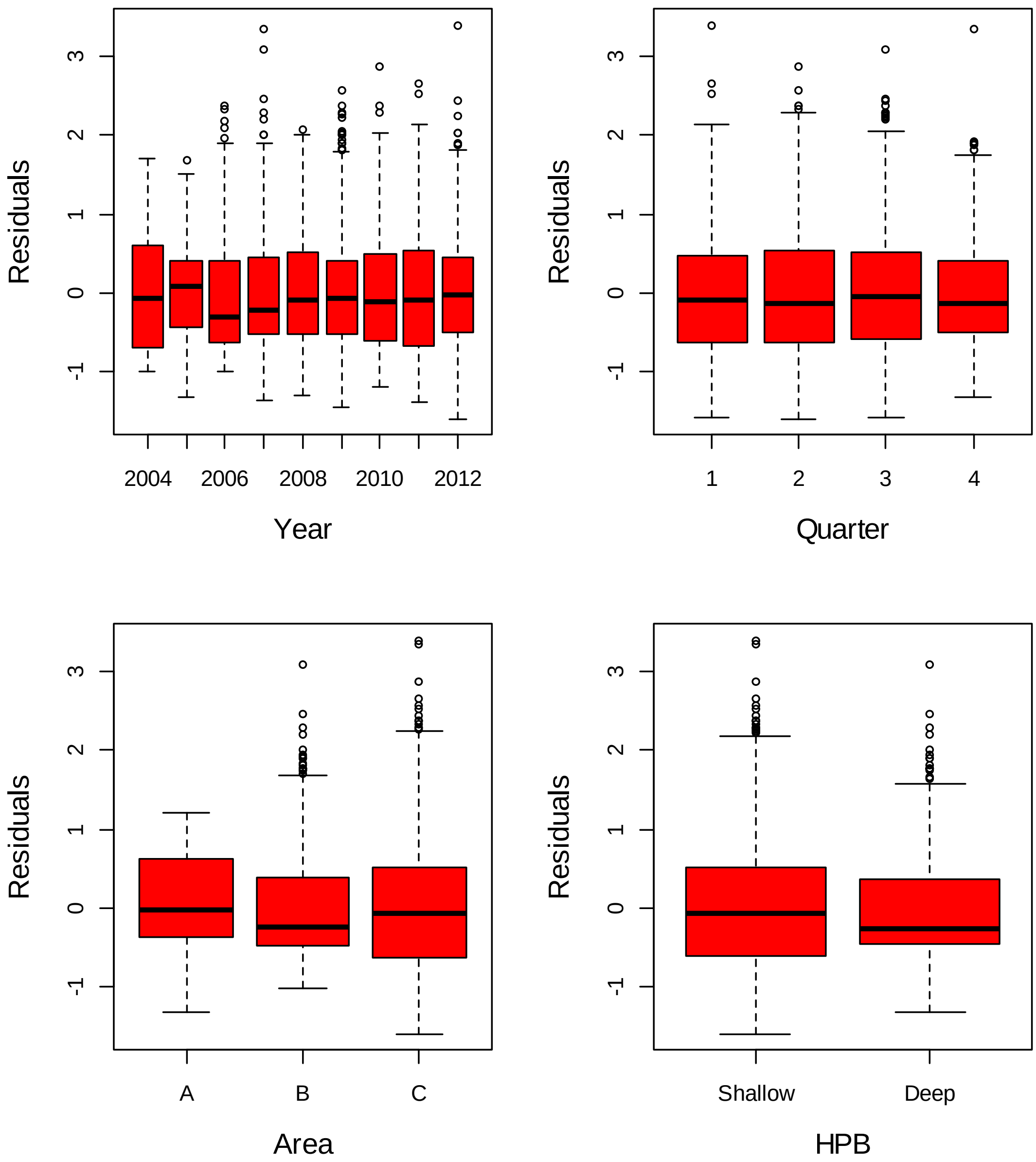
Year	Indian Ocean	
	No. of Hooks	No. of Sets
2004	1219020	349
2005	1983922	592
2006	2074671	624
2007	7822455	2476
2008	5404314	1781
2009	6399424	2137
2010	7683134	2271
2011	2424932	766
2012	1938611	547
Average	4105609	1283

Table 2. The observed percentage of zero-catch of blue shark for Taiwanese tuna longline vessels in the Indian Ocean from 2004 to 2012.

Year	Zero-catch
2004	59.03%
2005	58.11%
2006	61.86%
2007	68.09%
2008	73.50%
2009	50.44%
2010	53.81%
2011	53.52%
2012	29.98%
Average	56.48%



Appendix Fig. 1. Annual residual plots from the GLM model.



Appendix Fig. 2. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and HPB for GLM model.

Appendix Table 1. Deviance tables for the GLM model.

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Analysis of Deviance Table

Model: gaussian, link: identity

Response: log(DATA$CPUE)

Terms added sequentially (first to last)


      Df Deviance Resid. Df Resid. Dev       F    Pr(>F)    
NULL                   4737     2806.8                      
yy     8  115.184      4729     2691.6 26.9952 < 2.2e-16 ***
Q      3   52.698      4726     2638.9 32.9349 < 2.2e-16 ***
A      2   68.424      4724     2570.5 64.1450 < 2.2e-16 ***
HPB    1   32.313      4723     2538.2 60.5841 8.604e-15 ***
Q:A    3   13.402      4720     2524.8  8.3761 1.497e-05 ***
Q:HPB  3    8.933      4717     2515.8  5.5827 0.0008068 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
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