Updated historical catches and standardized CPUE series of blue shark by Taiwanese tuna longline fisheries in the North Pacific Ocean[1]

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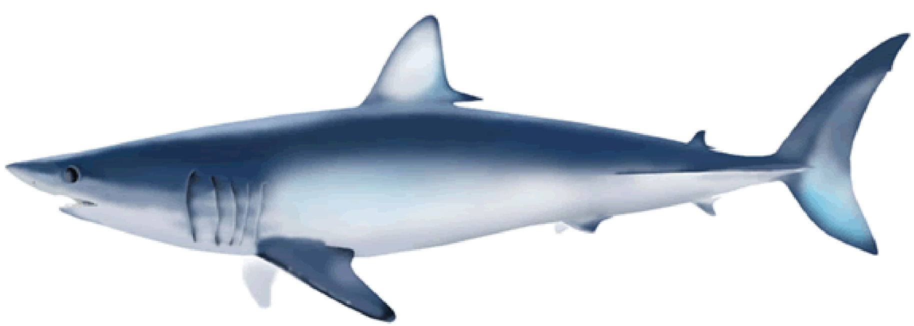

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ABSTRACT

In the present study, the blue shark catch and effort data from observers' records of Taiwanese large longline fishing vessels operating in the North Pacific Ocean from 2004-2011 were analyzed. Due to 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 by zero inflated negative binomial model. The analysis of standardized CPUE showed a stable increasing trend for blue sharks. The results suggested that the blue shark stock in the North Pacific Ocean seems at the level of optimum utilization. The results in this study are preliminary and further investigation is needed.

1. Introduction

Blue shark is the major shark by-catch species of Taiwanese large longline fishery. Since FAO and international environmental groups has paid a lot of attention to 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 data have been confounded with many factors, such as under-reporting and target-shifting effects. Therefore, the observer program for the large longline fishery was conducted to obtain detailed data for more comprehensive stock assessment and management studies. Recently, the increase of coverage rate of observations enable us to get a better estimation of shark by-catch. Thus, the objective of this study is to update the historical catches and CPUE of blue shark in the North Pacific based on observers' records.

A large proportion of zero values is common in by-catch data obtained from fisheries studies involving counts of abundance or CPUE standardization. Zero-inflated modeling, which can account for a large proportion of zero values, is an appropriate approach to modeling zero-heavy data (Lambert 1992; Hall 2000). As sharks are common by-catch species, the zero inflated negative binomial (ZINB) model was also applied to address these excessive zeros of shark catch for CPUE standardization in this study.

2. Material and methods

The logbook data of Taiwanese large scale longline fishery from 1971 to 2011, 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 14 species including major tunas, billfishes and sharks. The species-specific catch data including tunas, billfishes, and sharks from observers' records in 2004-2011 were used to standardize CPUE of blue shark of Taiwanese large scale longline fishery in the North Pacific Ocean. In addition, the standardized CPUE was applied to back-estimate the historical blue shark catch.

Blue sharks caught by Taiwanese large scale longline fishery were mainly observed in the equatorial waters (**Figure 1**). Based on the suggestion of the ISC shark working group in 2012, the North Pacific Ocean was stratified as 2 areas namely A (north of 30ºN) and B (0ºN-30ºN).

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For standardization, CPUE was calculated by set of operations based on observers's records during the period of 2004-2011. The area strata used for the analysis were shown in **Figure 2**.

A large proportion of sets with zero catch of blue shark (50.10%) was found in observers' records. Hence, to address these excessive zeros, the Zero inflated Negative Binomial model (ZINB) was applied to the CPUE standardization of blue sharks. 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.nb function of the mass library of statistical computing language R (R Development Core and Team, 2005) to eliminate some biases by change of targeting species, fishing ground and fishing seasons.

The standardized CPUE series for blue shark was constructed without interaction. The model could then be described as:

Catch= Year + Quarter + Area + ε

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.

Empirical confidence intervals for standardized CPUE were calculated using a bootstrap resampling method. The historical blue shark catch in number can be back-estimated by using the equation below:

Catch_{back} = standardized CPUE × logbook effort
(The standardized CPUE before 2004 is substituted by using the average value of 2004-2011)

As the weight records were incomplete and might be biased, the catch in weight of blue shark was estimated using the multiplication of mean weight and catch in number. The mean weight of blue shark used in this study was 41.1 kg (Huang, 2006). Annual blue shark catch were obtained by using the back-estimated catch in weight divided by coverage rate.

3. Results and discussion

The blue shark bycatch data are characterized by many zero values and a long right tail (**Figure 3**). Overall, there were 50.10% of sets had zero bycatch of blue sharks.

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The standardized CPUE series for the blue shark using the zero inflated negative binomial model was shown in **Figures 4**. The standardized CPUE trend contains the combined effects from two models, one that calculates the probability of a zero observation and one that estimates the count per year.

The nominal CPUE of blue shark showed a strong inter-annual oscillation. This high variability was greatly reduced in the standardized CPUE series. Standardized CPUE series of the blue sharks caught by Taiwanese longline fishery showed a stable increasing trend (**Figure 4**). This stable trend suggested that the blue shark stock in the North Pacific Ocean seems at the level of optimum utilization.

The diagnostic results from the ZINB model (**Figures 5**) do not show any significant trend in the plots of the residuals against the model covariates. **Figure 6** shows the standard diagnostics of residuals vs. fitted, Pearson residuals vs. fitted, QQ plot and a histogram of the residuals. The plots of the Pearson residuals vs. the covariates for the variables were shown in **Figures 7-8**.

Estimated blue shark by-catch in number ranged from 13 in 1973 to 49,256 in 2011. The blue shark by-catch in weight ranged from 1 ton (1973) to 2,024 tons (2011) in the North Pacific Ocean (**Table 1**).

The back-estimations of historical blue shark by-catch in this report were based on observers' records from 2004-2011. However, 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 North Pacific (Bigelow *et al.*, 1999), and bigeye tuna in Indian Ocean (Okamoto *et al.*, 2001). In this report, environmental effects were not included in the model for standardization. Consequently, due to the short time series in CPUE standardization, the results in this report are preliminary and further investigation is needed.

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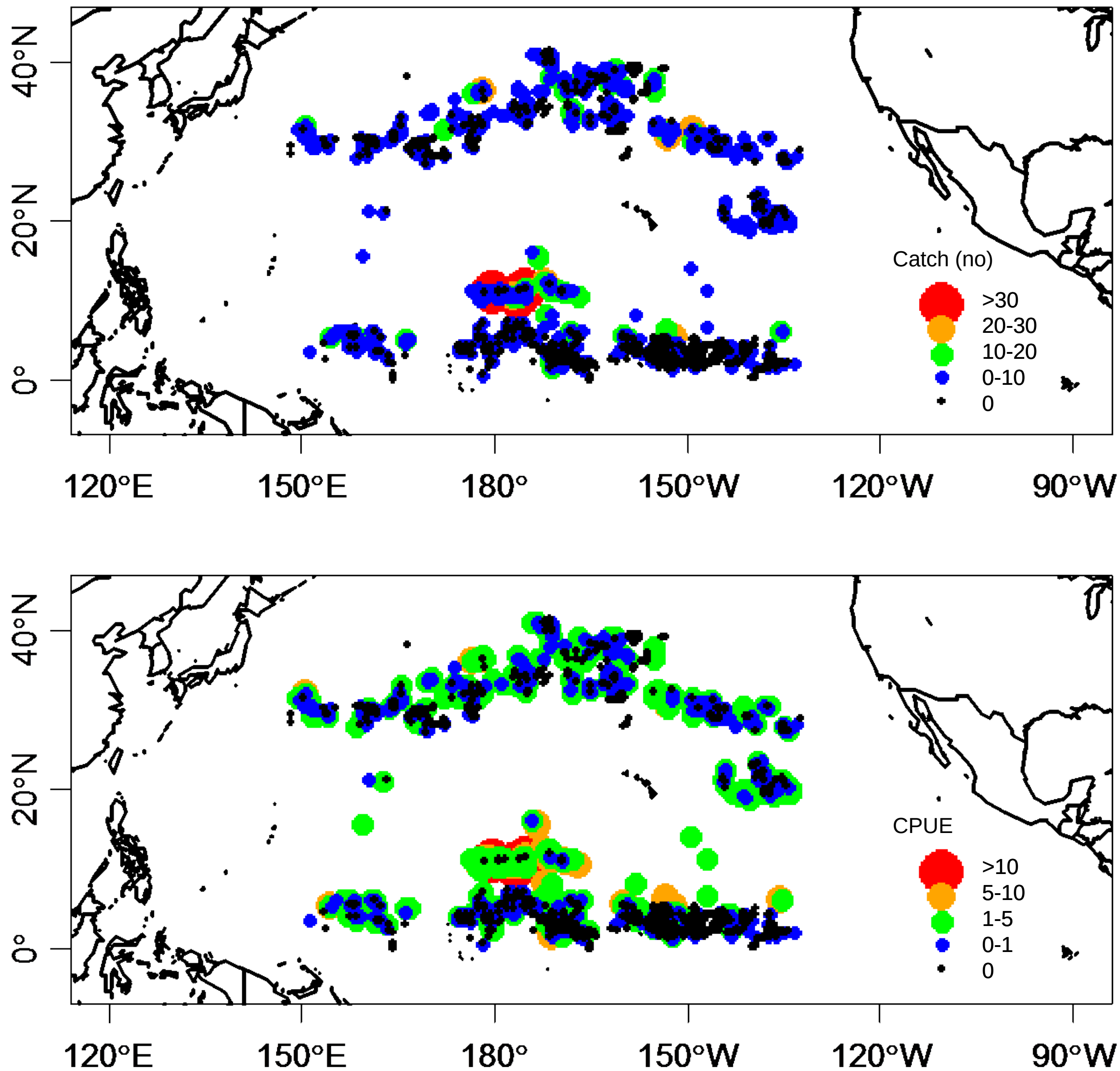

Figure 1. Distribution of fishing effort of Taiwanese tuna longline fisheries for observed blue shark catch and zero catch events from 2004-2011.

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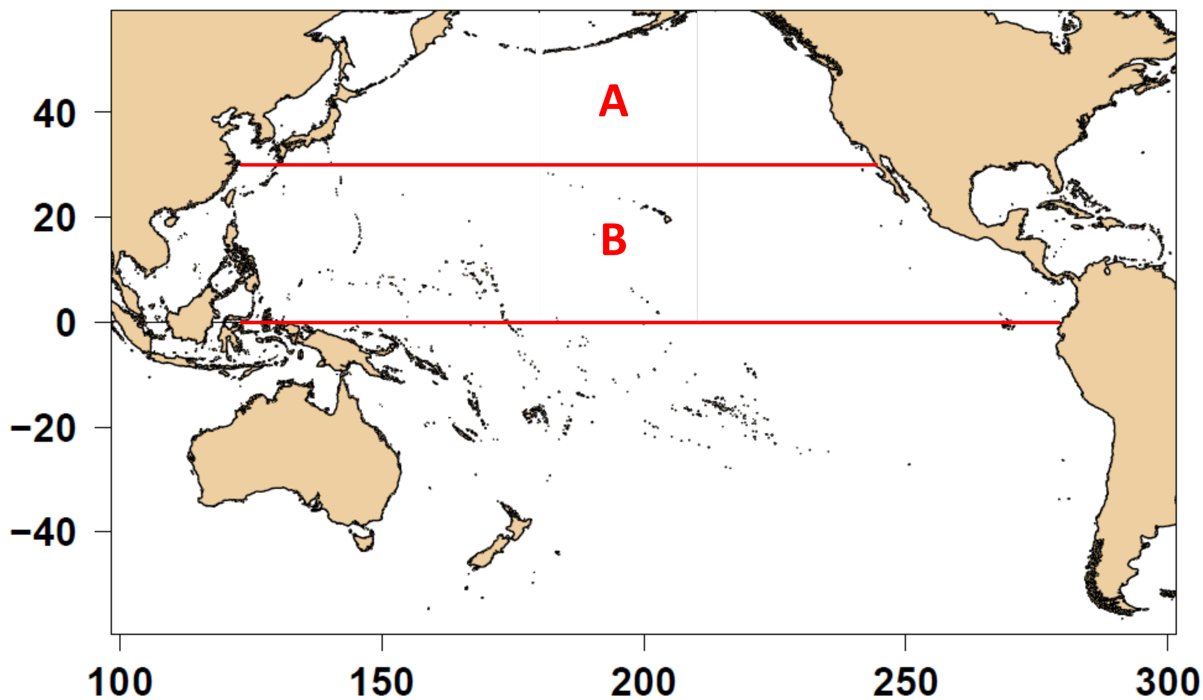

Figure 2. Area stratification used for the estimate of shark by-catch of the Taiwanese longline fishery in North Pacific Ocean.

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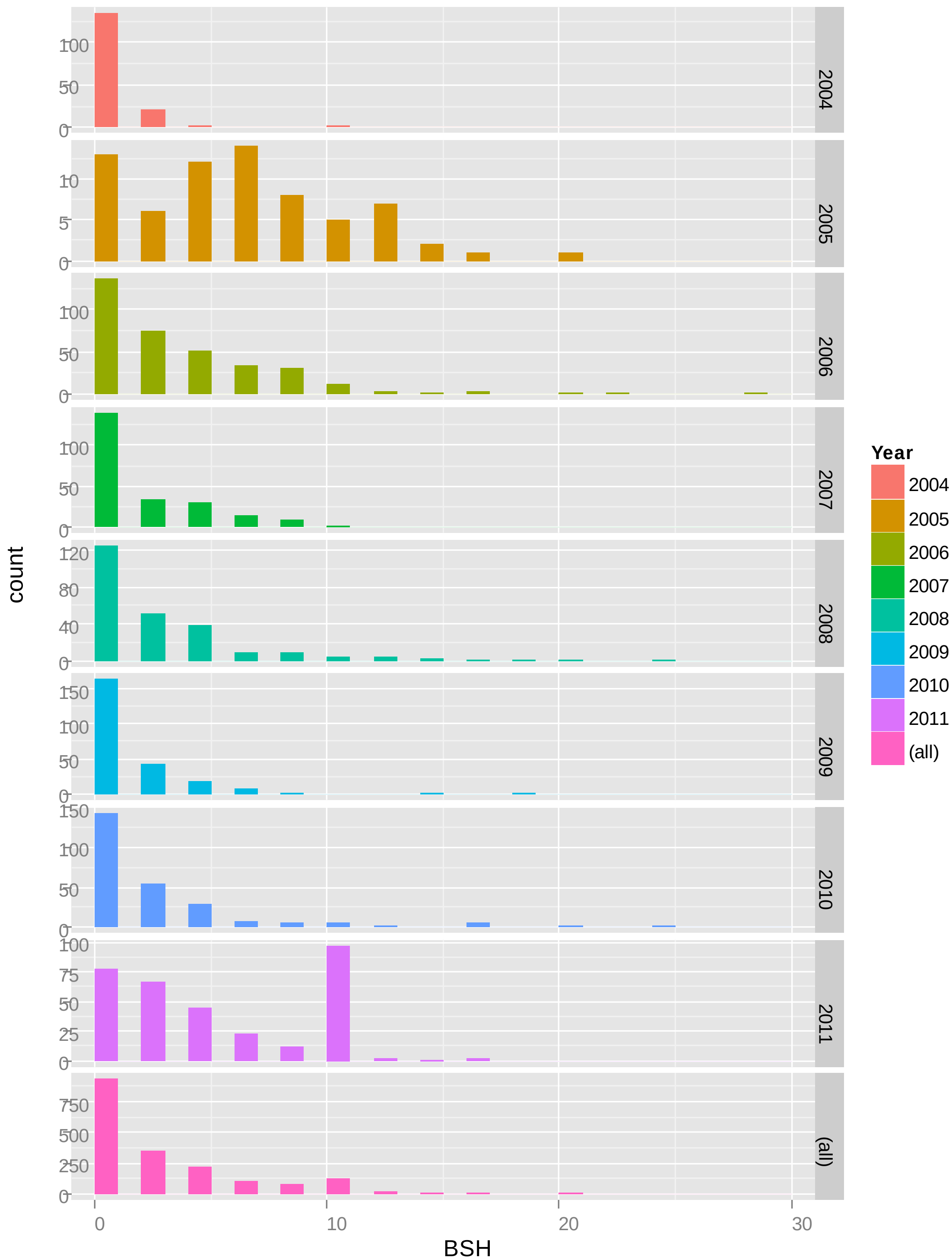

Figure 3. Frequency distribution of blue shark bycatch per set, 2004–2011.

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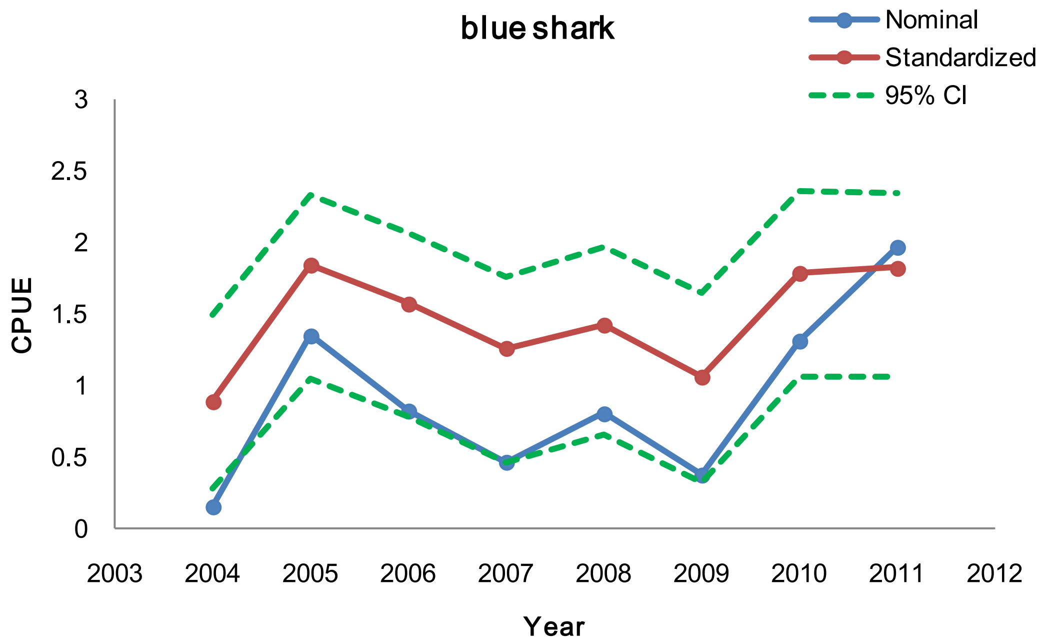

Figure 4. Nominal and standardized CPUE with 95% CI of blue shark by Taiwanese longline fisheries from 2004 to 2011.

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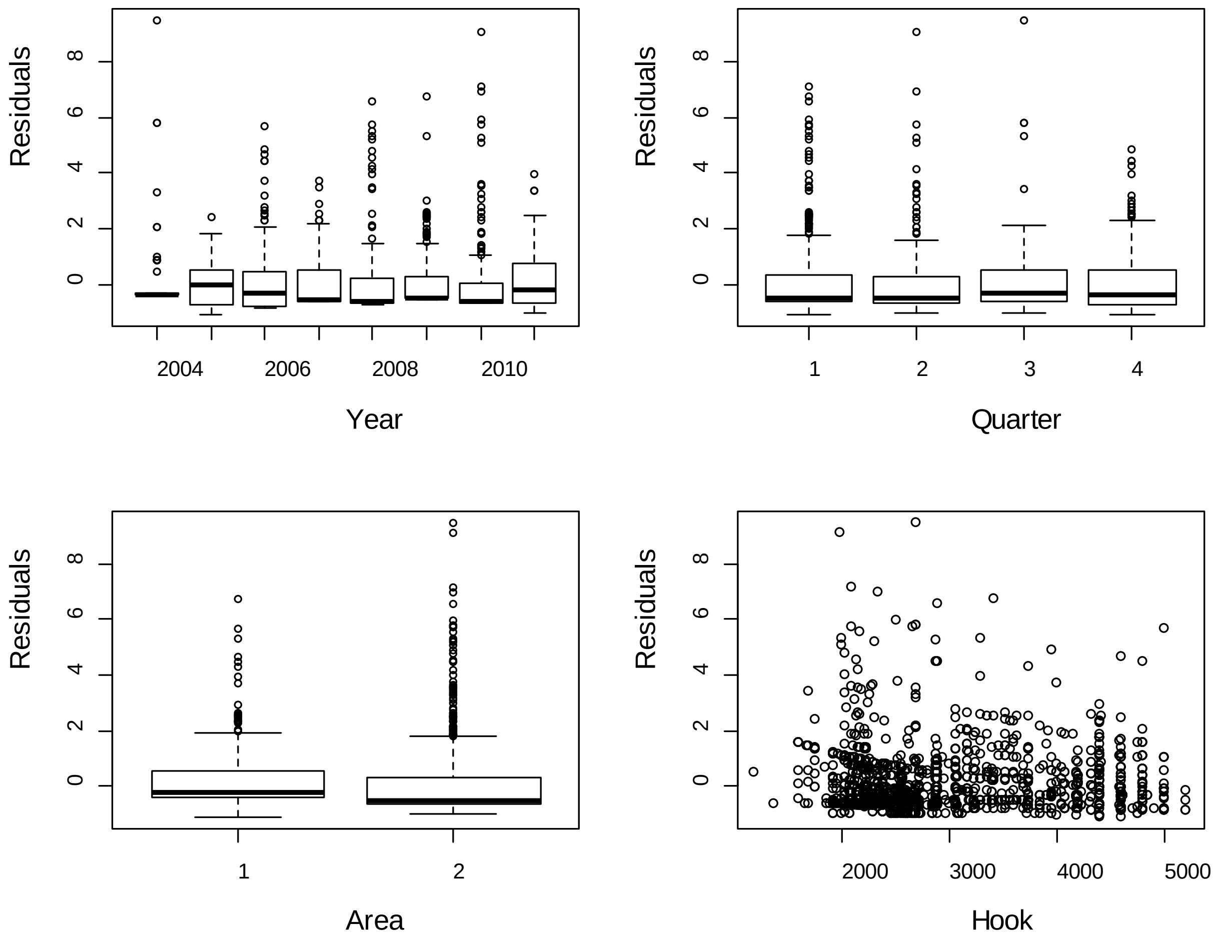

Figure 5. Plots of the Pearson residuals vs. the covariates for the variables Year, Quarter, Area and Hook.

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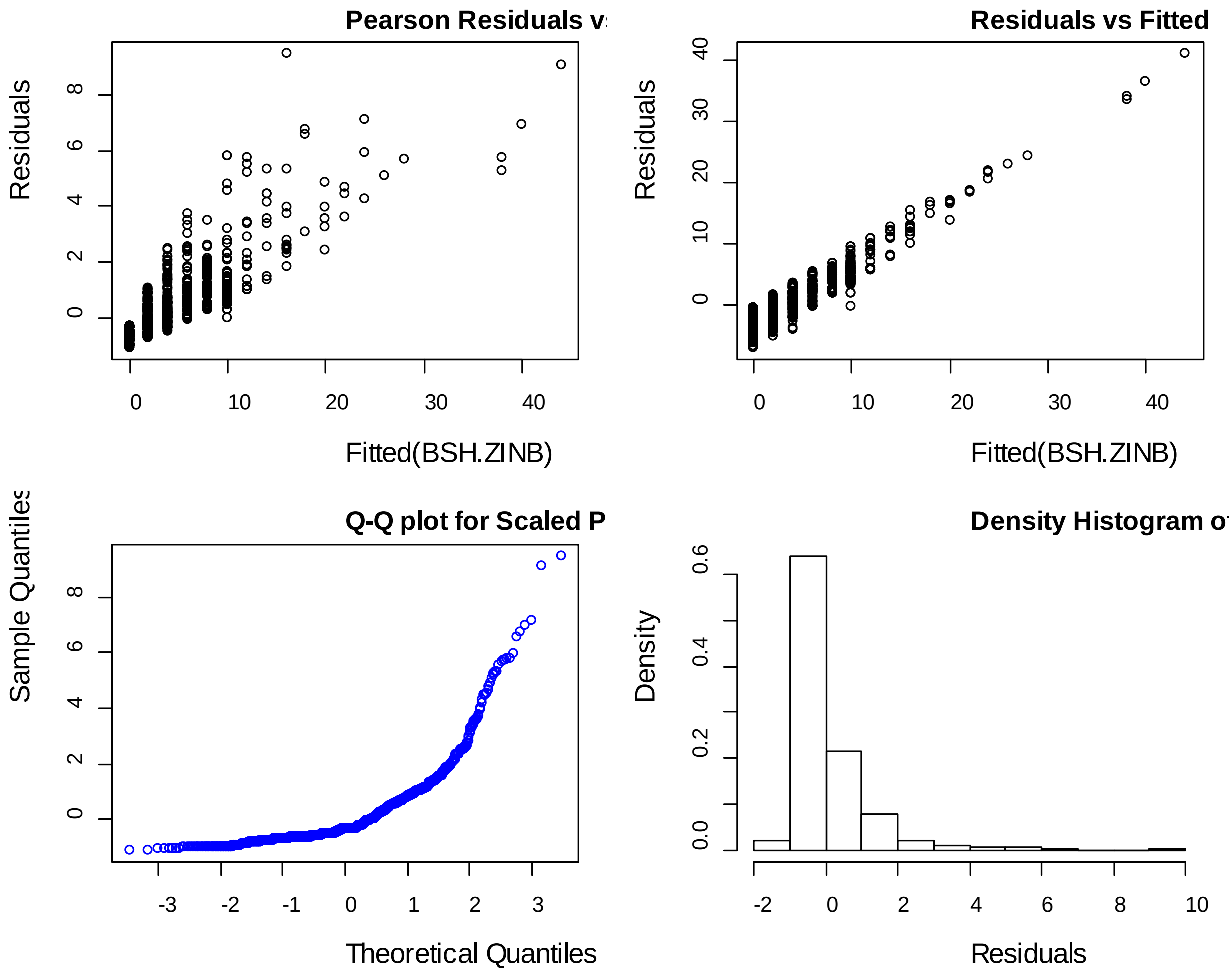

Figure 6. Diagnostic results from the ZINB model fit to the longline blue shark bycatch data.

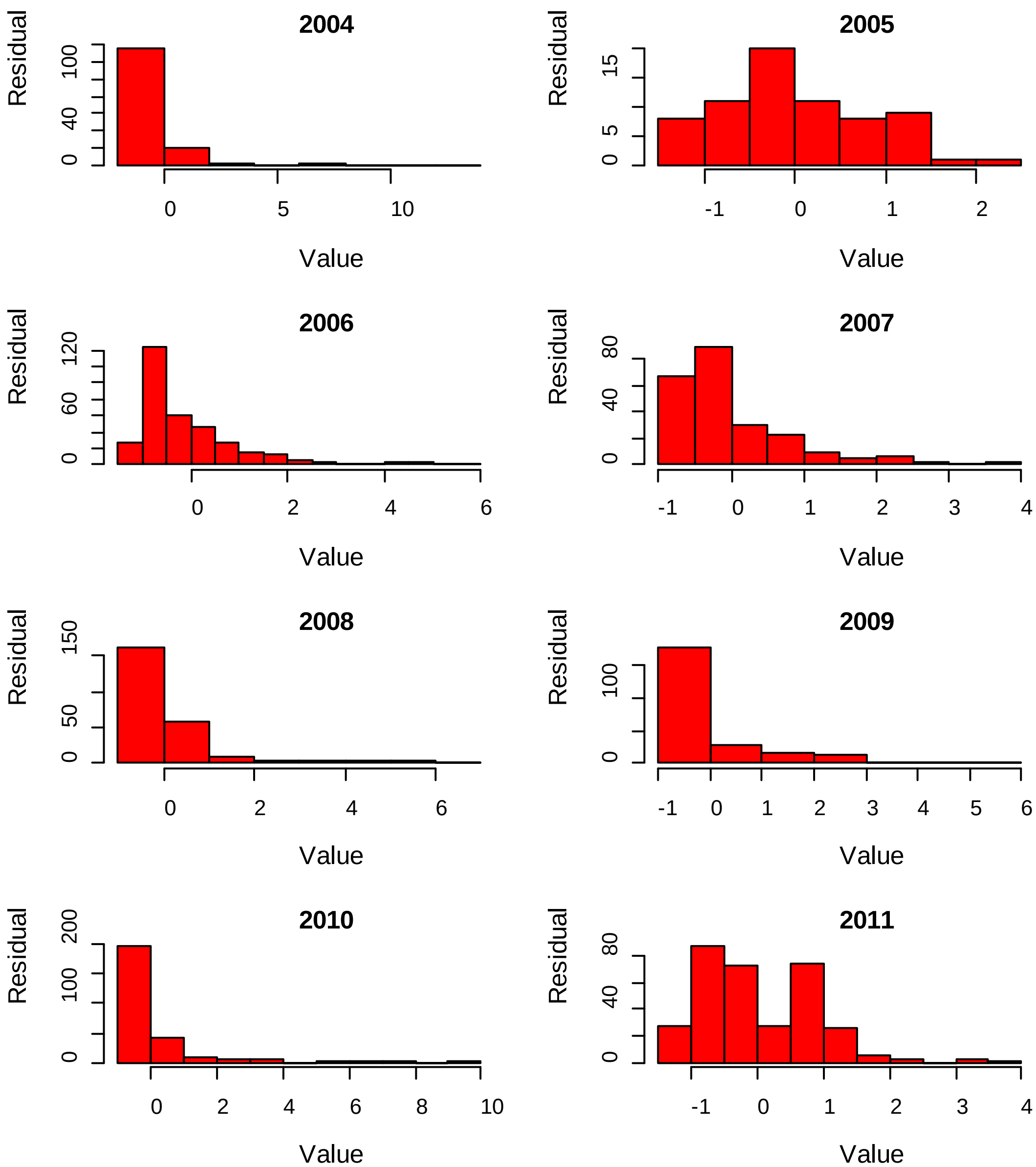

Figure 7. Annual residual plots from the ZINB model fit to the longline blue shark bycatch data.

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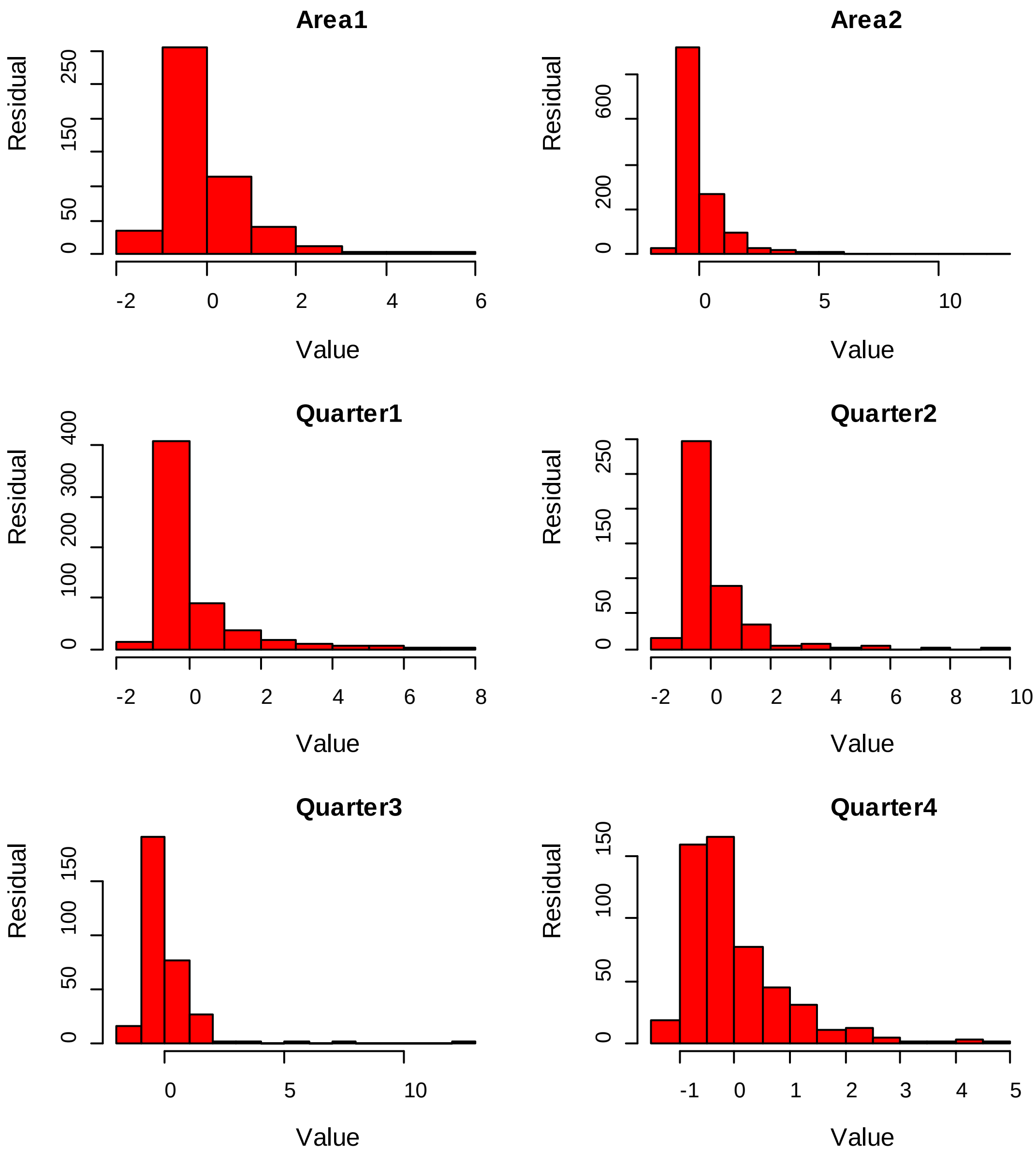

Figure 8. Plots of the Pearson residuals vs. the covariates for the variables.

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Table 1. Estimated annual blue shark by-catch in number and weight (ton) of the Taiwanese tuna longline fishery in the North Pacific Ocean.

Year	EstBSH (N)	EstBSH (ton)
1971	177	7
1972	167	7
1973	13	1
1974	4924	202
1975	7374	303
1976	293	12
1977	1777	73
1978	2198	90
1979	534	22
1980	1676	69
1981	1465	60
1982	189	8
1983	181	7
1984	13	1
1985	4232	174
1986	5072	208
1987	2075	85
1988	380	16
1989	1982	81
1990	7951	327
1991	8502	349
1992	2778	114
1993	2195	90
1994	453	19
1995	23548	968
1996	10139	417
1997	11821	486
1998	12415	510
1999	22989	945
2000	25220	1037
2001	36289	1491
2002	50058	2057
2003	28656	1178
2004	26821	1102
2005	42678	1754
2006	35158	1445
2007	26157	1075
2008	24503	1007
2009	12859	529
2010	15811	650
2011	49256	2024

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Appendix 1. Deviance tables for the zero Inflated negative binomial model (ZINB).

```
Count model coefficients (negbin with log link):
            Estimate Std. Error z value Pr(>|z|)    
(Intercept) -7.21617    0.21008 -34.349  < 2e-16 ***
Year2005     0.48883    0.24086   2.029  0.04241 *  
Year2006     0.30482    0.20329   1.499  0.13376    
Year2007     0.05517    0.22738   0.243  0.80828    
Year2008     0.49686    0.20478   2.426  0.01526 *  
Year2009     0.24486    0.22399   1.093  0.27431    
Year2010     1.00462    0.19768   5.082 3.73e-07 ***
Year2011     0.98317    0.18812   5.226 1.73e-07 ***
Quarter2     0.46417    0.08669   5.354 8.60e-08 ***
Quarter3     0.42727    0.09360   4.565 4.99e-06 ***
Quarter4     0.26401    0.08443   3.127  0.00177 ** 
Area2       -0.04545    0.08345  -0.545  0.58598    
Log(theta)   0.83672    0.08471   9.878  < 2e-16 ***

Zero-inflation model coefficients (binomial with logit link):
            Estimate Std. Error z value Pr(>|z|)    
(Intercept)  0.75574    0.28409   2.660  0.00781 ** 
Year2005    -3.10725    0.50343  -6.172 6.74e-10 ***
Year2006    -2.54852    0.27858  -9.148  < 2e-16 ***
Year2007    -1.58601    0.28897  -5.488 4.05e-08 ***
Year2008    -1.90851    0.28392  -6.722 1.79e-11 ***
Year2009    -1.38961    0.30936  -4.492 7.06e-06 ***
Year2010    -2.21064    0.30252  -7.307 2.72e-13 ***
Year2011    -3.67524    0.30107 -12.207  < 2e-16 ***
Quarter2    -0.05747    0.16430  -0.350  0.72648    
Quarter3    -0.29040    0.20132  -1.442  0.14917    
Quarter4     0.33148    0.18614   1.781  0.07494 .  
Area2        1.54055    0.17952   8.582  < 2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1 

Theta = 2.3088 
Number of iterations in BFGS optimization: 1 
Log-likelihood: -3540 on 25 Df
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