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

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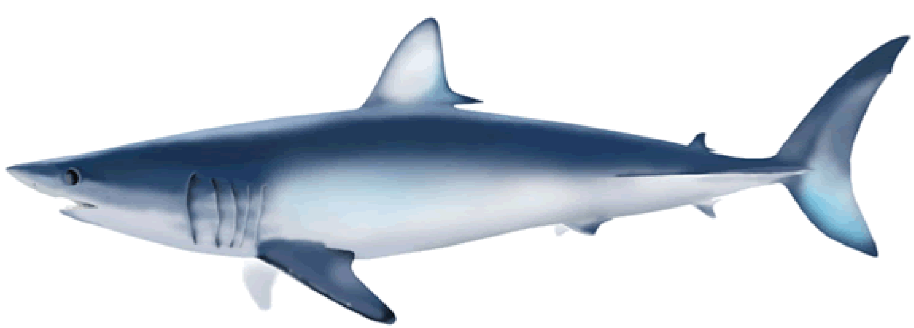

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ABSTRACT

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 2005-2019 were analyzed. Due to large percentage of zero shortfin mako shark catch, the catch per unit effort (CPUE) of shortfin mako shark, as 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 shark showed an inter-annual fluctuation with two peaks (2013, 2014 and 2018, 2019). Estimated shortfin mako shark catch in weight from the Taiwanese large-scale tuna longline fishery ranged from 0 metric tons (MT) in 1973 to 156 MT in 2015, and it decreased thereafter and increased again to 142 MT in 2019.

1. Introduction

The shortfin mako shark, *Isurus oxyrinchus,* is one of the most commonly shark species caught by the Taiwanese commercial offshore longline fishery and is one of the major by-catch shark species 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 was listed as "Endangered" on the IUCN Red List of Threatened Species (Rigby *et al*., 2019), was listed on the CITES Appendix II (CITES, 2019). 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. The blue shark (*Prionace glauca*) and shortfin mako and are the two 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 update the CPUE standardization and to estimate the catches of shortfin mako sharks by the Taiwanese LTLL in the North Pacific based on the logbook data.

2. Material and methods

2.1. Source of data

The logbook data of the Taiwanese large-scale tuna longline fishery from 1971 to 2019, provided by the Overseas Fisheries Development Council, Taiwan 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

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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 2005-2019 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, *T. 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 four areas namely A (north of 25°N), B (0°N-25°N, east of 0°W), C (0°N-25°N, 0°W-40°W), and D (0°N-25°N, west of 40°W). The area strata used for the analysis are shown in **Figure 2**. For standardization, CPUE was calculated by set of operations based on logbook records during the period of 2005-2019.

A large proportion of sets with zero catch of shortfin mako shark (~85%) was found in the logbook records. Hence, to address these excessive zeros, a 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 Team, 2017) 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:

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(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 $\leqq$ 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 are shown in **Figure 2**.

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 2005-2019. The shortfin mako by-catch in number before 2005 was back-estimated using the following equation:

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

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.

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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 2005-2019 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 148.76 cm (n=11,173) and the estimated mean weight was 52.02 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, 84.8% 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 are listed in **Table 3**. The nominal and standardized CPUE of shortfin mako shark showed an inter-annual fluctuation (**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, peaked in 2014, decreased thereafter and increased again in 2018 and 2019 (**Figure 4**).

The diagnostic results from the ZINB model do not indicate severe departure from model assumptions (**Figures 5-6**). 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 **Figure 6**. The ANOVA tables for each model are given in **Tables 4-5**. All main effects tested were significant (mostly $P < 0.01$) and included in the final model.

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 shortfin mako shark by-catch in weight of Taiwanese LTLL fishery ranged from almost 0 metric tons (MT) in 1971 to 125 MT in 2014, with a mean of 37 MT and 792 individuals in the North Pacific Ocean (**Table 6**). The 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 and increased again in 2019 (**Table 6**).

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. In addition, the change of logbook reporting system is another possible factor influencing the CPUE. The paper logbook has been replaced by e-logbook since 2017. Despite of the transition year of 2017, the 100% coverage rate of 2018 and 2019 may lead to the increase of CPUE in these two years.

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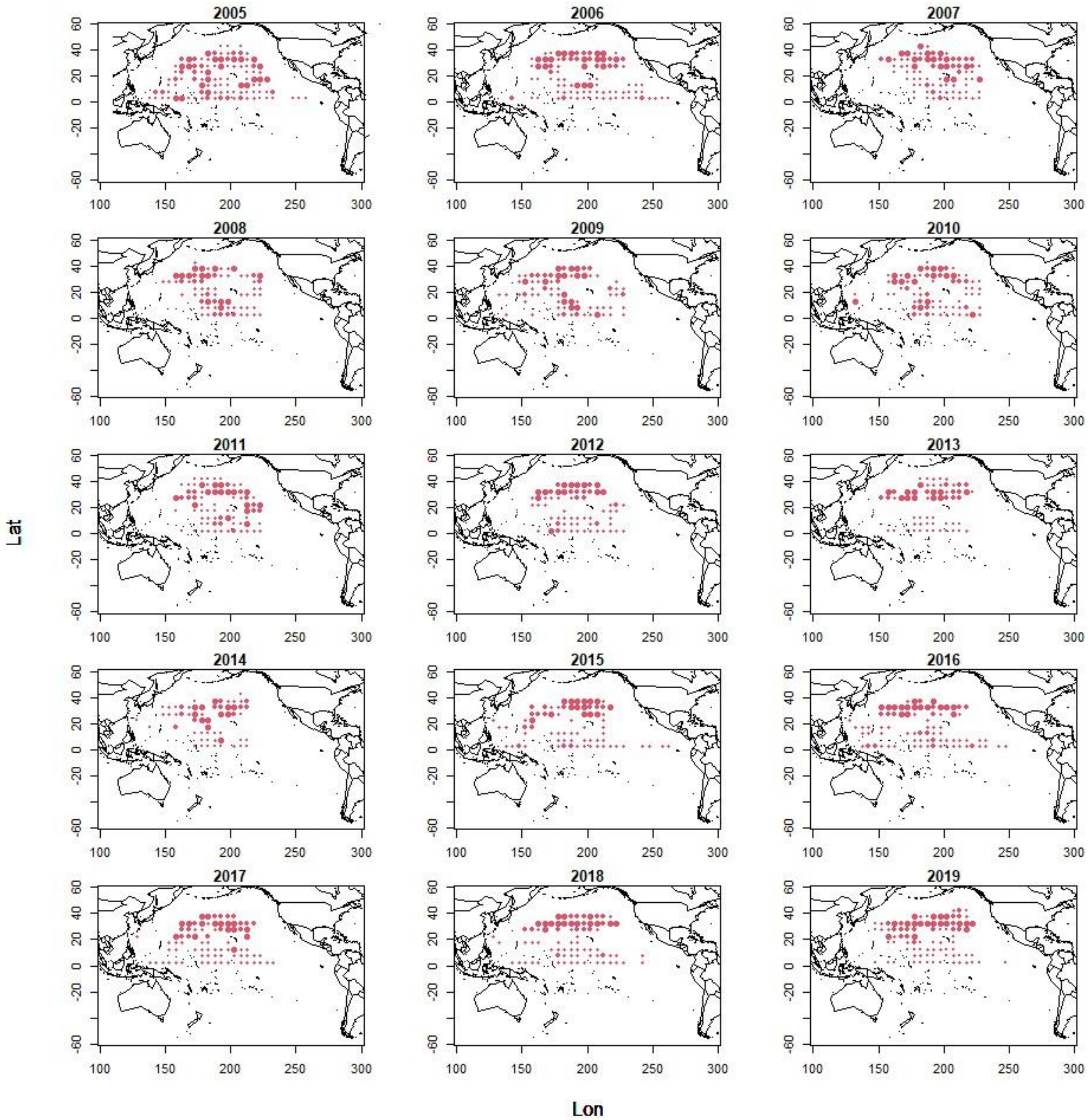

Figure 1. Nominal CPUE distribution of shortfin mako sharks caught by the Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005-2019.

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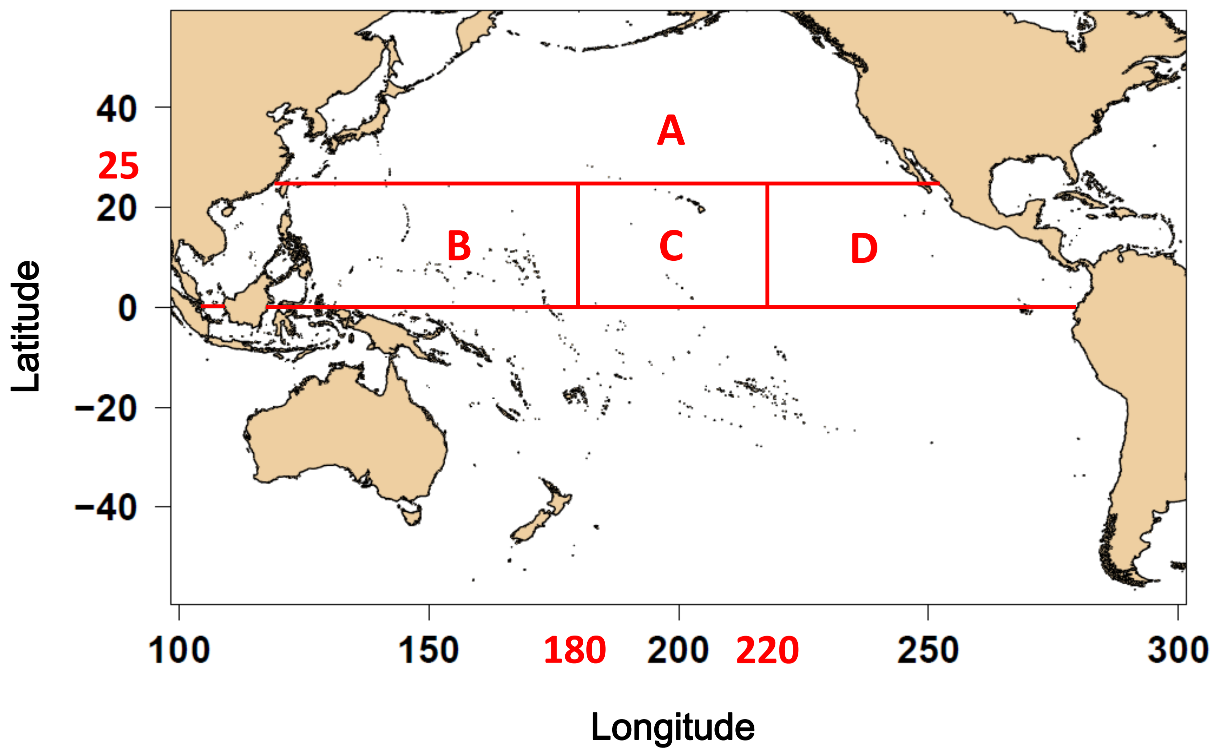

Figure 2. Area stratification used for the estimate of shortfin mako shark by-catch of the Taiwanese large-scale tuna longline fishery in North Pacific Ocean.

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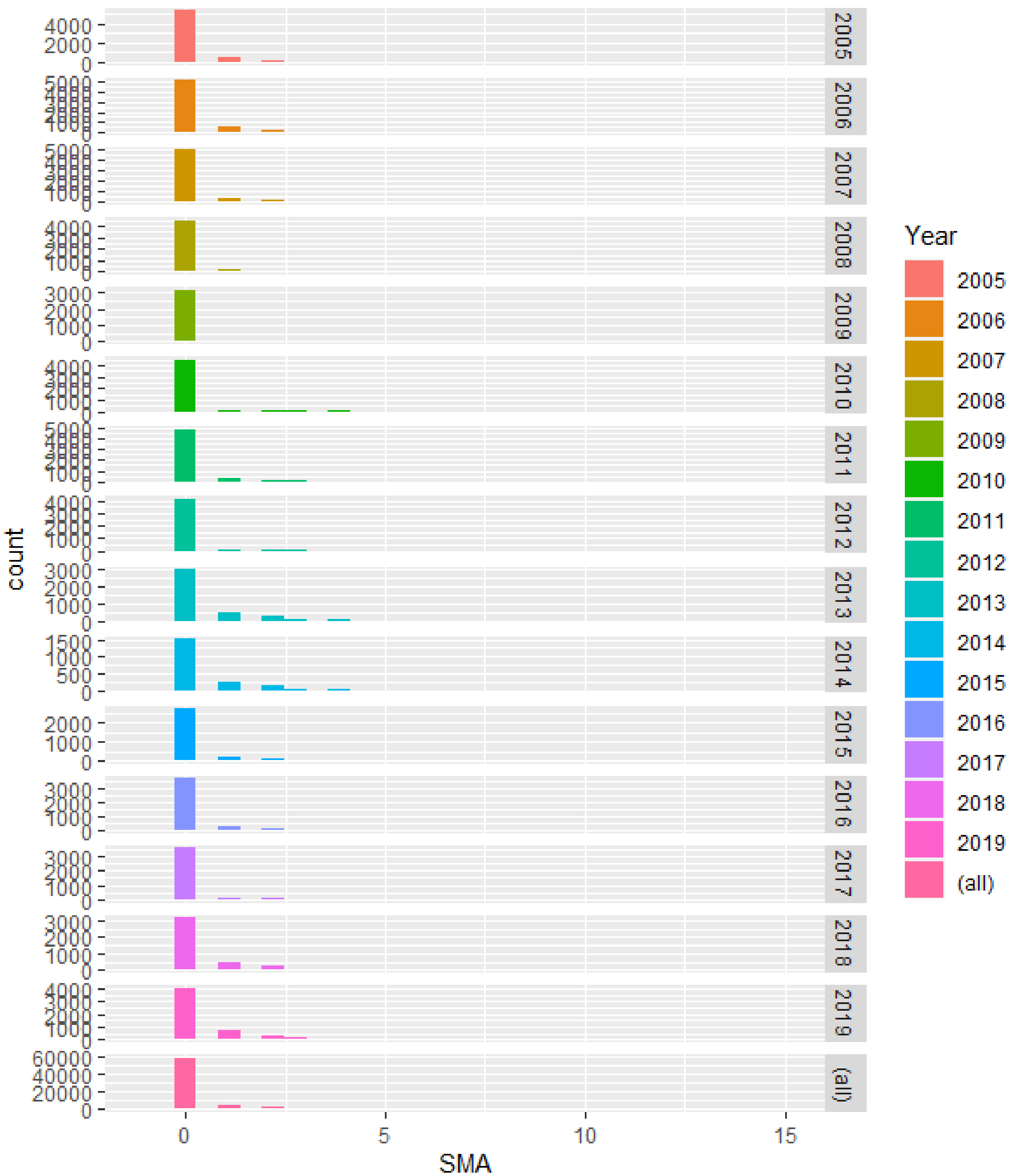

Figure 3. Frequency distribution of the shortfin mako shark by-catch per set, 2005–2019.

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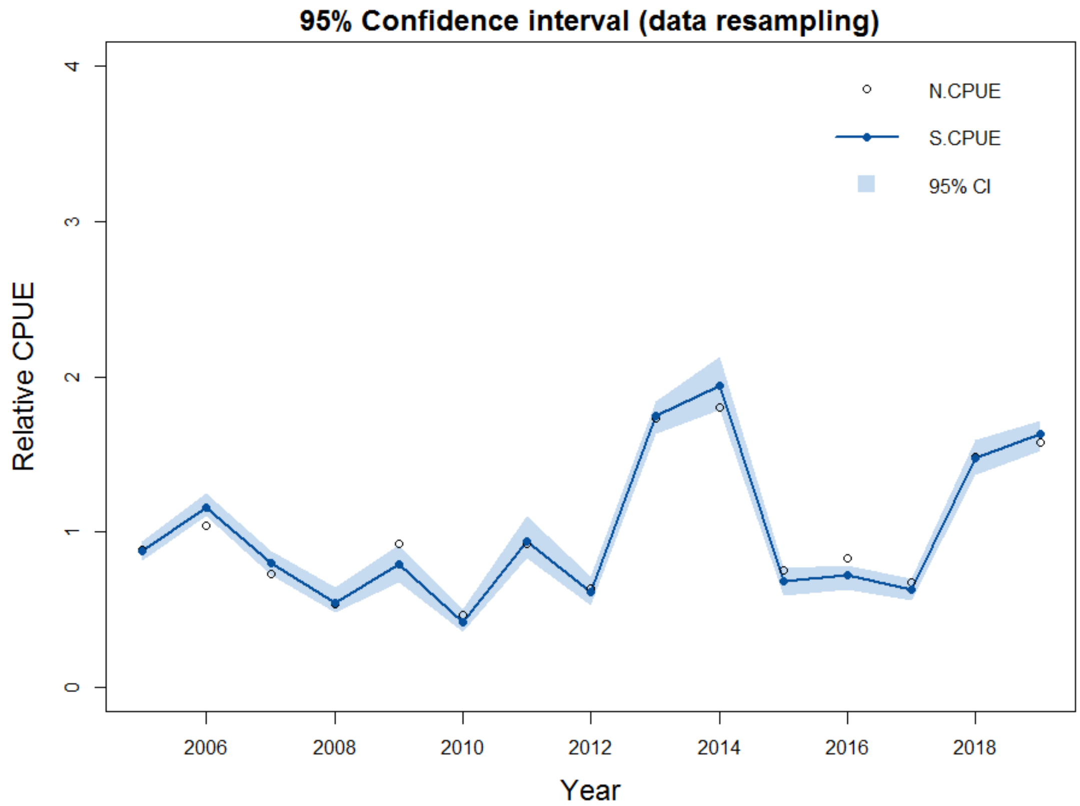

Figure 4. Relative nominal (open circle) and standardized CPUE with 95% C.I. of shortfin mako shark by the Taiwanese large-scale tuna longline fishery in the North Pacific Ocean from 2005 to 2019.

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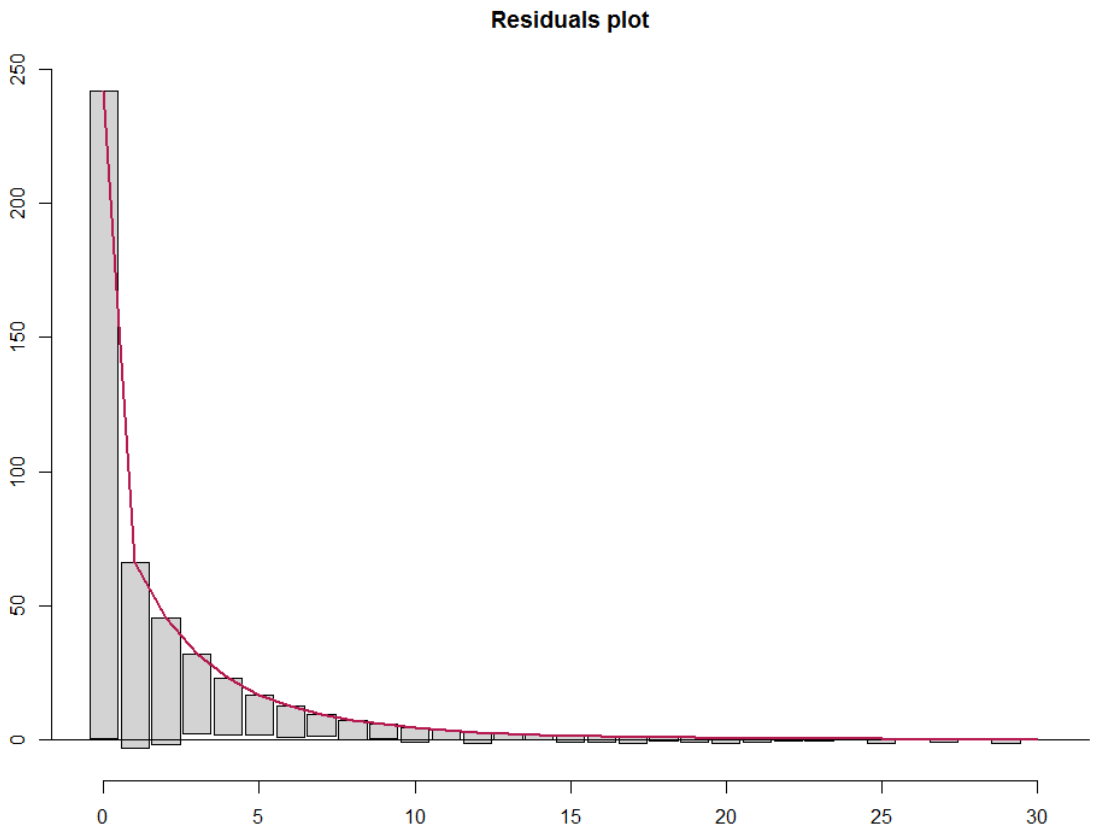

Figure 5. Diagnostic results from the ZINB model fit to the shortfin mako shark caught by the Taiwan large-scale tuna longline fishery.

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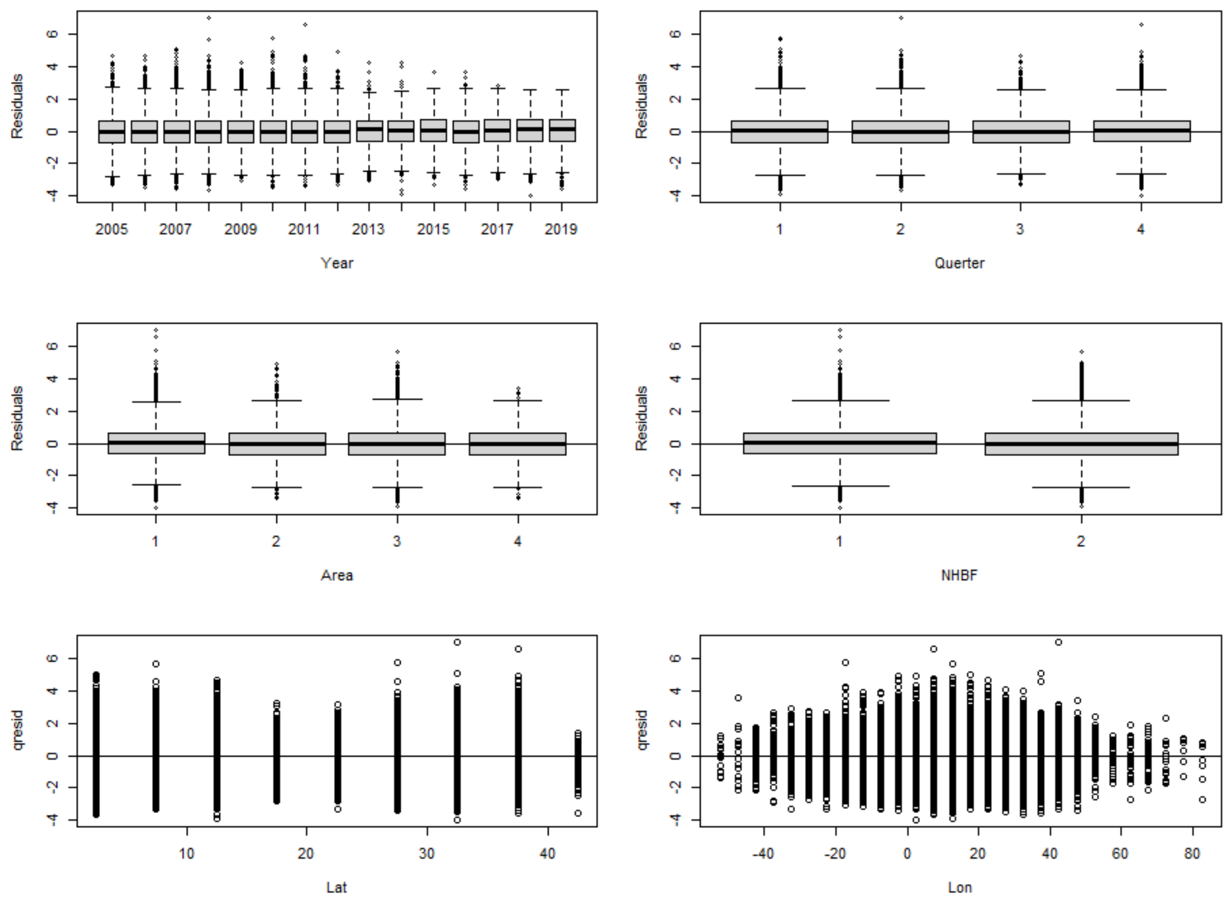

Figure 6. Box plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area, NHBF, Lat and Lon.

Table 1. Estimated annual shortfin mako shark (SMA) mean PCL and mean weight from the 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
2017	156.96	60.71
2018	152.74	56.13
2019	158.70	62.67
Average	148.76	52.02

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Table 2. Estimated annual shortfin mako shark (SMA) zero-catch percentage of the 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	91.34%
2016	77.94%
2017	90.56%
2018	79.66%
2019	76.04%
Average	84.82%

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

	nominal	standardized	Std_CV	relative	Rel_CV
2005	0.0910	0.2460	3.8655	0.8798	3.9689
2006	0.1020	0.3248	3.2789	1.1615	3.2310
2007	0.0710	0.2229	4.7468	0.7971	4.9013
2008	0.0490	0.1531	7.2986	0.5476	7.1787
2009	0.0860	0.2213	9.0386	0.7914	8.4778
2010	0.0440	0.1179	9.2967	0.4217	9.1202
2011	0.0870	0.2624	7.6729	0.9383	7.4683
2012	0.0610	0.1716	7.4402	0.6137	7.4781
2013	0.1640	0.4900	3.6980	1.7523	3.3225
2014	0.1690	0.5436	6.0661	1.9438	5.2239
2015	0.0656	0.1919	7.0592	0.6861	6.7622
2016	0.0725	0.2020	5.6202	0.7223	5.5421
2017	0.0591	0.1764	5.9596	0.6307	5.8984
2018	0.1301	0.4139	4.1672	1.4803	3.9449
2019	0.1379	0.4568	3.3612	1.6335	3.3833
Average	0.0874	0.2796			

Table 4. Analysis of Deviance Table of count model.

```
Call:
zeroinfl(formula = SHK ~ Yr + Qtr + Area + NHBF + Lat + Lon, data = dat, offset = log(Hook),
    dist = "negbin")

Pearson residuals:
     Min       1Q   Median       3Q      Max 
-0.73503 -0.24640 -0.14812 -0.09456 66.89345 

Count model coefficients (negbin with log link):
              Estimate Std. Error z value Pr(>|z|)    
(Intercept) -7.9444481  0.1344589 -59.085  < 2e-16 ***
Yr2006       0.4042461  0.0581891   6.947 3.73e-12 ***
Yr2007       0.3280496  0.0647078   5.070 3.98e-07 ***
Yr2008       0.0080367  0.0960038   0.084 0.933285    
Yr2009       0.9678547  0.0901398  10.737  < 2e-16 ***
Yr2010       0.4000224  0.1036466   3.859 0.000114 ***
Yr2011       1.0645115  0.0761171  13.985  < 2e-16 ***
Yr2012       1.1297571  0.0806961  14.000  < 2e-16 ***
Yr2013       1.1235932  0.0578833  19.411  < 2e-16 ***
Yr2014       1.1202400  0.0684812  16.358  < 2e-16 ***
Yr2015       0.6924203  0.0801124   8.643  < 2e-16 ***
Yr2016       0.6459587  0.0740235   8.726  < 2e-16 ***
Yr2017       0.8496365  0.0769889  11.036  < 2e-16 ***
Yr2018       0.9721556  0.0594928  16.341  < 2e-16 ***
Yr2019       0.9500616  0.0550389  17.262  < 2e-16 ***
Qtr2         0.2212418  0.0520654   4.249 2.14e-05 ***
Qtr3        -0.5008013  0.1246510  -4.018 5.88e-05 ***
Qtr4         0.0323161  0.0326422   0.990 0.322170    
Area2       -0.6196384  0.1348166  -4.596 4.30e-06 ***
Area3        0.8346703  0.1127592   7.402 1.34e-13 ***
Area4        0.6295612  0.1618570   3.890 0.000100 ***
NHBF2       -0.7393498  0.0590759 -12.515  < 2e-16 ***
Lat         -0.0255876  0.0040807  -6.270 3.60e-10 ***
Lon         -0.0160656  0.0009451 -16.999  < 2e-16 ***
Log(theta)   0.1093981  0.0443660   2.466 0.013671 *  
```

Table 5. Analysis of Deviance Table of Zero-inflated model.

```
Zero-inflation model coefficients (binomial with logit link):
             Estimate Std. Error z value Pr(>|z|)    
(Intercept)  1.539109   0.180135   8.544  < 2e-16 ***
Yr2006       1.516656   0.125969  12.040  < 2e-16 ***
Yr2007       1.884500   0.127908  14.733  < 2e-16 ***
Yr2008       1.515752   0.165475   9.160  < 2e-16 ***
Yr2009       2.390033   0.138868  17.211  < 2e-16 ***
Yr2010       2.225719   0.181266  12.279  < 2e-16 ***
Yr2011       2.050012   0.125132  16.383  < 2e-16 ***
Yr2012       2.946243   0.139764  21.080  < 2e-16 ***
Yr2013       1.142220   0.117379   9.731  < 2e-16 ***
Yr2014       1.331314   0.135171   9.849  < 2e-16 ***
Yr2015       1.272054   0.130013   9.784  < 2e-16 ***
Yr2016       1.287054   0.120147  10.712  < 2e-16 ***
Yr2017       1.817975   0.128685  14.127  < 2e-16 ***
Yr2018       1.025964   0.115060   8.917  < 2e-16 ***
Yr2019       0.940291   0.108370   8.677  < 2e-16 ***
Qtr2         0.027035   0.064696   0.418 0.676039    
Qtr3        -0.564930   0.151434  -3.731 0.000191 ***
Qtr4         0.058798   0.079141   0.743 0.457515    
Area2        0.384869   0.166110   2.317 0.020506 *  
Area3        1.961091   0.145830  13.448  < 2e-16 ***
Area4        2.441849   0.216654  11.271  < 2e-16 ***
NHBF2       -0.627406   0.080694  -7.775 7.54e-15 ***
Lat         -0.115887   0.005825 -19.894  < 2e-16 ***
Lon         -0.041730   0.002125 -19.635  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Theta = 1.1156 
Number of iterations in BFGS optimization: 65 
Log-likelihood: -3.187e+04 on 49 Df
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Table 6. Estimated annual shortfin mako shark by-catch in number and weight (MT) of the 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)	EstSMA (ton)	Year	EstSMA (n)	EstSMA (ton)
1971	7	0	1996	752	39
1972	6	0	1997	679	36
1973	0	0	1998	788	41
1974	188	10	1999	1,647	85
1975	282	15	2000	1,521	80
1976	16	0	2001	1,601	83
1977	93	5	2002	2,162	113
1978	99	6	2003	1,402	73
1979	20	1	2004	2,320	121
1980	64	3	2005	1,788	75
1981	58	3	2006	2,032	119
1982	7	0	2007	1,316	73
1983	7	0	2008	822	30
1984	1	0	2009	986	26
1985	162	8	2010	684	25
1986	194	10	2011	1,572	71
1987	79	4	2012	964	69
1988	15	1	2013	2,174	125
1989	76	4	2014	2,680	104
1990	304	16	2015	2,320	156
1991	325	17	2016	2,132	150

1992	106	6	2017	665	40
1993	84	4	2018	1,550	87
1994	17	1	2019	2,271	142
1995	1,739	91			

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