**ISC/17/SHARKWG-3/09**

# Standardized CPUE and historical catch estimate of shortfin mako shark by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean

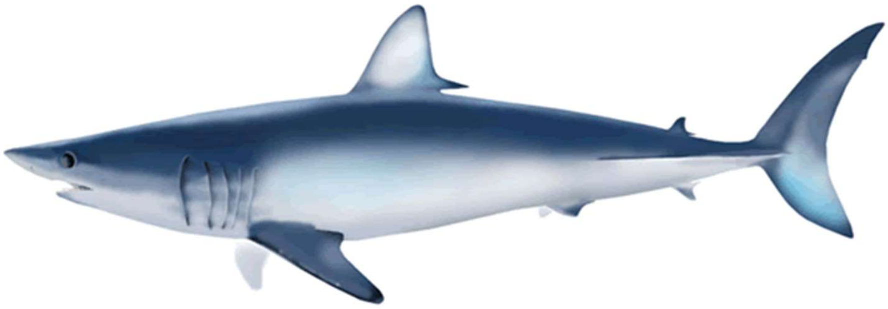
Wen-Pei Tsai [A] , Yen-Jun Wang [A] , Shan-Hui Su [B] , and Kwang-Ming Liu [B, C, D]

[A] Department of Fisheries Production and Management, National Kaohsiung Marine University, Kaohsiung 808, Taiwan

[B] Institute of Marine Affairs and Resource Management, National Taiwan Ocean University, Keelung 20224, Taiwan

[C] George Chen Shark Research Center, National Taiwan Ocean University, Keelung 20224, Taiwan

[D] Corresponding author. Email: kmliu@mail.ntou.edu.tw



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**ABSTRACT**

In the present study, the shortfin mako shark catch and effort data from the logbook records of the Taiwanese large-scale tuna longline fishing vessels operating in the North Pacific Ocean from 1971-2016 were analyzed. Due to the large percentage of zero shortfin mako shark catch, the catch per unit effort (CPUE) of shortfin mako shark, as the number of fish caught per 1,000 hooks, was standardized using a zero inflated negative binomial model. Both nominal and standardized CPUE of shortfin mako sharks showed stable but slightly decreasing trends. The back-estimated catch (1971-2004) was relative low before 1995 and increased to more than 100 MT and fluctuated thereafter. In all, the estimated shortfin mako shark by-catch in weight of Taiwanese LTLL fishery ranged from almost 0 metric tons (MT) in 1971 to 156 MT in 2015, with a mean of 41 MT and 789 individuals in the North Pacific Ocean. Many 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. Although shortfin mako sharks are homeotherm, the behavior of sharks with these characteristic is also triggered by the environmental temperature. Environmental effects should be included in the future standardization models.

# 1. Introduction

Shortfin mako shark, *Isurus oxyrinchus*, is one of the most commonly shark species caught by the Taiwanese commercial offshore longline fishery and is the major by-catch of tuna longline fisheries in the far seas. Shortfin mako is a large apex predator that exhibits slow growth, low fecundity and late maturity, and is particularly susceptible to exploitation owing to its life-history characteristics (Campana *et al*., 2005). Clarke *et al*. (2006) mentioned that about half a million shortfin mako sharks were utilized in the global shark fin trade in 2000. Given the high fishing pressure on this species and declining population trends, the shortfin mako is currently listed as "Vulnerable" on the IUCN Red List of Threatened Species (Dulvy *et al*., 2008), but very little is known about the stock status of this species in the North Pacific Ocean despite of several studies using per recruit analyses and demographic approaches in the Northwest Pacific Ocean (Chang and Liu 2009, Tsai *et al.* 2011, Tsai *et al.* 2014, Tsai *et al.*, 2015). Since the International organizations and regional fisheries management organizations (RFMO's) have concerned on the conservation of elasmobranchs in recent years, it is necessary to examine the recent trend of shark species by examining the logbook of tuna fisheries. Shortfin mako and blue shark (*Prionace glauca*) are the major shark species for the Taiwanese large-scale tuna longline (LTLL) fisheries. Reliable catch estimate for shortfin mako shark can be developed because the logbook records of shortfin mako sharks were representative of actual catches as all sharks were retained due to its high market value. Thus, the objectives of this study are to standardize the CPUE and to estimate the historical catches of shortfin mako sharks in the North Pacific based on the logbook data.

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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 Zero-inflated modeling, which can account for a large proportion of zero values, is an appropriate approach to model zero-heavy data (Lambert 1992; Hall 2000). As sharks are common by-catch species in the tuna longline fishery, the zero inflated negative binomial (ZINB) model was therefore applied to address these excessive zeros of shark catch for CPUE standardization in this study. The CPUEs of shortfin mako sharks in the North Pacific Ocean were standardized using ZINB based on logbook data and hopefully the CPUE series can be used in the shortfin mako stock assessment in 2018.

# 2. Material and methods

## 2.1. Source of data

The logbook data of the Taiwanese large-scale tuna longline fishery from 1971 to 2016, provided by the Overseas Fisheries Development Council of the Republic of China, were used in this study. These logbook data contain basic information on fishing time, area, number of hooks and catches of 18 species (14 species before 2005) including major tunas, billfishes and sharks. The shark by-catch of the Taiwanese tuna longline fleets was never reported until 1981 because of its low economic value compared with tunas. During the period from 1981 to 2004, 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 2005. As the Taiwanese longline fishery has widely covered the North Pacific Ocean, our fishery statistics must be one of the most valuable information that can be used to describe the population status of pelagic sharks.

The species-specific catch data including tunas, billfishes, and sharks from logbook records in 2005-2016 were used to standardize CPUE of shortfin mako shark of the Taiwanese large-scale longline fishery in the North Pacific Ocean. In addition, the nominal CPUE was applied to back-estimate the historical shortfin mako catch (before 2005) of the Taiwanese large-scale longline fleets.

## 2.2. CPUE standardization

Shortfin mako sharks caught by the Taiwanese LTLL fishery in the North Pacific Ocean were mainly observed in the equatorial waters where bigeye tuna, *Thunnus obesus*, was the targeting species and in the subtropical and temperate waters where albacore tuna, *Thunnus alalunga*, was the targeting species (**Figure 1**). Based on the distributions of effort from the logbook (**Figure 1**), the North Pacific Ocean was stratified as 4 areas namely A (north of 25ºN), B (0ºN-25ºN, west of 0ºW), C (0ºN-25ºN, 0ºW-40ºW), and D (0ºN-25ºN, west of 40ºW). The area strata used for the analysis were shown in **Figure 2**. For standardization, CPUE was calculated by set of operations based on logbook records during the period of 2005-2016.

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A large proportion of sets with zero catch of shortfin mako shark (~90%) was found in the logbook records. Hence, to address these excessive zeros, the Zero inflated Negative Binomial model (ZINB, Lambert 1992; Hall 2000) was applied to the standardization of shortfin mako shark CPUE. The ZINB is a mixture of two distributions, one distribution is typically a Poisson or negative binomial distribution that can generate both zero and nonzero counts, and the second distribution is a constant distribution that generates only zero counts. The model was fit using glm function of statistical computing language R (R Development Core and Team, 2013) to eliminate the biases by change of targeting species, fishing ground and fishing seasons.

The standardized CPUE series for shortfin mako shark was constructed with interaction effects. The main variables chosen as input into the ZINB analyses were year (Y), quarter (Q), area (A), latitude (LAT), longitude (LON) and HPB (number of hooks per basket, HPB). The effect of gear configuration of HPB was used to account for the shift of targeting species. The following additive model was applied to the data in this study:

The standardized CPUE series for shortfin mako shark was constructed without interaction. The model is described as:

Catch= Year + Quarter + Area + HPB + LAT + LON

For the Zero Inflated Negative Binomial:

(Part 1: count models- Negative Binomial; Part 2: Binomial, link = logit)

The probability distribution of a zero-inflated negative binomial random variable Y is given by

$$\Pr(\mathrm{Y} = y) = \begin{cases} \omega + (1-\omega)(1+k\lambda)^{1/k} & \text{for } y = 0 \\ (1-\omega)\frac{\Gamma(y+1/k)}{\Gamma(y+1)\Gamma(1/k)}\frac{(k\mu)^y}{(1+k\lambda)^{y+1/k}} & \text{for } y = 1, 2, \ldots \end{cases}$$

where *k* is the negative binomial dispersion parameter.

The effect of gear configuration, HPB, was categorized into two classes: shallow set (HPB ≦ 15), and deep set (HPB > 15) (Walsh, 2011), and 4 quarters were categorized: the 1st quarter (Jan-Mar), the 2nd quarter (Apr-Jun), the 3rd quarter (Jul-Sep), and the 4th quarter (Oct-Dec). Continuous variables tested were the LAT and LON. The area strata used for the analysis were shown in **Figure 2**.

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The best model for ZINB models were selected using the stepwise AIC method (Venables and Ripley, 2002). For model diagnostics, the rootograms function in R countreg package (Kleiber and Zeileis, 2016) was used to assess the influence of observations that exert on the model. The distribution of residuals was used to verify the assumption of the ZINB models. These diagnostic plots were used to evaluate the fitness of the models.

Empirical confidence interval of standardized CPUE was estimated by using a bootstrap resampling method. The number of bootstrapped sub-samples was 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 10,000 replicates (Efron and Tibshirani, 1993).

## 2.3. Estimate of historical shortfin mako shark catch

Annual shortfin mako by-catch in number ($C_y$) was obtained by using the logbook catch divided by coverage rate for 2005-2016. The shortfin mako by-catch in number before 2005 was back-estimated using the following equation:

$$C_y = \sum_{i}^{4} \frac{\text{Nominal } CPUE_{i,} \times Logbook\ effort_i}{Coverage\ rate}, \quad (4)$$

where y is year, $i = 1$ is area A, $i = 2$ is area B, $i = 3$ is area C and $i = 4$ is area D. Coverage rate is the total catch (bigeye tuna, albacore tuna, yellowfin tuna, and swordfish) in logbook to that in Task 1. The nominal CPUE before 2005 was represented by the mean of nominal CPUE in the period of 2005-2007 because there were no species-specific shark catch data in logbook before 2005.

As the weight records were incomplete and might be biased, the catch in weight of shortfin mako shark was estimated by using annual mean weight multiplied by the estimated/back-estimated catch in number. No catch information before 2015, the average value of 2005-2007 was used and assumed constant for 1971-2004. All size data not recorded in PCL (*FL* recorded in logbook data) were converted to PCL based on the Joung and Hsu (2005) converting equations. The annual mean PCL of shortfin mako sharks was calculated based on the logbook length data in the period of 2005-2016 and the mean weight was obtained by substituting the mean PCL into the W-PCL relationship (sexes-combined) as following: $W = 2.28\times10^{-5}\ PCL^{2.88}$ (Su *et al*., 2017).

# 3. Results and discussion

The annual mean PCL of shortfin mako sharks recorded in the logbook was listed in **Table 1.** The average PCL was 146.92 cm (n=3,106) and the estimated mean weight was 50.53 kg. The frequency distributions of shortfin mako shark by-catch per set are characterized by many zero values and a long right tail (**Figure 3**). Overall, 84.67% of total sets had zero shortfin mako shark by-catch (**Table 2**).

The best models for ZINB models chosen based on AIC were " Catch ~ HPB + Year + Quarter + LAT + LON ". The detail values for nominal and standardized CPUE were listed in **Tables 3-4**. The nominal CPUE of shortfin mako shark showed an inter-annual fluctuation. However, this variability was reduced in the standardized CPUE series (**Figure 4**). The standardized CPUE series contains the combined effects from two models, one that calculates the probability of a zero observation and the other one estimates the count per year. In general, the standardized CPUE series of the shortfin mako sharks caught by the Taiwanese LTLL fishery decreased from 2006 to 2010 and increased slightly thereafter (**Figure 4**).

The diagnostic results from the ZINB model do not indicate severe departure from model assumptions (**Figures 5-7**). The Q-Q normal plots (the upper panel) for ZINB model showed that the error distributions are close to normal (**Figure 5**). There is also no wave-like pattern for the residuals showed that the data is appropriately captured by the model. Additional residual plots for each factor were provided in **Figures 6-7**. The ANOVA tables for each model are given in **Tables 5-6**. Most main effects (except for Area factor) tested were significant (mostly $P < 0.01$) and included in the final model. However, the deviance tables were not provided in this study. The standard residuals (e.g., Poisson or deviance) are often not so informative because they mostly capture the modeling of the mean but not of the entire distribution. In case of discrete distributions (as ZINB). To verify that the model solves the problem of excess zeroes, another alternative which checks the marginal distribution of the data is the so-called rootogram. This plot (**Figure 5**) often better at displaying the problems of excess zeros and/or overdispersion than Q-Q plots of randomized quantile residuals (Kleiber & Zeileis , 2016).

The back-estimations of historical shark by-catch before 2005 in this report were based on logbook records from 2005-2007. Estimated shortfin mako shark by-catch in number ranged from 0 in 1973 to 2,680 in 2014. The back-estimated catch was relative low before 1995 and increased to more than 100 MT and fluctuated thereafter, peaked at 156 MT in 2015, and slight decreased thereafter (**Table 7**). In all, the estimated shortfin mako shark by-catch in weight of Taiwanese LTLL fishery ranged from almost 0 metric tons (MT) in 1971 to 156 MT in 2015, with a mean of 41 MT and 789 individuals in the North Pacific Ocean (**Table 7**).

Many 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 (Bigelow *et al.,* 1999), and big-eye tuna in the Indian Ocean (Okamoto *et al.,* 2001). Although shortfin mako sharks are homeotherm, the behavior of sharks with these characteristic is also triggered by the environmental temperature (Weng *et al*., 2007). Environmental effects should be included in the future standardization models.

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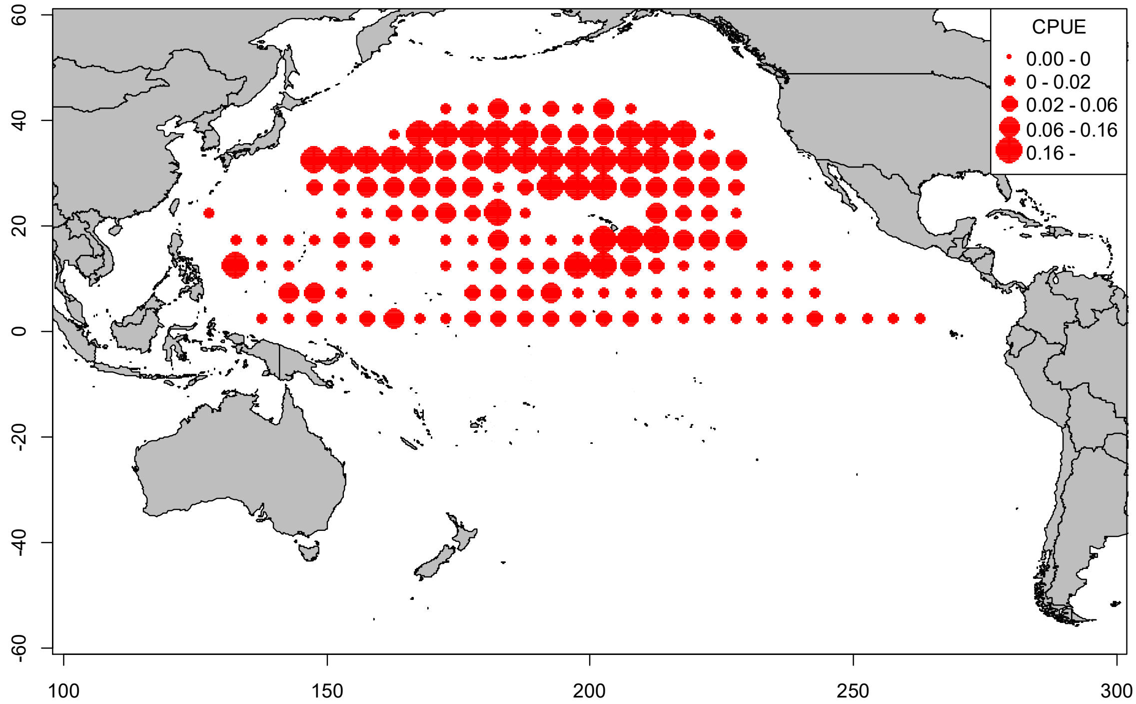


**Figure 1.** Nominal CPUE distribution of shortfin mako sharks caught by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005-2016.

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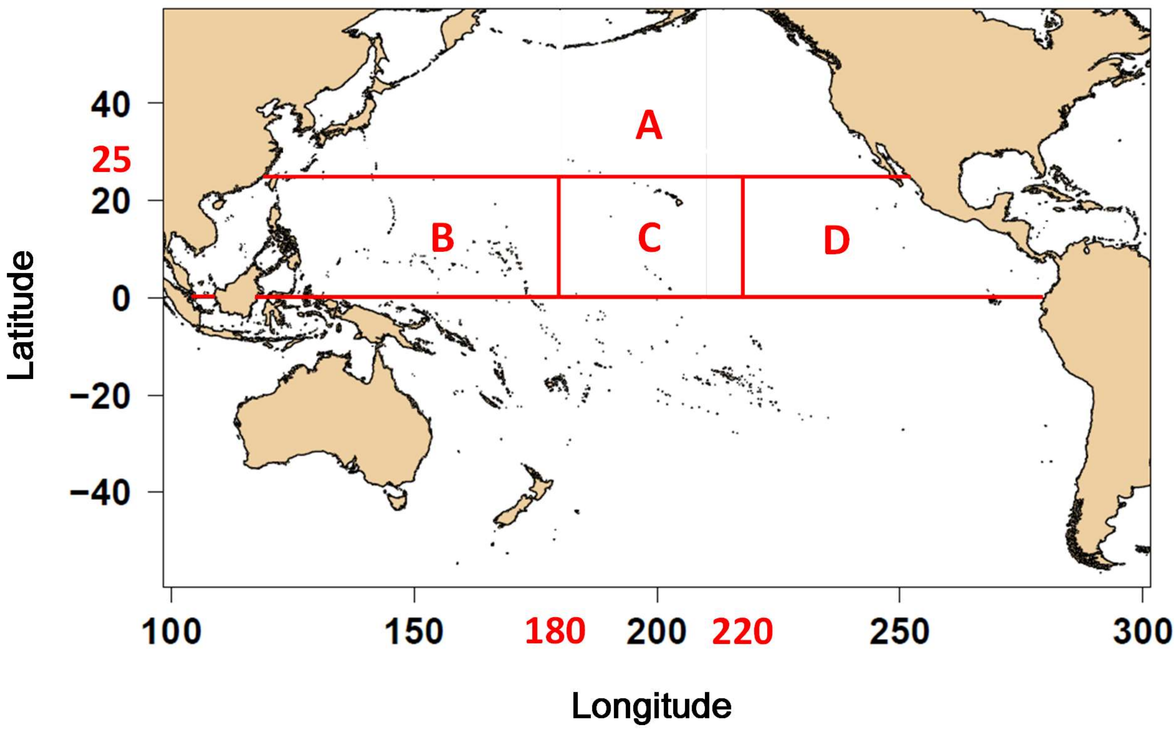


**Figure 2.** Area stratification used for the estimate of shortfin mako shark by-catch of the Taiwanese large-scale tuna longline fishery in North Pacific Ocean.

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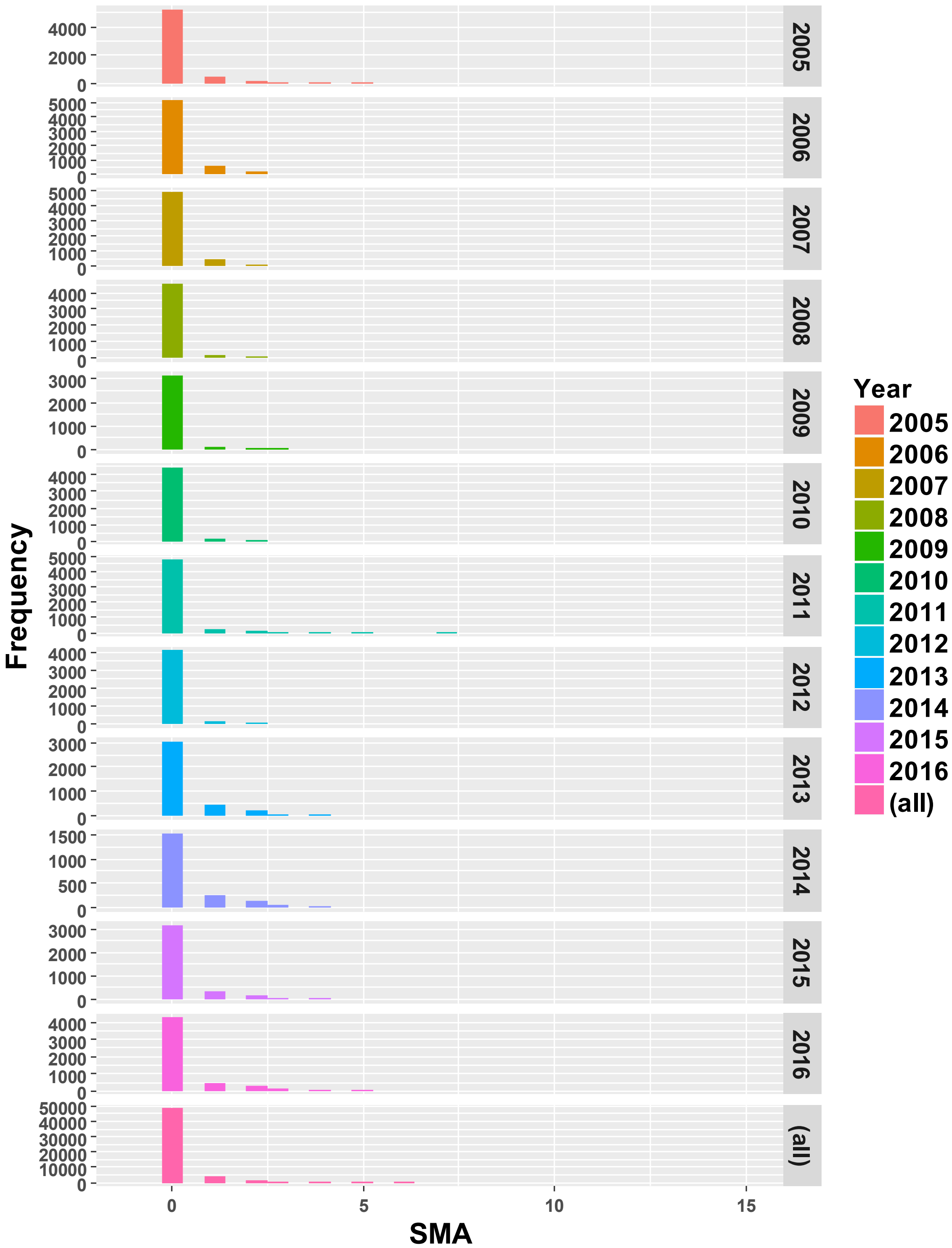


**Figure 3.** Frequency distribution of shortfin mako shark by-catch per set, 2005–2016.

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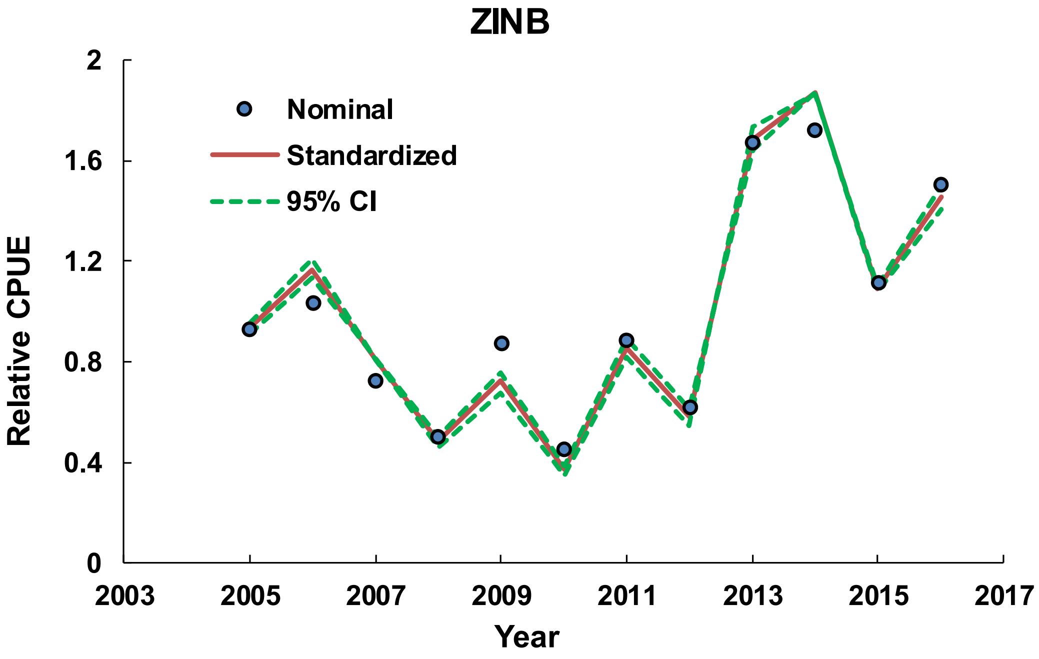


**Figure 4.** Relative nominal and standardized CPUE with 95% C.I. of shortfin mako shark by Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005 to 2016.

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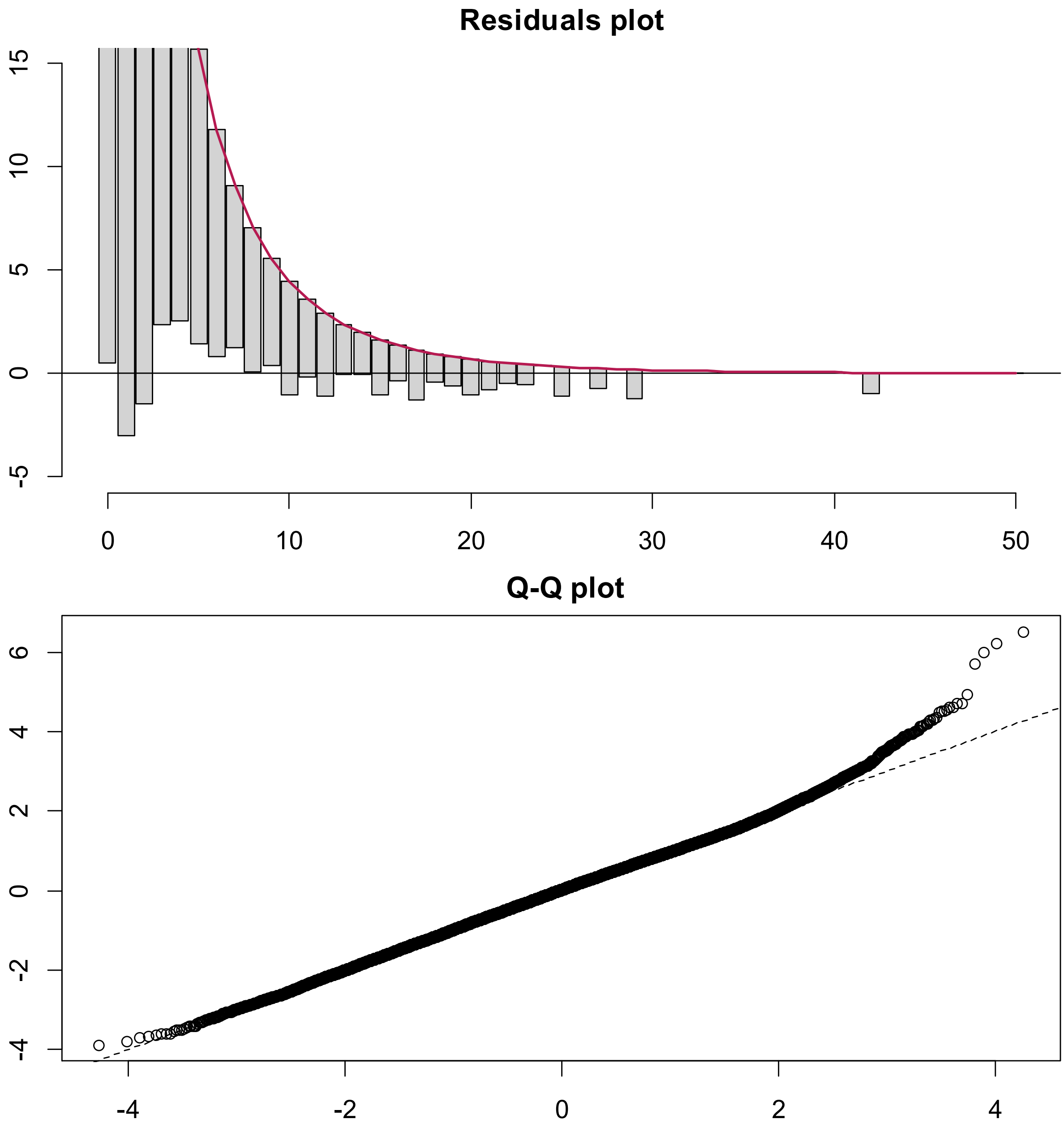


**Figure 5.** Diagnostic results from the ZINB model fit to the longline shortfin mako shark bycatch data.

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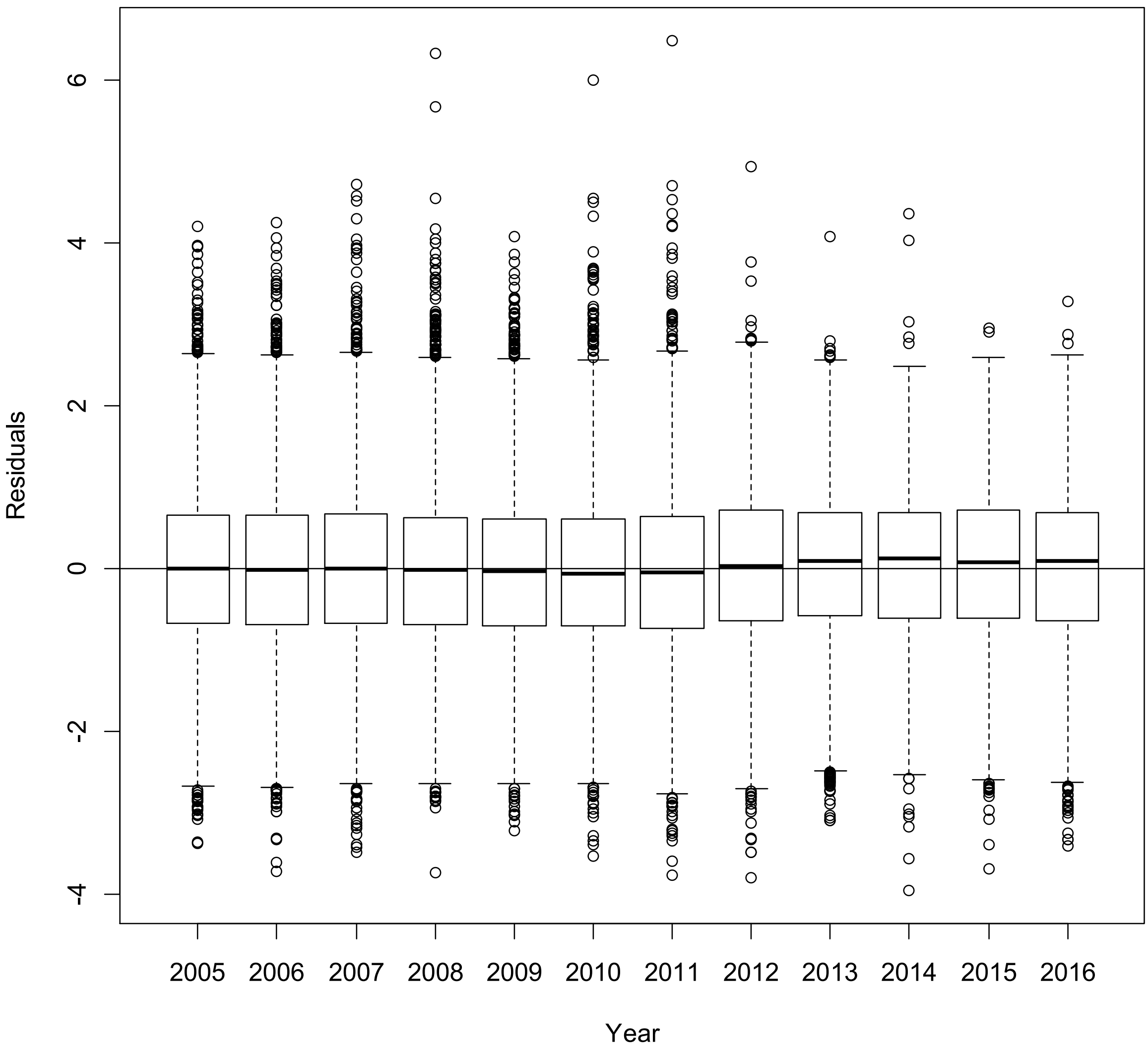


**Figure 6.** Box plots of the Pearson residuals vs. the covariates for the variables Year.

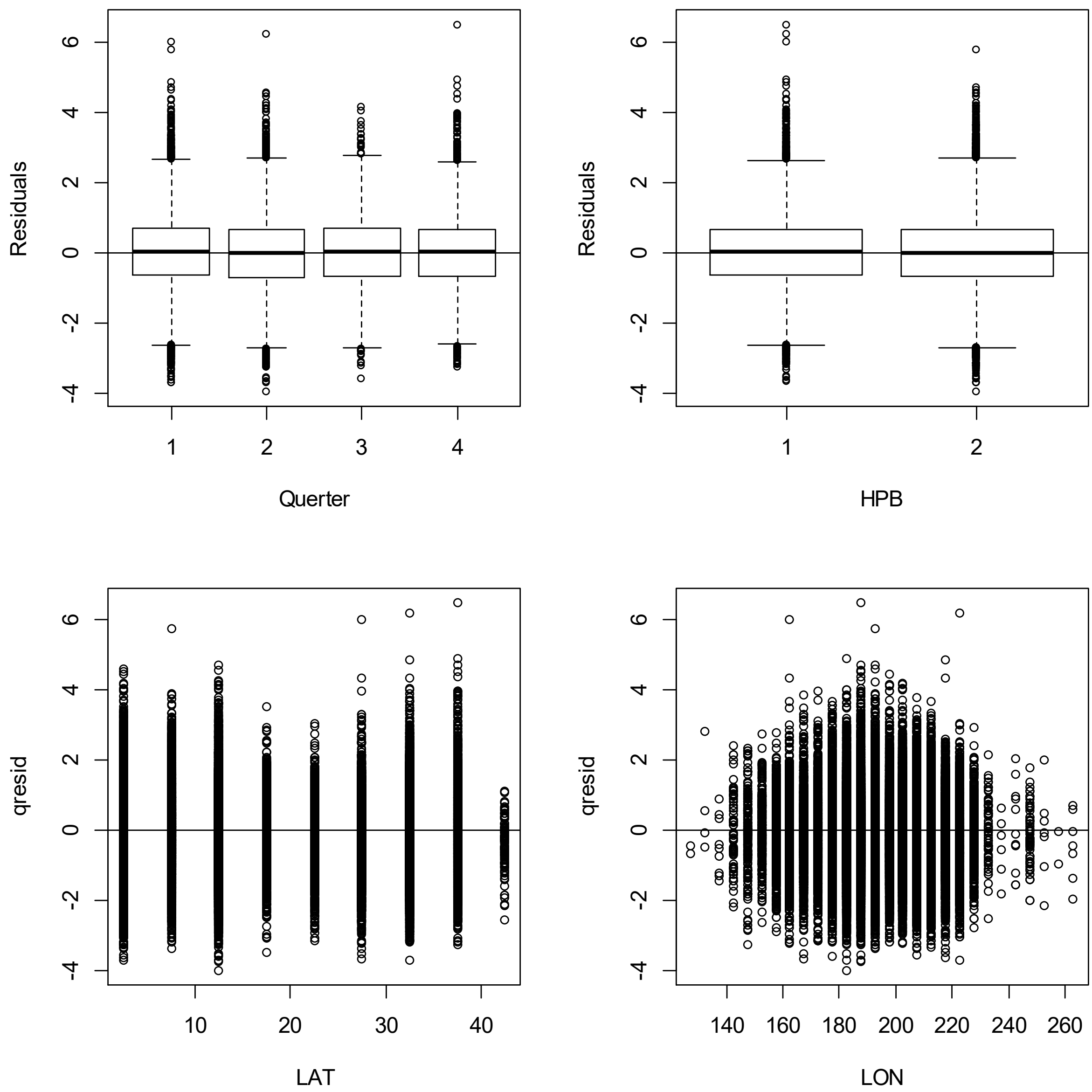


**Figure 7.** Box plots of the Pearson residuals vs. the covariates for the variables Quarter, HPB, LAT and LON.

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**Table 1.** Estimated annual shortfin mako shark (SMA) mean PCL and mean weight from logbook data.

| Year | Mean PCL | Mean W |
|---|---|---|
| 2005 | 138.94 | 41.84 |
| 2006 | 156.06 | 58.47 |
| 2007 | 153.65 | 55.90 |
| 2008 | 132.36 | 36.38 |
| 2009 | 118.39 | 26.39 |
| 2010 | 132.75 | 36.69 |
| 2011 | 142.49 | 44.99 |
| 2012 | 167.35 | 71.50 |
| 2013 | 155.42 | 57.78 |
| 2014 | 135.27 | 38.73 |
| 2015 | 163.84 | 67.27 |
| 2016 | 166.52 | 70.48 |
| Average | 138.94 | 41.84 |

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**Table 2.** Estimated annual shortfin mako shark (SMA) zero-catch percentage of Taiwanese large-scale tuna longline fishery in the North Pacific Ocean.

| Year | SMA Zero % |
|---|---|
| 2005 | 83.59% |
| 2006 | 79.88% |
| 2007 | 86.02% |
| 2008 | 92.44% |
| 2009 | 91.86% |
| 2010 | 94.07% |
| 2011 | 90.12% |
| 2012 | 92.31% |
| 2013 | 73.82% |
| 2014 | 72.59% |
| 2015 | 81.34% |
| 2016 | 77.94% |
| Average | 84.67% |

**Table 3.** Estimated nominal and standardized CPUE values for shortfin mako shark of the Taiwanese tuna longline fishery in the North Pacific Ocean.

| Year | Original values | | Bias-corrected bootstrap confidence intervals | | | | | |
|---|---|---|---|---|---|---|---|---|
| | N_CPUE (hook) | N_CPUE (cell) | S_CPUE | Lower CI | Upper CI | Mean | STD | CV |
| 2005 | 0.091 | 0.309 | 0.301 | 0.279 | 0.326 | 0.302 | 0.012 | 4.11% |
| 2006 | 0.102 | 0.377 | 0.376 | 0.352 | 0.406 | 0.376 | 0.013 | 3.58% |
| 2007 | 0.071 | 0.255 | 0.261 | 0.236 | 0.292 | 0.260 | 0.014 | 5.43% |
| 2008 | 0.049 | 0.165 | 0.155 | 0.134 | 0.179 | 0.156 | 0.012 | 7.39% |
| 2009 | 0.086 | 0.285 | 0.233 | 0.197 | 0.271 | 0.233 | 0.019 | 8.21% |
| 2010 | 0.044 | 0.140 | 0.120 | 0.101 | 0.139 | 0.120 | 0.010 | 8.16% |
| 2011 | 0.087 | 0.274 | 0.276 | 0.238 | 0.320 | 0.276 | 0.021 | 7.49% |
| 2012 | 0.061 | 0.189 | 0.188 | 0.160 | 0.220 | 0.188 | 0.015 | 8.23% |
| 2013 | 0.164 | 0.528 | 0.544 | 0.506 | 0.588 | 0.544 | 0.021 | 3.85% |
| 2014 | 0.169 | 0.552 | 0.603 | 0.545 | 0.670 | 0.603 | 0.034 | 5.65% |
| 2015 | 0.109 | 0.328 | 0.351 | 0.321 | 0.386 | 0.351 | 0.016 | 4.69% |
| 2016 | 0.148 | 0.451 | 0.470 | 0.437 | 0.504 | 0.469 | 0.018 | 3.81% |

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**Table 4.** The area specific nominal CPUE values from 2005 to 2007 for shortfin mako shark of the Taiwanese tuna longline fishery in the North Pacific Ocean.

| Area | Year | | | Mean |
|---|---|---|---|---|
| | 2005 | 2006 | 2007 | |
| 1 | 0.112 | 0.131 | 0.102 | 0.115 |
| 2 | 0.078 | 0.040 | 0.006 | 0.041 |
| 3 | 0.077 | 0.053 | 0.035 | 0.055 |
| 4 | 0.085 | 0.015 | 0.048 | 0.049 |

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**Table 5.** Analysis of Deviance Table of count model.

```
Call:
zeroinfl(formula = SMA ~ HPB + Year + Quarter + LAT + LON,
    offset = log(Hook), dist = "negbin")

Pearson residuals:
    Min      1Q  Median      3Q     Max
-0.6991 -0.3174 -0.1674 -0.1018 53.9049

Count model coefficients (negbin with log link):
             Estimate Std. Error z value Pr(>|z|)
(Intercept) -5.243437   0.218624 -23.984  < 2e-16 ***
HPB2        -0.263505   0.074344  -3.544 0.000394 ***
Year2006     0.344777   0.059423   5.802 6.55e-09 ***
Year2007     0.335733   0.067332   4.986 6.16e-07 ***
Year2008    -0.049039   0.101576  -0.483 0.629247
Year2009     0.896923   0.090723   9.886  < 2e-16 ***
Year2010     0.216547   0.101208   2.140 0.032385 *
Year2011     1.032005   0.076815  13.435  < 2e-16 ***
Year2012     1.078493   0.083211  12.961  < 2e-16 ***
Year2013     1.100327   0.061133  17.999  < 2e-16 ***
Year2014     1.037226   0.071069  14.595  < 2e-16 ***
Year2015     0.792439   0.068479  11.572  < 2e-16 ***
Year2016     0.891000   0.060427  14.745  < 2e-16 ***
Quarter2     0.487947   0.058584   8.329  < 2e-16 ***
Quarter3    -0.142852   0.123977  -1.152 0.249222
Quarter4     0.046329   0.037411   1.238 0.215580
LAT         -0.035510   0.003089 -11.496  < 2e-16 ***
LON         -0.013346   0.001046 -12.758  < 2e-16 ***
Log(theta)  -0.002106   0.048778  -0.043 0.965565
```

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**Table 6.** Analysis of Deviance Table of Zero-inflated model.

```
Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)    
(Intercept)  7.188643   0.370724  19.391  < 2e-16 ***
HPB2         0.295902   0.089200   3.317 0.000909 ***
Year2006     1.239862   0.122856  10.092  < 2e-16 ***
Year2007     1.747823   0.124948  13.988  < 2e-16 ***
Year2008     1.548859   0.164550   9.413  < 2e-16 ***
Year2009     2.293923   0.138573  16.554  < 2e-16 ***
Year2010     1.981180   0.167519  11.827  < 2e-16 ***
Year2011     2.096272   0.124465  16.842  < 2e-16 ***
Year2012     2.794377   0.139416  20.043  < 2e-16 ***
Year2013     1.108251   0.117834   9.405  < 2e-16 ***
Year2014     1.046913   0.133225   7.858 3.90e-15 ***
Year2015     1.232235   0.124660   9.885  < 2e-16 ***
Year2016     1.025783   0.112840   9.091  < 2e-16 ***
Quarter2     0.294900   0.071099   4.148 3.36e-05 ***
Quarter3    -0.236066   0.148920  -1.585 0.112923    
Quarter4    -0.315836   0.085126  -3.710 0.000207 ***
LAT         -0.122063   0.004526 -26.971  < 2e-16 ***
LON         -0.028317   0.001782 -15.889  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Theta = 0.9979 
Number of iterations in BFGS optimization: 47 
Log-likelihood: -2.677e+04 on 37 Df
```

**Table 7**. Estimated annual shortfin mako shark by-catch in number and weight (MT) of Taiwanese large-scale tuna longline fishery in the North Pacific Ocean. * For years before 2005 were estimated based on the average Area specific nominal CPUE of 2005-2007.

| Year | EstSMA (N) | EsSMA (ton) |
|---|---|---|
| 1971 | 7 | 0 |
| 1972 | 6 | 0 |
| 1973 | 0 | 0 |
| 1974 | 188 | 10 |
| 1975 | 282 | 15 |
| 1976 | 16 | 0 |
| 1977 | 93 | 5 |
| 1978 | 99 | 6 |
| 1979 | 20 | 1 |
| 1980 | 64 | 3 |
| 1981 | 58 | 3 |
| 1982 | 7 | 0 |
| 1983 | 7 | 0 |
| 1984 | 1 | 0 |
| 1985 | 162 | 8 |
| 1986 | 194 | 10 |
| 1987 | 79 | 4 |
| 1988 | 15 | 1 |
| 1989 | 76 | 4 |
| 1990 | 304 | 16 |
| 1991 | 325 | 17 |
| 1992 | 106 | 6 |
| 1993 | 84 | 4 |
| 1994 | 17 | 1 |
| 1995 | 1739 | 91 |
| 1996 | 752 | 39 |
| 1997 | 679 | 36 |
| 1998 | 788 | 41 |
| 1999 | 1647 | 85 |
| 2000 | 1521 | 80 |
| 2001 | 1601 | 83 |

| | | |
|---|---|---|
| 2002 | 2162 | 113 |
| 2003 | 1402 | 73 |
| 2004 | 2320 | 121 |
| 2005 | 1788 | 75 |
| 2006 | 2032 | 119 |
| 2007 | 1316 | 73 |
| 2008 | 822 | 30 |
| 2009 | 986 | 26 |
| 2010 | 684 | 25 |
| 2011 | 1572 | 71 |
| 2012 | 964 | 69 |
| 2013 | 2174 | 125 |
| 2014 | 2680 | 104 |
| 2015 | 2320 | 156 |
| 2016 | 2132 | 150 |

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