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## **Update on the CPUE standardization of the blue shark caught by the Taiwanese large-scale tuna longline fishery in the Indian Ocean**

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### **SUMMARY**

The catches and efforts of the blue shark in the Indian Ocean were estimated based on the observers' records (2005-2020) of Taiwanese tuna longline fisheries. 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 (DLN) that treats the proportion of positive sets and the CPUE of positive catches separately. The standardized CPUE showed a stable increasing trend for blue sharks from 2005 to 2014 (the second peak), although decreased in 2015, it increased again in 2016. Overall, the standardized CPUE series of the blue shark caught by Taiwanese longline fishery showed a stable trend. The stable trend suggested that blue shark stocks in the Indian Ocean seems at the level of optimum utilization.

### **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 in the logbook 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” in the logbook has been further separated into four sub-categories namely the blue shark, *Prionace glauca*, mako shark, *Isurus spp.*, silky shark, *Carcharhinus 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 have concerned about 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 the 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 in the coverage rate of observations enabled us to get a better estimation of shark by-catch. Therefore, it is useful to examine recent trends in the 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.

## 2. Material and methods

### 2.1. Source of data

Data were collected across the Indian Ocean by scientific fishery observers from the Overseas Fisheries Development Council of the Republic of China onboard Taiwanese large longline vessels. Between 2005 and 2020, data from a total of 25,472 longline sets were collected, which amounted to a total effort of 55,489,511 hooks and yielded 33,170 blue sharks. The summary of these data was shown in **Table 1**. Due to the catch rate of blue sharks might be affected by the changes of targeting species, fishing ground, and fishing seasons, we considered several effects in our models, including fishing

strategy and spatial–temporal influence. For standardization, CPUE was calculated by set of operations based on observers' records during the period of 2005-2020.

## 2.2. CPUE standardization

A large proportion of sets with zero catch of blue sharks (about 56%) 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 GLM models, one model is used to estimate the proportion of positive catches 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, 2020) 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-quarter (YrQtr), latitude-longitude (LatLong), hooks per basket (HPBC), vessel size (CTNO) and target species (GRP). Additionally, we fit a smoothing spline to the vessel operational hooks data and input it in the both model, as an effort factors. For the DLN modeling, the catch rates of the positive catch events (sets with positive blue shark catch) were modeled assuming a lognormal error distribution:

$$\ln(\text{CPUE}) = \mu + \text{YrQtr} + \text{LatLong} + \text{HPBC} + \text{ns}(\text{Hooks}, 10) + \text{CTNO} + \text{GRP} + \text{HPBC} * \text{GRP} + \varepsilon_1 \quad (1)$$

where  $\mu$  is the mean, HPBC\*GRP are interaction terms,  $\varepsilon_1$  is a normal random error term. The effect of gear configuration of HPBC was categorized into the four classes of 1-5, 6-9, 10-15, and >15, vessel size was categorized into three classes (CTNO, CT5; CT6; CT7), and target species was categorized into four classes (GRP, ALB; BET; YFT; SBT, Fig.1). To calculate the proportion of positive records we used a model assuming a binomial error distribution ( $\varepsilon_2$ ):

$$\text{PA} = \mu + \text{YrQtr} + \text{LatLong} + \text{HPBC} + \text{ns}(\text{Hooks}, 10) + \text{CTNO} + \text{GRP} + \text{HPBC} : \text{GRP} + \varepsilon_2 \quad (2)$$

The best model for both Lognormal and Binominal models were selected using the stepwise AIC method (Venables and Ripley, 2002). The final estimate of annual abundance index was obtained by the product of the marginal year means (Lo *et al.*, 1992).

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

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 spatial distribution of efforts, catch and CPUE of blue sharks for Taiwanese large tuna longline fishery in the Indian Ocean from 2005 to 2020 was showed in **Fig.2**. The blue shark bycatch data from the Taiwanese large longline fishery characterized by many zero values. Overall, 56.44% 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

$$\ln(\text{CPUE}) = \mu + \text{YrQr} + \text{LatLong} + \text{HPBC} + \text{ns}(\text{Hooks}, 10) + \text{CTNO} + \text{GRP} + \text{HPBC} * \text{GRP} + \varepsilon_1$$

$$\text{PA} = \mu + \text{YrQr} + \text{LatLong} + \text{HPBC} + \text{ns}(\text{Hooks}, 10) + \text{CTNO} + \text{GRP} + \text{HPBC} : \text{GRP} + \varepsilon_2$$

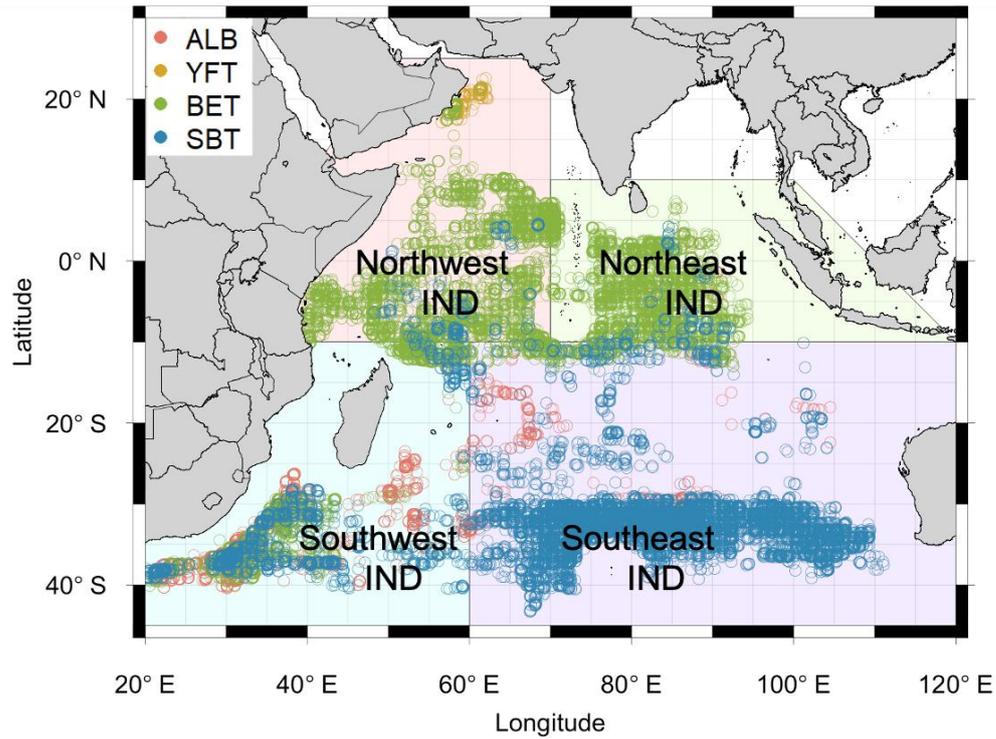
The best models were then used in the later analyses.

Standardized CPUE series of the blue shark in the Indian Ocean using the DLN model were shown in **Figure 3**. The detail values for nominal and standardized CPUE were listed in **Tables 3**. 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 an inter-annual fluctuation, particularly in years 2007 and 2009 (**Fig. 3**). However, this 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. 3**). These stable trends suggested that the blue shark stock in the Indian Ocean seems at the level of optimum utilization during the period of 2005-2020.

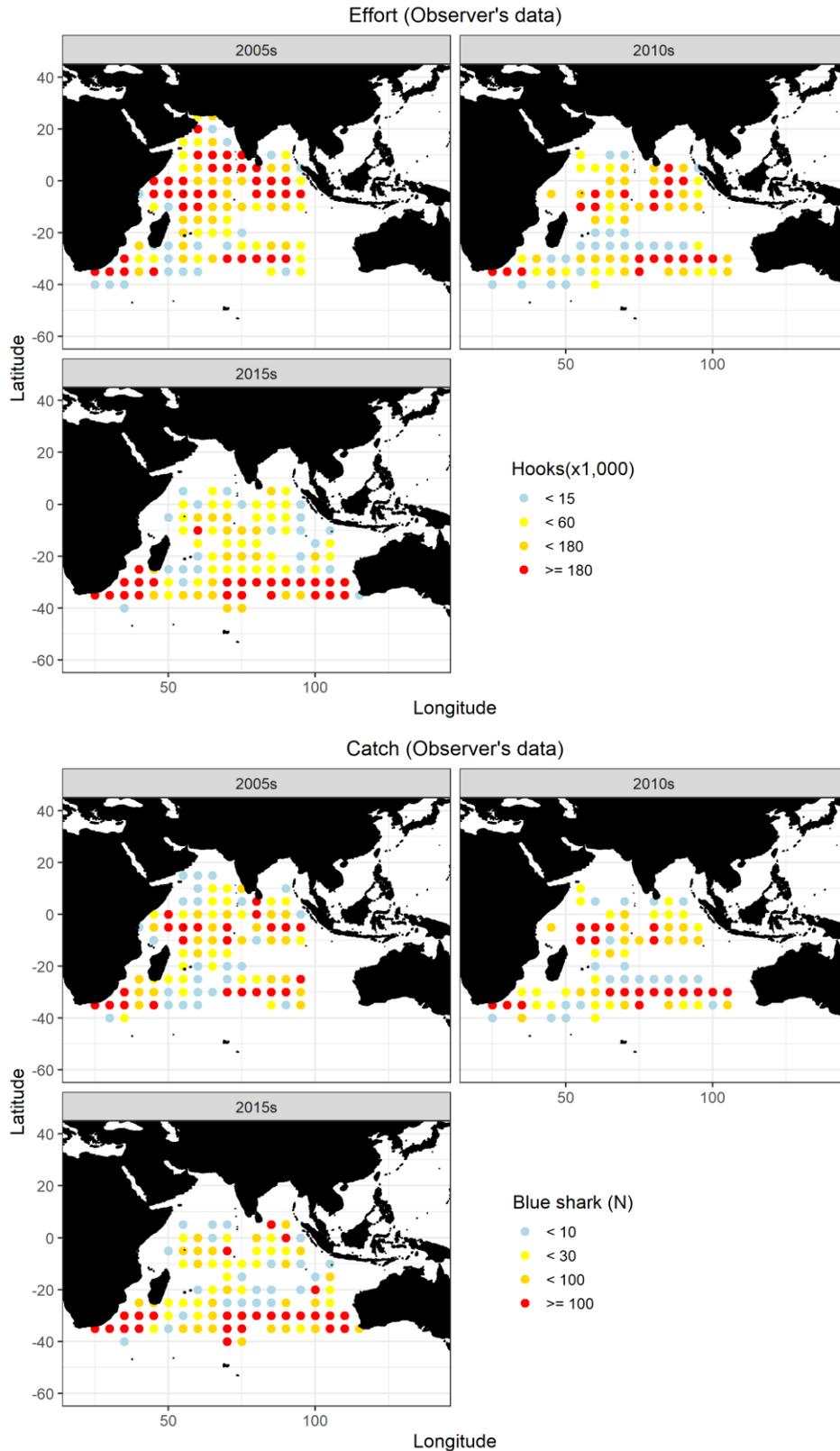
The diagnostic results from the DLN model do not indicate any severe departure from model assumptions (**Figs. 4-5**). Additionally, the influence plot for the Lognormal model are provided in **Appendix**. The ANOVA tables for each model are given in **Table 4**. Most main effects and interaction terms tested were significant (mostly  $P < 0.01$ ) and have been included in the final model, except interaction term (HPBC\*GRP) effects in the Log-normal model ( $P = 0.45$ ). 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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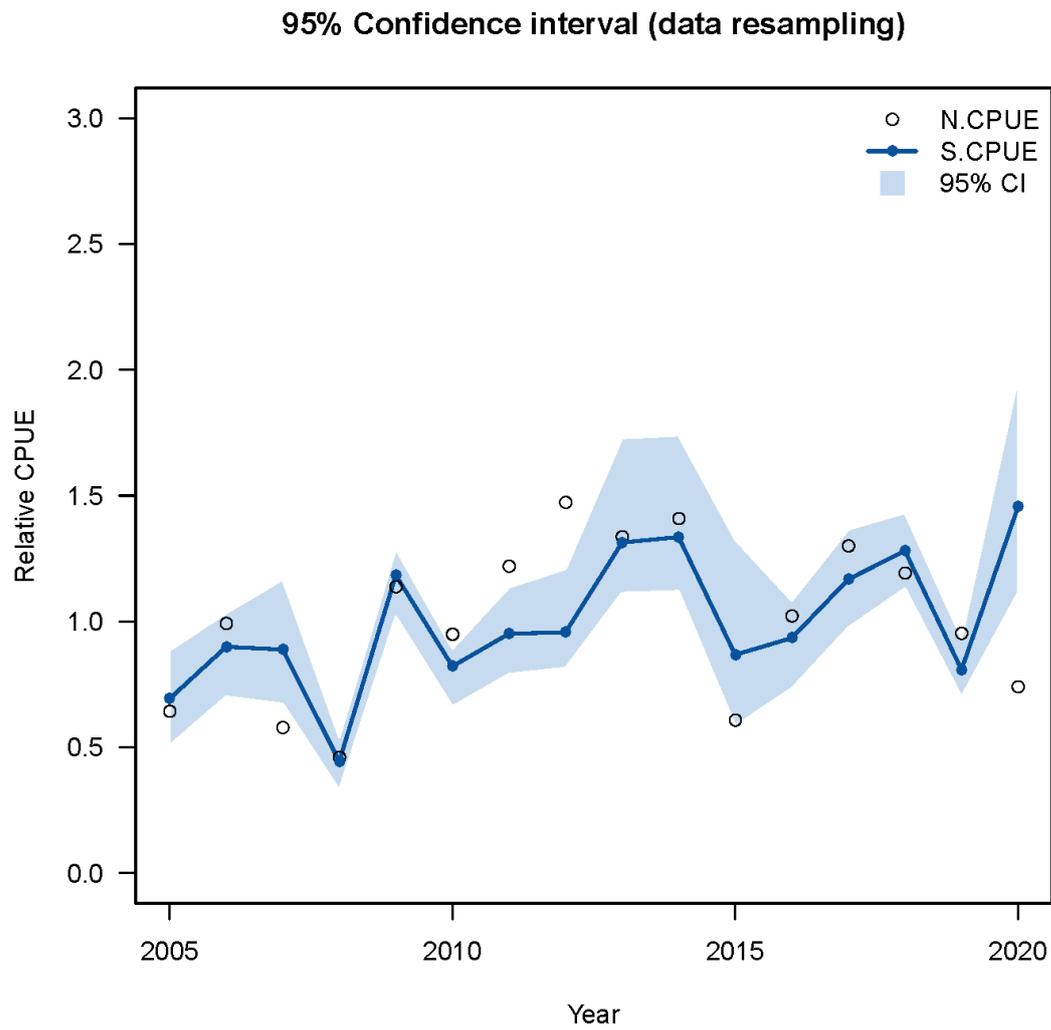
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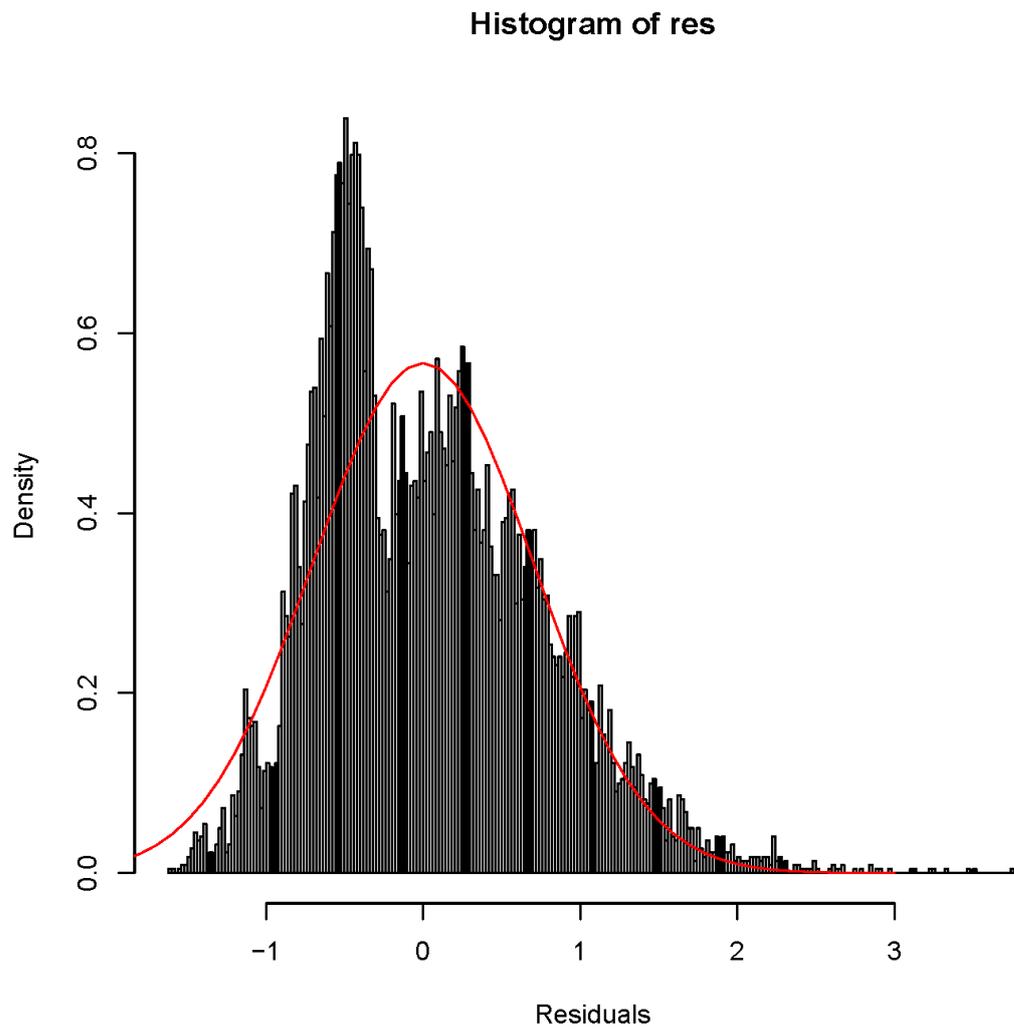
**Figure 1.** The observed effort distributions of the Taiwanese large-scale tuna longline fishery in the Indian Ocean from 2005 to 2020. Red circles: albacore fleet (ALB); Yellow circles: yellowfin tuna fleet (YFT); Green circles: bigeye tuna fleet (BET); Blue circles: southern bluefin tuna fleet (SBT).



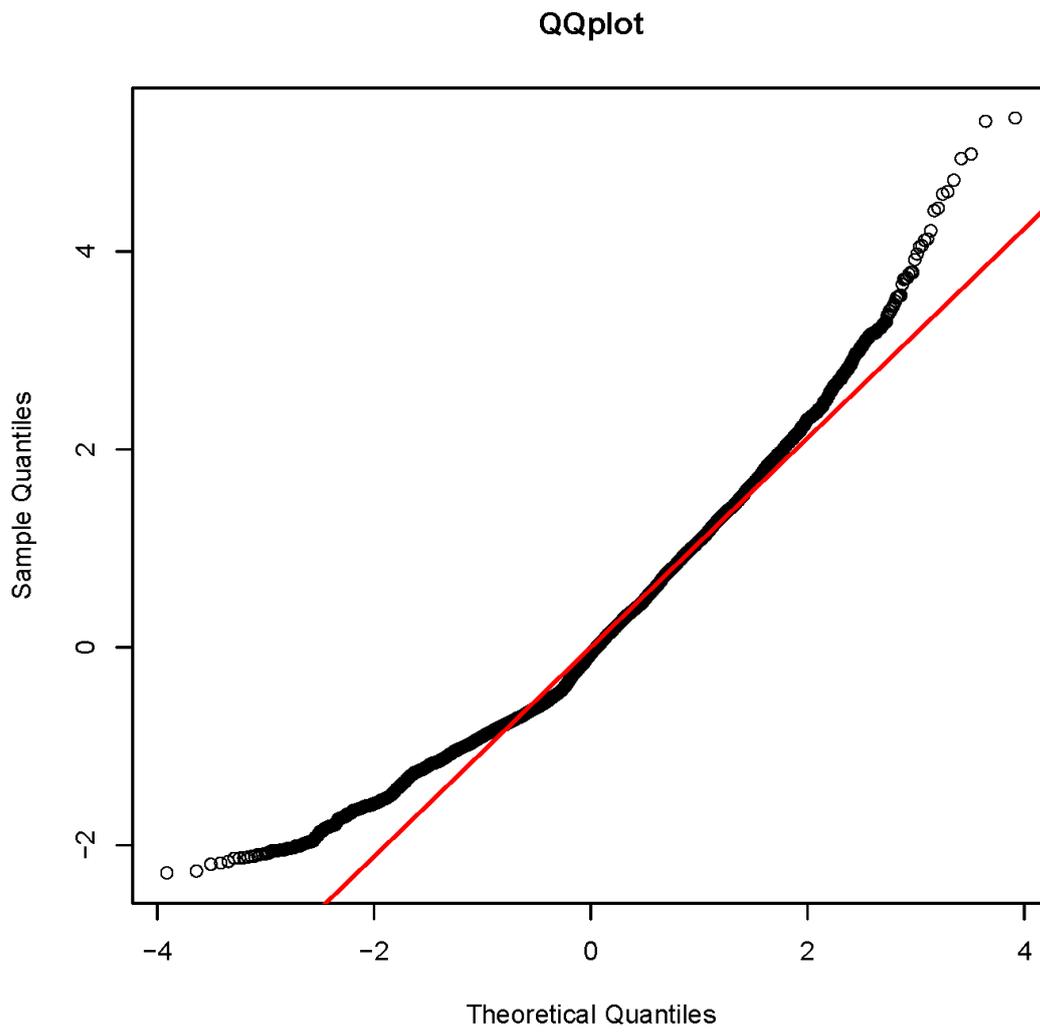
**Figure 2.** The spatial distribution of observed efforts and blue shark catches for Taiwanese tuna longline vessels in the Indian Ocean from 2005 to 2020 (2005s: 2005-2009; 2010s: 2010-2014; 2015s: 2015-2020).



**Figure 3.** The observed nominal and standardized BPUE with 95% CI of blue shark by Taiwanese longline vessels in the Indian Ocean from 2005 to 2020.



**Figure 1.** Residual histogram from the GLM model fit to the Indian Ocean longline blue shark bycatch data.



**Figure 5.** Q-Q plots for the GLM model fit to the Indian Ocean longline blue shark bycatch data.

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

Year	Indian Ocean		
	No. of Sets	No. of Hooks	No. of blue shark catches
2005	592	1,418,853	561
2006	624	1,419,307	866
2007	2,441	5,687,204	2,022
2008	1,781	4,244,936	1,201
2009	2,183	5,323,131	3,726
2010	2,274	5,482,599	3,200
2011	764	1,891,751	1,423
2012	506	1,175,039	1,065
2013	1,212	2,458,764	2,022
2014	1,270	2,541,816	2,203
2015	1,089	2,154,457	805
2016	1,684	3,408,190	2,142
2017	1,894	3,870,576	3,096
2018	2,109	4,238,252	3,109
2019	2,832	5,669,997	3,231
2020	2,217	4,504,639	2,498
Average	1,592	3,468,094	2,073

**Table 2.** The observed percentage of zero-catch of blue shark for Taiwanese tuna longline vessels in the Indian Ocean from 2005 to 2020.

Year	Percentage of zero-catch
2005	59.03%
2006	58.11%
2007	61.86%
2008	67.99%
2009	73.51%
2010	50.98%
2011	53.89%
2012	53.27%
2013	52.77%
2014	47.94%
2015	49.84%
2016	62.90%
2017	56.95%
2018	47.10%
2019	47.73%
2020	58.75%
Average	56.27%

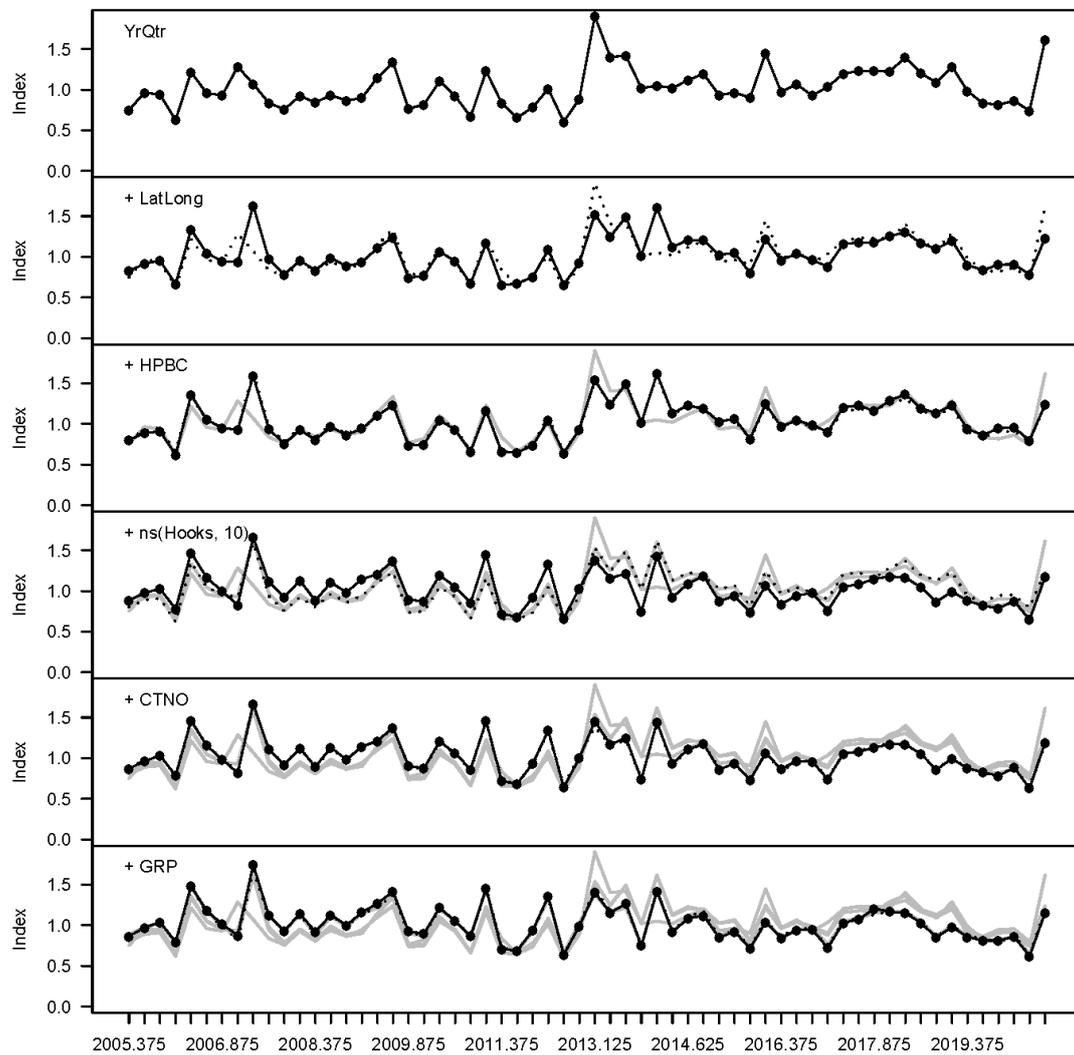
**Table 3.** Estimated nominal and standardized CPUE values for blue shark of the Taiwanese tuna longline fishery in the North Atlantic Ocean.

Year	Nominal	Standardized
2005	0.39539	0.23353
2006	0.61016	0.30309
2007	0.35554	0.29947
2008	0.28293	0.14961
2009	0.69996	0.39905
2010	0.58366	0.27694
2011	0.75008	0.32069
2012	0.90635	0.32248
2013	0.82236	0.44281
2014	0.86670	0.45013
2015	0.37364	0.29241
2016	0.62849	0.31494
2017	0.79988	0.39352
2018	0.73356	0.43178
2019	0.58591	0.27238
2020	0.45525	0.49059

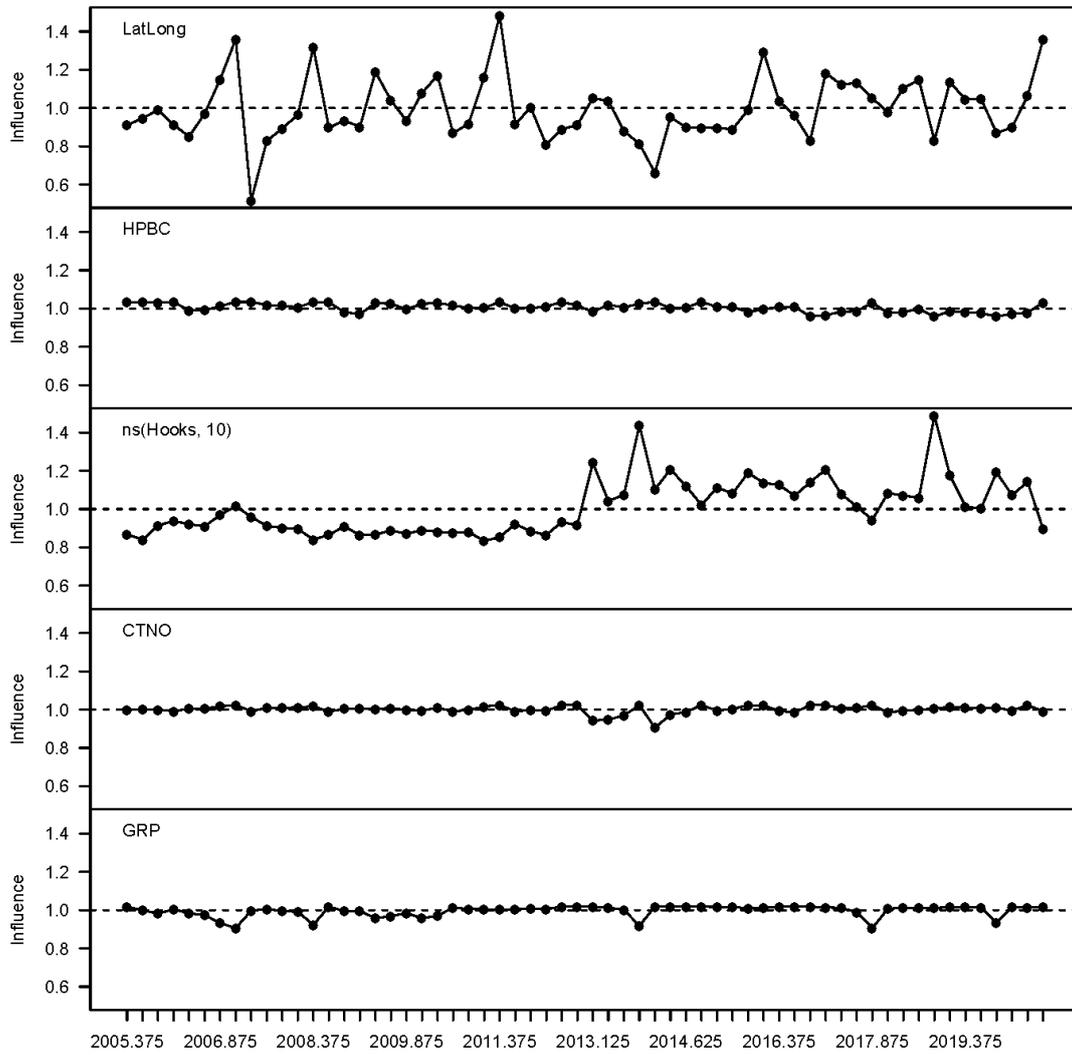
**Table 1.** Deviance tables for the DLN model of blue shark.

<b>Log-normal Model</b>						
	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL			11028	520.47		
YrQtr	59	42.588	10969	477.89	19.7702	< 0.001 ***
LatLong	129	60.742	10840	417.14	12.8965	< 0.001 ***
HPBC	2	1.323	10838	415.82	18.1205	< 0.001 ***
ns(Hooks, 10)	10	19.377	10828	396.44	53.0724	< 0.001 ***
CTNO	2	0.798	10826	395.65	10.9228	< 0.001 ***
GRP	3	0.497	10823	395.15	4.5388	< 0.01 **
HPBC:GRP	2	0.058	10821	395.09	0.7916	0.453
<b>Binomial Model</b>						
	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)
NULL			25197	34540		
YrQtr	59	1376.53	25138	33163	23.3310	< 0.001 ***
LatLong	139	2009.33	24999	31154	14.4556	< 0.001 ***
HPBC	2	53.34	24997	31100	26.6707	< 0.001 ***
ns(Hooks, 10)	10	56.74	24987	31044	5.6743	< 0.001 ***
CTNO	2	14.17	24985	31029	7.0844	< 0.001 ***
GRP	4	64.71	24981	30965	16.1777	< 0.001 ***
HPBC:GRP	2	19.26	24979	30945	9.6317	< 0.001 ***

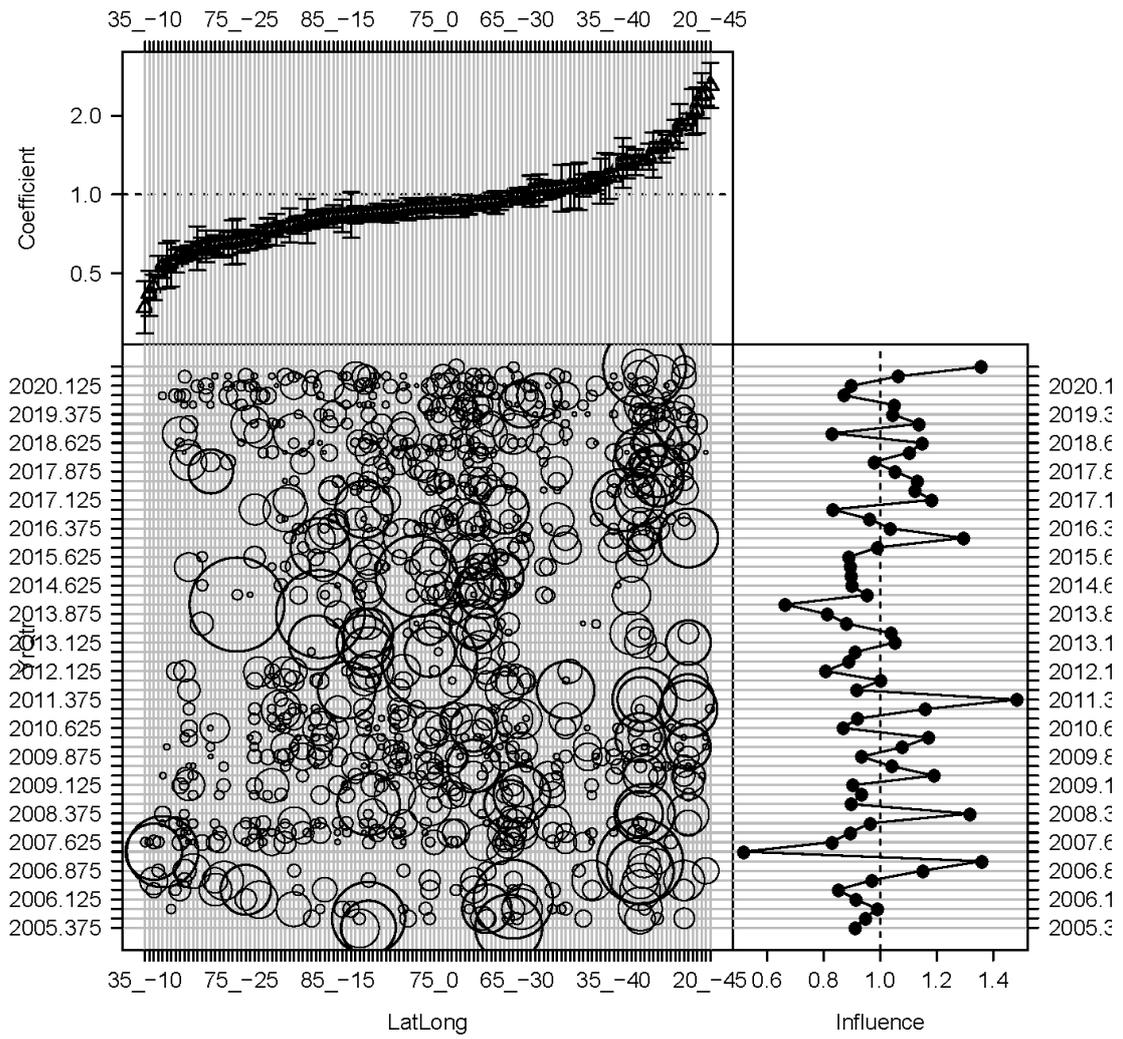
## Appendix



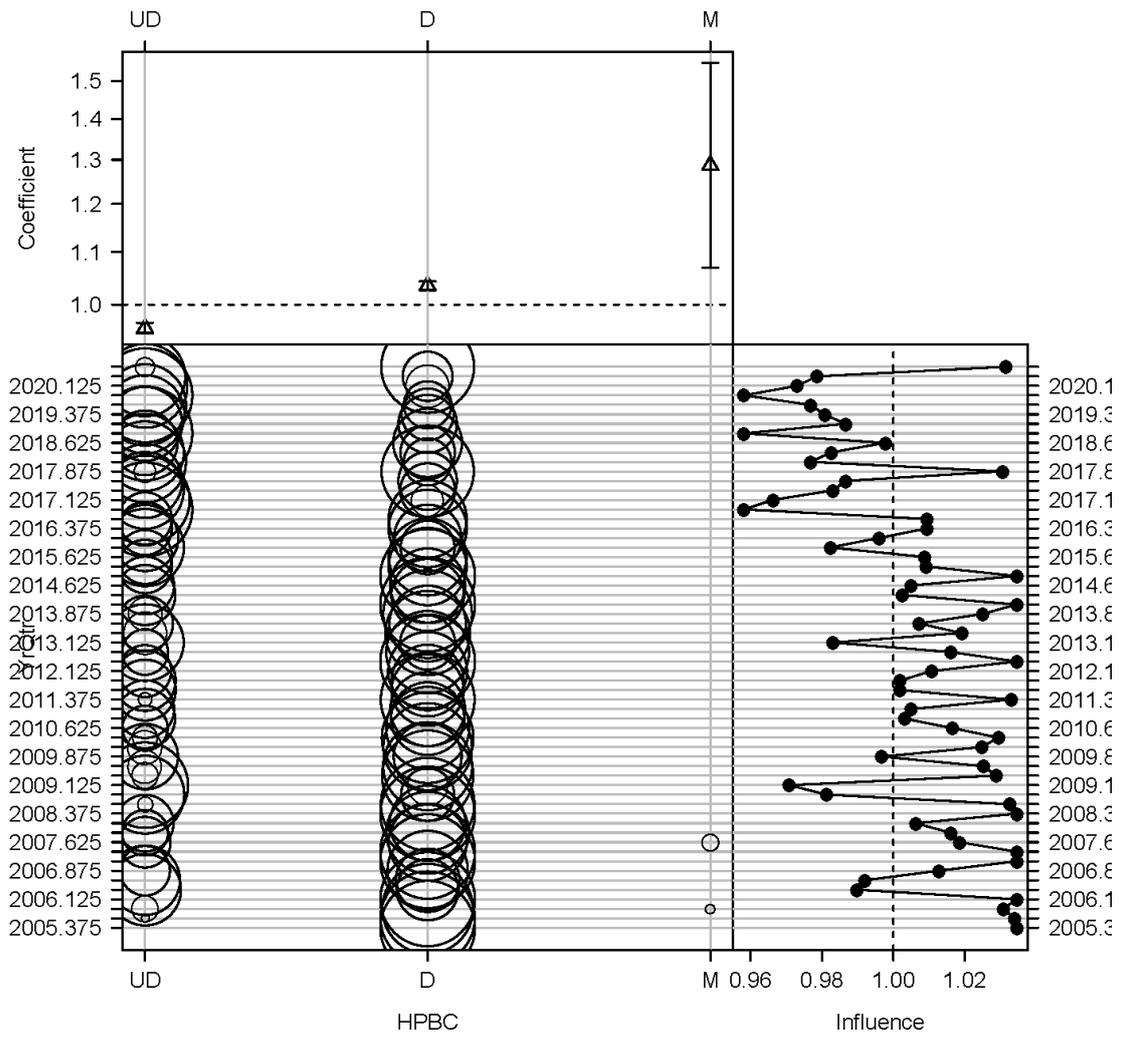
**Appendix Fig. 1.** Influence plots shows the change in the CPUE time series caused by each covariate for blue shark CPUE in the Indian Ocean by the Taiwanese fleet.



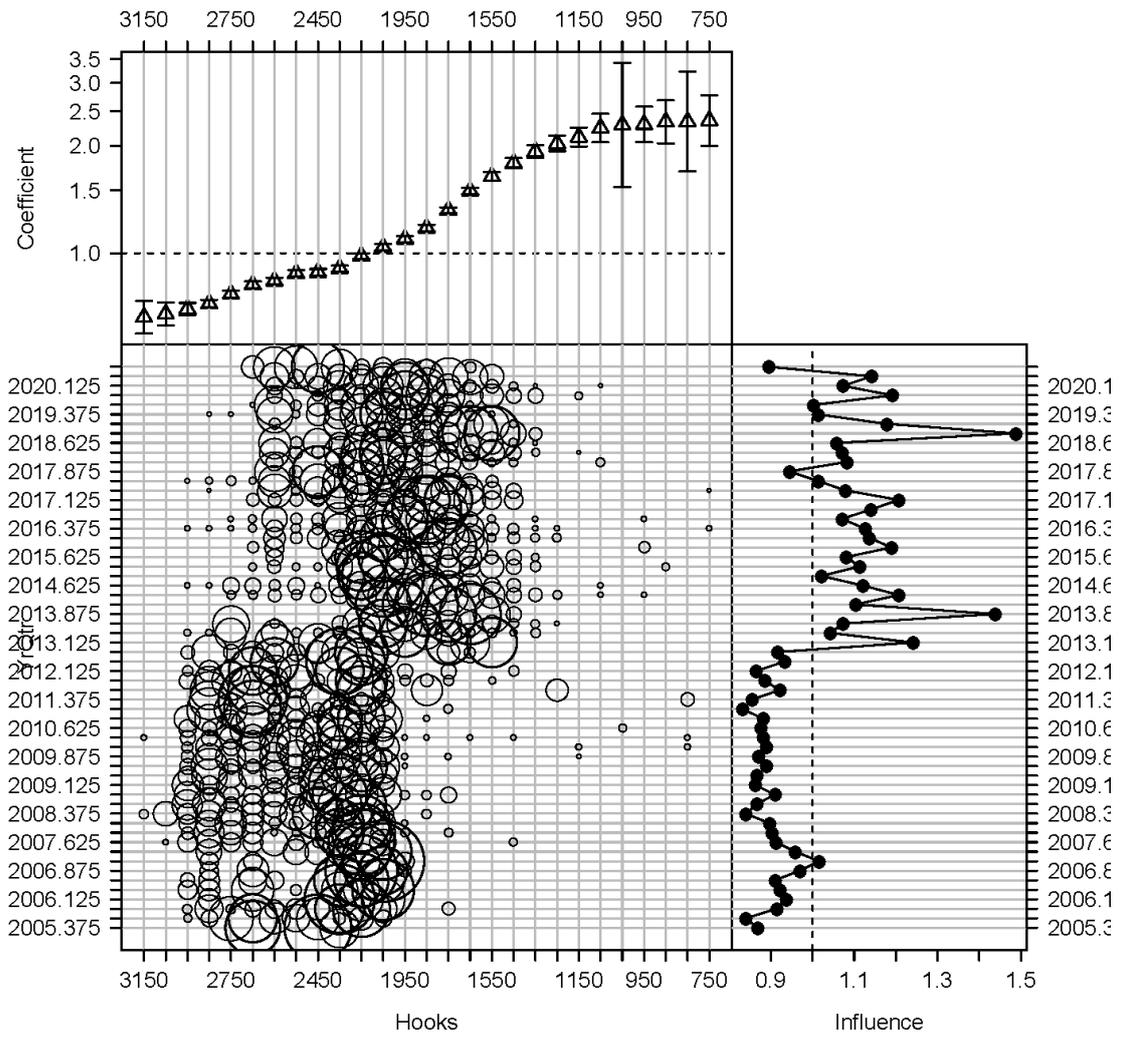
**Appendix Fig. 2.** The Influence plots shows the change in the CPUE time series caused by each covariate.



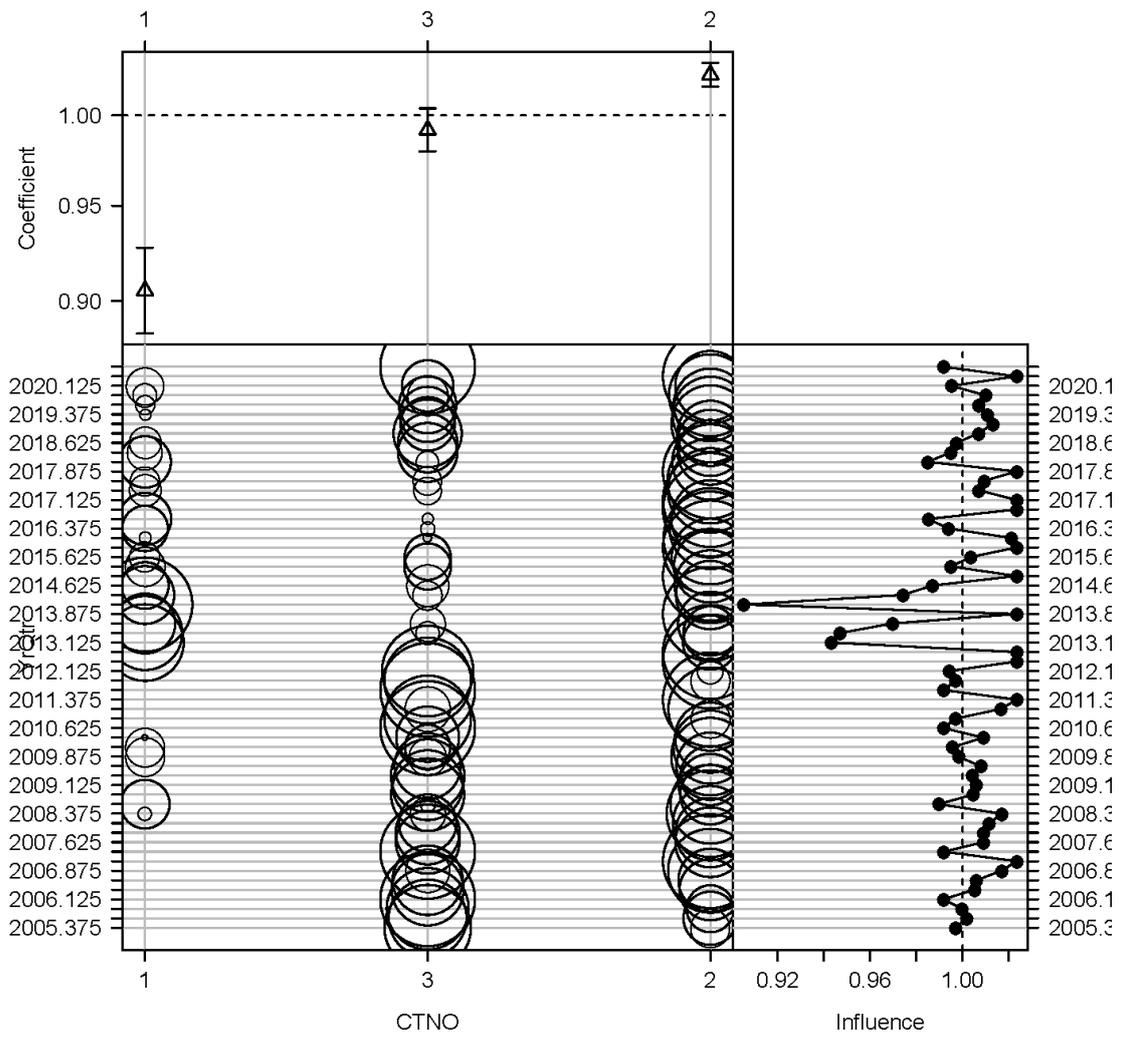
**Appendix Fig. 3.** The Influence plots shows the influence of the LatLong effect.



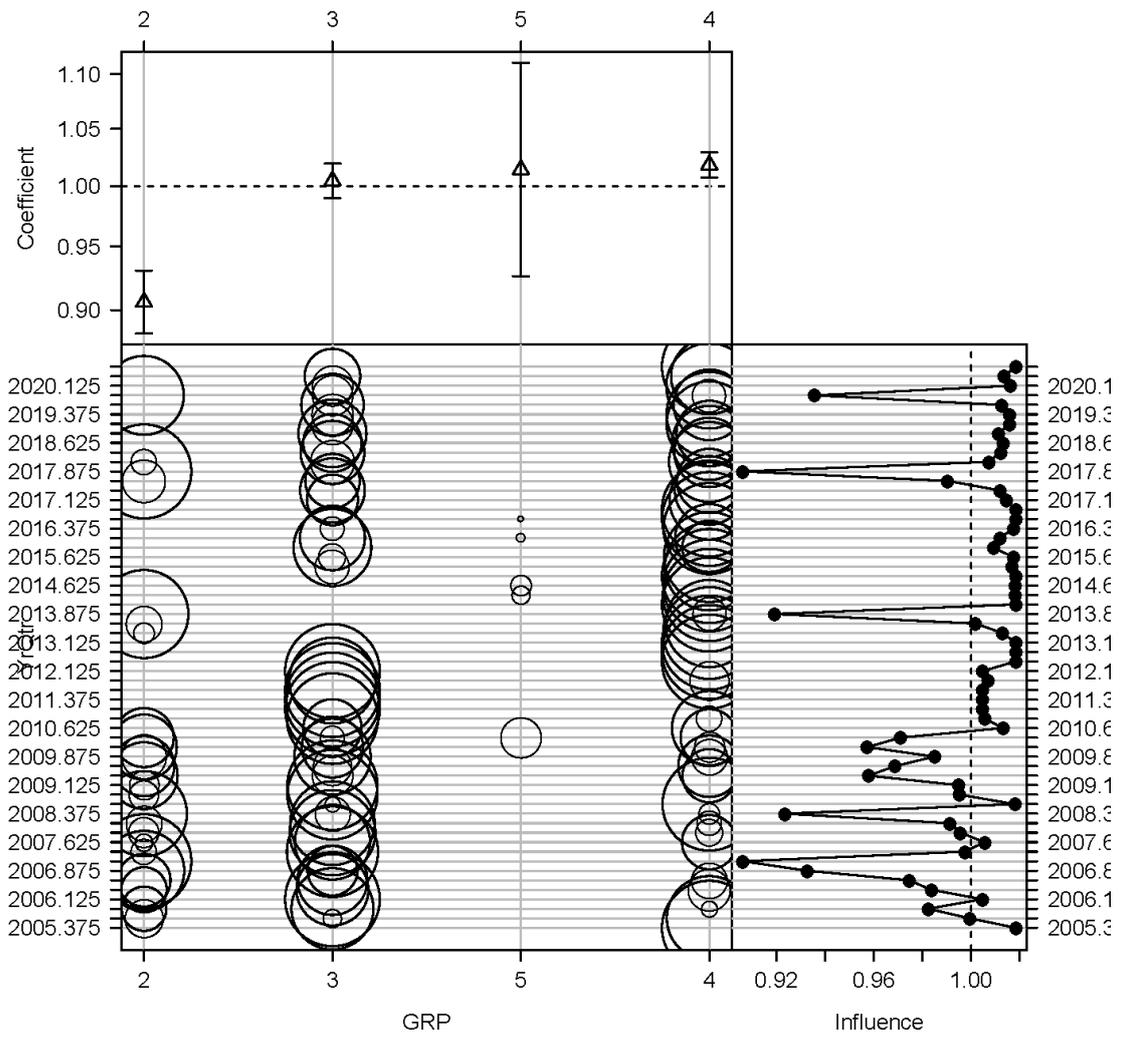
**Appendix Fig. 4.** The Influence plots shows the influence of the HPBC effect.



**Appendix Fig. 5.** The Influence plots shows the influence of the Hooks effect.



**Appendix Fig. 6.** The Influence plots shows the influence of the CTNO effect.



**Appendix Fig. 7.** The Influence plots shows the influence of the GRP effect.