Receieved: 3, 17 & 23 September 2013

CPUE standardization of striped marlin (*Kajikia audax*) caught by Taiwanese longline fishery in the Indian Ocean

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ABSTRACT

This study provided a CPUE standardization of striped marlin (*Kajikia audax*) caught by the Taiwanese longline fishery in the Indian Ocean for time periods of 1980-2011 and 1995-2011. The delta-lognormal GLM model is adopted to perform the CPUE standardization analysis since blue marlin is caught by Taiwanese longline fleet as bycatch species and large amount of zero catches are recorded in the operational data sets. The results indicate that the influence of incorporating environmental effects on CPUE standardization is not significant for striped marlin in the Indian Ocean. The CPUEs in Area MONS and Coastal area revealed similar trends and they substantially decreased since 1980 although the CPUE obviously fluctuated in early years. The CPUE in Area ISSG fluctuated before 1990, substantially increased between 1990 and 1995, and sharply decreased thereafter. In recent years, CPUEs obviously increased for all three areas. The area-aggregated CPUE obviously fluctuated before 1995 and it revealed obvious and continuous decline trend thereafter, while it slightly increased in recent two years.

1. INTRODUCTION

Based on the report of IOTC WPB (IOTC, 2011), striped marlin are considered to be bycatch of industrial fisheries. Striped marlin are caught almost exclusively under drifting longlines (98%) with remaining catches recorded under gillnets and troll lines. The catches under drifting longlines have been recorded under Taiwan, Japan, Republic of Korea fleets and, recently, Indonesia and several NEI fleets. In recent years, the fleets of Taiwan (longline) and to a lesser extent Indonesia (longline) are attributed with the highest catches of striped marlin. The minimum average annual catch estimated for the period 2005 to 2009 is around 2,779 t.

After 1994, the data of catch and effort with 1-degree resolution and the information of number of hooks between float (NHBF) began to be available. In addition to explore the pattern of relative abundance of striped marlin in the Indian Ocean for the time series from 1980 to 2011, this paper also attempt to the standardize CPUE of striped marlin caught by Taiwanese longline fleet in the Indian Ocean for the period of 1995 to 2011. Since striped marlin are bycatch species of Taiwanese lognline fleet, large amount of zero-catches are recorded from Taiwanese longline fleet and the proportions of zero-catch reached about 70-80% of total operation sets since 1998 (Fig. 1). Historically, ignoring zero observations or replacing them by a constant was the most common approach. Currently, the most popular way to deal with zeros is through the delta approach (Maunder and Punt, 2004). Therefore, the delta-lognormal GLM (Pennington, 1983; Lo et. al., 1992; Pennington, 1996) is applied to standardize the CPUE in this study.

2. MATERIALS AND METHODS

2.1. Catch and Effort data

In this study, daily set-by-set catch and effort data (logbook) of Taiwanese longline fishery with 5x5 degree grid for 1980-2011 1x1 degree grid for 1995-2011 are provided by Oversea Fisheries Development Council of Taiwan (OFDC). In order to reduce the variability of catch condition of striped marlin for each vessel, the catch and effort data are aggregated to be monthly operational set by set data, i.e. aggregated by year, month, vessel scale (ton-degree), longitude, latitude and NHBF.

2.2. Definition of fishing areas

Based on the comments of IOTC (2012), the ecological geographic areas in the Indian Ocean are adopted as the factor of fishing area for the CPUE standardization (Fig. 2). Area 1 is the Indian Monsoon Gyres Province (MONS); Area 2 is the Indian South Subtropical Gyre Province (ISSG); Area 3 is the Indian Ocean Coastal Biome.

2.3. Environmental data

The details of environmental data used in this study were described in the paper of Nishida et al. (2012).

2.4. CPUE Standardization

The delta-lognormal GLM is applied to standardize the CPUE in this study and the main effects considered in this analysis are year, month, area, vessel scale and NHBF.

The environmental effects included in the model are sheer currents (SC), thermocline depth (TD), and temperature at depth of 15m (T15) and temperature gradient at depth of 15m (TG15). Although the some environmental effects (e.g. TD and SC) likely reveal nonlinear relationship with CPUE and might be considered as categorical effects (Wang and Nishida, 2013), all of environmental effects are still treated as continuous variables for simplifying the model. The time-lags of environmental effects on the CPUE are also taken into account in the model. We linked the time series of CPUE data together with the environmental effects based on the time-lags calculated by Wang and Nishida (2013).

The effect of number of hooks between float (NHBF) are treated as three categories (regular: <=9 hooks; deep: 10-14 hooks; ultra deep: >=15 hooks) (Wang and Nishida, 2011).

As discussions during the meeting of the Working Party on Billfish in 2013, the CPUE standardization analysis is suggested to be carried out based on the data for entire time series of 1980-2011. The CPUEs of bigeye tuna and albacore characterized into 3 categories are incorporated as targeting effects because NHBF is only available after 1994 (Wang et al., 2012). In addition, environmental effects are not considered to be used in the CPUE standardization.

Hinton and Maunder (2004) indicated that interactions with the year effect would invalidate the year effect as an index of abundance. The interactions between environmental effects not considered into the model because there may be high autocorrelation would occur among environmental effects. In addition, vessels with different scales were not operated in entire Indian Ocean for every month and thus the interactions with vessel scale are not considered in the model. For the interactions between effects, therefore, the interactions between the effects of year and area and between the effects of month, area and NHBF are considered in the GLM. The delta and lognormal models are conducted as follows:

Lognormal model for CPUE of positive catch for 1995-2011:

$$\begin{aligned}\log(CPUE) = {} & \mu + Y + M + A + CT + NHBF \\ & + TD + T55 + TG55 + SC + \text{interactions} + \varepsilon^{\log}\end{aligned}$$

Lognormal model for CPUE of positive catch for 1980-2011:

$$\log(CPUE) = \mu + Y + M + A + CT + T\_ALB + T\_BET + \text{interactions} + \varepsilon^{\log}$$

Delta model for presence and absence of positive catch for 1995-2011:

$$PA = \mu + Y + M + A + CT + NHBF + TD + T55 + TG55 + SC + \text{interactions} + \varepsilon^{del}$$

Delta model for presence and absence of positive catch for 1980-2011:

$$PA = \mu + Y + M + A + CT + T\_ALB + T\_BET + \text{interactions} + \varepsilon^{del}$$

where	*CPUE*	is the nominal CPUE of positive catch of striped marlin (catch in number/1,000 hooks),
	PA	is the nominal presence and absence of positive catch,
	μ	is the intercept,
	Y	is the effect of year,
	M	is the effect of month,
	A	is the effect of fishing area,
	CT	is the effect of vessel scale,
	NHBF	is the effect of number of hooks between float,
	T_BET	is the effect of the CPUE of bigeye tuna,
	T_ALB	is the effect of the CPUE of albacore tuna,
	TD	are the environmental effects of thermocline depth,
	T15	are the environmental effects of temperature at depth of 15m,
	TG15	are the environmental effects of temperature gradient at depth of 15m,
	SC	are the environmental effects of sheer currents,
	ε^{log}	is the error term, $\varepsilon^{log} \sim N(0, \sigma^2)$,
	ε^{del}	is the error term, $\varepsilon^{del} \sim Bin(n, p)$.

The area-specific standardized CPUE trends are estimated based on the exponentiations of the adjust means of the interaction between year and area effects (Butterworth, 1996; Maunder and Punt, 2004).

The standardized relative abundance index is calculated by the product of the standardized CPUE of positive catches and the standardized probability of positive catches:

$$index = e^{\log(CPUE)} \times \left(\frac{e^P}{1+e^P} \right)$$

2.5. Adjustment by area size

The estimation of annual nominal and standardized CPUE is calculated from the weighted average of the area indices (Punt et al., 2000).

$$U_y = \sum_a S_a U_{y,a}$$

Where U_y is CPUE for year y,

$U_{y,a}$ is CPUE for year y and area a,

S_a is the relative size of the area a to the four new areas.

The relative sizes of fishing areas are calculated by GIS software and the relative sizes are listed below.

Area 1	Area 2	Area 3
0.297	0.429	0.274

3. RESULTS AND DISCUSSION

Based on the lognormal model selection for 1995 to 2011, the effects of TG15 and SC are excluded from the lognormal model since these effects are not statistically significant. The selected lognormal model is:

$$\begin{aligned}\log(CPUE) &= \mu + Y + M + A + CT + NHBF + TD + T15 \\ &\quad + Y*A + M*A + M*NHBF + A*NHBF\end{aligned}$$

The ANOVA table of the selected lognormal model is shown in the Table 1. Except for the effect of year, the results indicate that the main effect of NHBF is the most significant effect for the model and the secondarily significant main effect is the effects of area. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 3).

Based on the delta model selection for 1995 to 2011, the effect of SC is excluded from the delta model since this effect are not statistically significant. The selected delta model is:

$$PA = \mu + Y + M + A + CT + NHBF + TD + T15 + TG15$$
$$+ Y * A + M * A + M * NHBF + A * NHBF$$

The ANOVA table of the selected delta model is shown in the Table 2. The most explanatory effect for the mode is the effect of TD, and the secondary is the effect of area.

We also examined the CPUE standardizations based on the data from 1995 to 2011without environmental effects. For the lognormal model, all main effects and interactions are statistically significant. The selected lognormal model is:

$$\log(CPUE) = \mu + Y + M + A + CT + NHBF$$
$$+ Y * A + M * A + M * NHBF + A * NHBF$$

The ANOVA table of the selected lognormal model is shown in the Table 3. Except for the effect of year, the results indicate that the main effect of NHBF is the most significant effect for the model and the secondarily significant main effect is the effect of area. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 4).

For the delta model without environmental effects for 1995 to 2011, all main effects and interactions are also statistically significant. The selected lognormal model is:

$$PA = \mu + Y + M + A + CT + NHBF$$
$$+ Y * A + M * A + M * NHBF + A * NHBF$$

The ANOVA table of the selected delta model is shown in the Table 4. The main effect of area is the most significant effect for the model. The secondarily significant main effects are the effects of year and month.

For the delta model selection without environmental effects for 1995 to 2011, all main effects and interactions are also statistically significant. The selected lognormal model is:

$$PA = \mu + Y + M + A + CT + NHBF$$
$$+ Y * A + M * A + M * NHBF + A * NHBF$$

The ANOVA table of the selected delta model is shown in the Table 4. The main effect of area is also the most significant effect for the model. The secondarily significant main effects are the effect of NHBF and vessel scale.

For lognormal model analysis based on the data from 1980 to 2011, all main effects and interactions are statistically significant. The selected lognormal model is:

$$\begin{aligned}\log(CPUE) = \mu + Y + M + A + CT + T\_ALB + T\_BET \\ + Y*A + M*A + M*T\_ALB + M*T\_BET \\ + A*T\_ALB + A*T\_BET + T\_ALB*T\_BET\end{aligned}$$

The ANOVA table of the selected lognormal model is shown in the Table 5. The results indicate that the main effect of area is the most significant effect for the model and the secondarily significant main effect is the effect of the CPUE of albacore tuna. The distribution of residuals adequately conforms to the assumption of normal distribution (Fig. 5).

All main effects and interactions are also statistically significant for the delta model analysis based the data from 1980 to 2011. The selected delta model is:

$$\begin{aligned}PA = \mu + Y + M + A + CT + T\_ALB + T\_BET \\ + Y*A + M*A + M*T\_ALB + M*T\_BET \\ + A*T\_ALB + A*T\_BET + T\_ALB*T\_BET\end{aligned}$$

The ANOVA table of the selected delta model is shown in the Table 6. The most explanatory main effect for the mode is also the effect of area and the secondary are the main effects of the CPUE of bigeye and albacore tuna.

The area-specific nominal and standardized CPUE are shown in Fig. 6. Generally, trends of standardized CPUEs are close to nominal CPUEs. In addition, the trend of CPUE standardized with environmental effects is almost the same with that standardized without environmental effects. The CPUEs in Area 1 (MONS) and Area 3 for (Coastal area) revealed similar trends and they substantially decreased since 1980 although the CPUE obviously fluctuated in early years. The CPUE in Area 2 (ISSG) fluctuated before 1990, substantially increased between 1990 and 1995, and sharply decreased thereafter. In recent years, CPUEs obviously increased for all three areas. For the time period after 1995, the standardized CPUEs based on different data sets revealed quite similar trends for three areas.

Fig. 7 shows the area-aggregated nominal and standardized CPUE of striped marlin in the Indian Ocean. The CPUE obviously fluctuated before 1995 and it revealed obvious and continuous decline trend thereafter, while it slightly increased in recent two years.

ACKNOWLEDGMENTS

We thank Dr. Humber Agrelli Andrade, Universidade Federal Rural de Pernambuco – UFRPE, Brazil, Dr. Rishi Sharma, Fishery Officer (Stock Assessment), Indian Ocean Tuna Commission, and Dr. Rui Coelho, Instituto Português do Mar e da Atmosfera (IPMA), Portugal provided comments that improved the results of this study.

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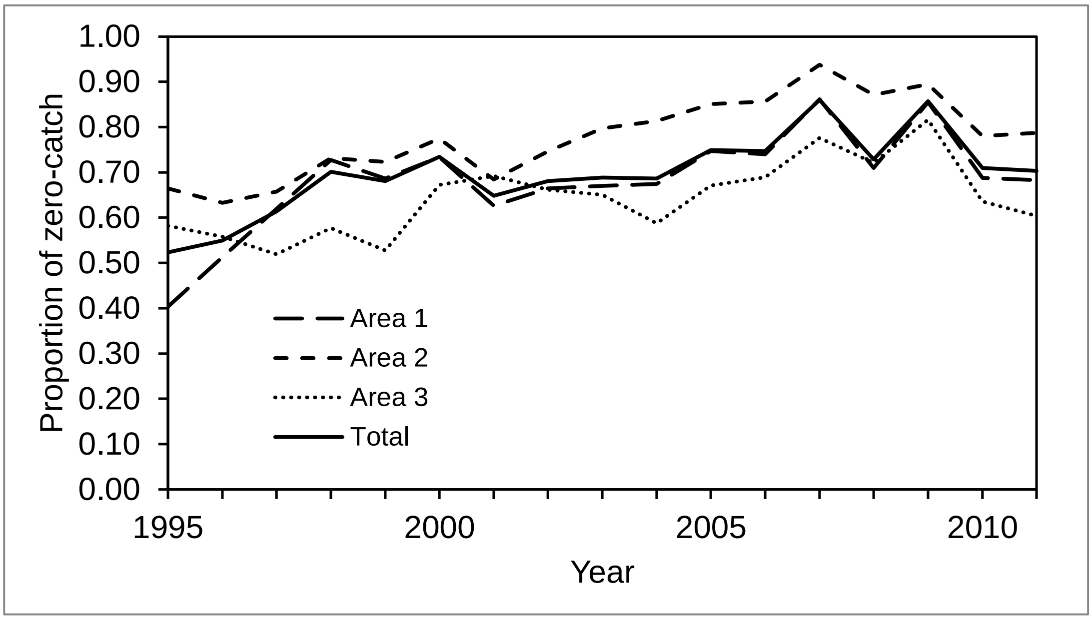

Fig. 1. Annual proportions of operation sets for zero-catch of striped marlin caught by Taiwanese longline fleet for three ecological areas and for entire Indian Ocean.

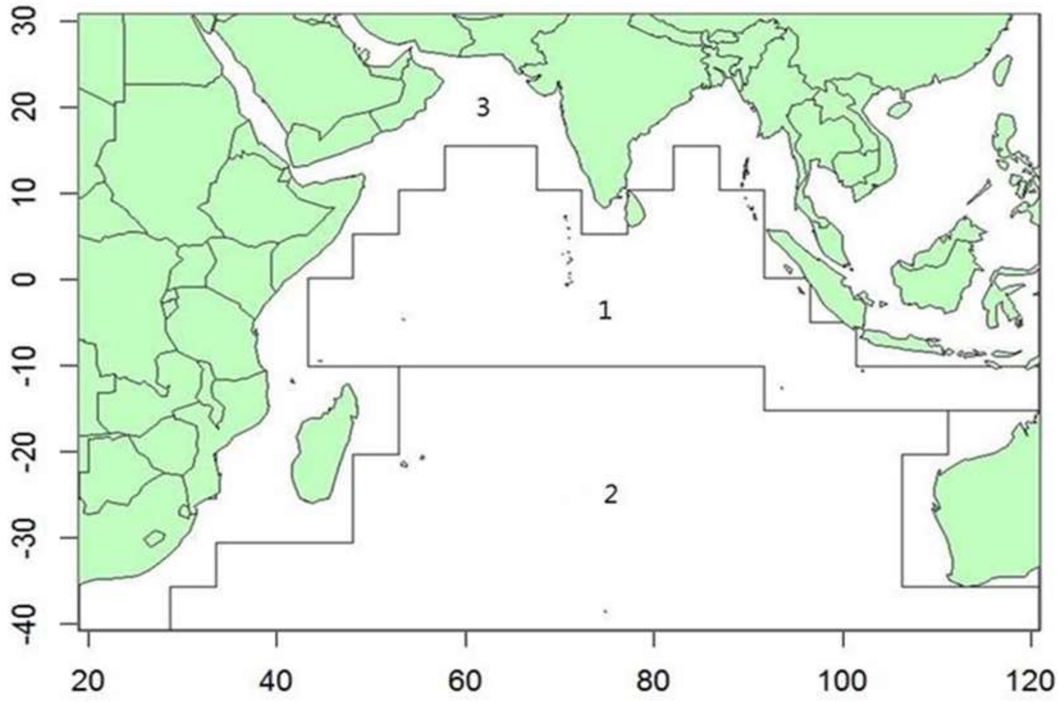

Fig. 2. The definition of ecological geographic areas in the Indian Ocean.

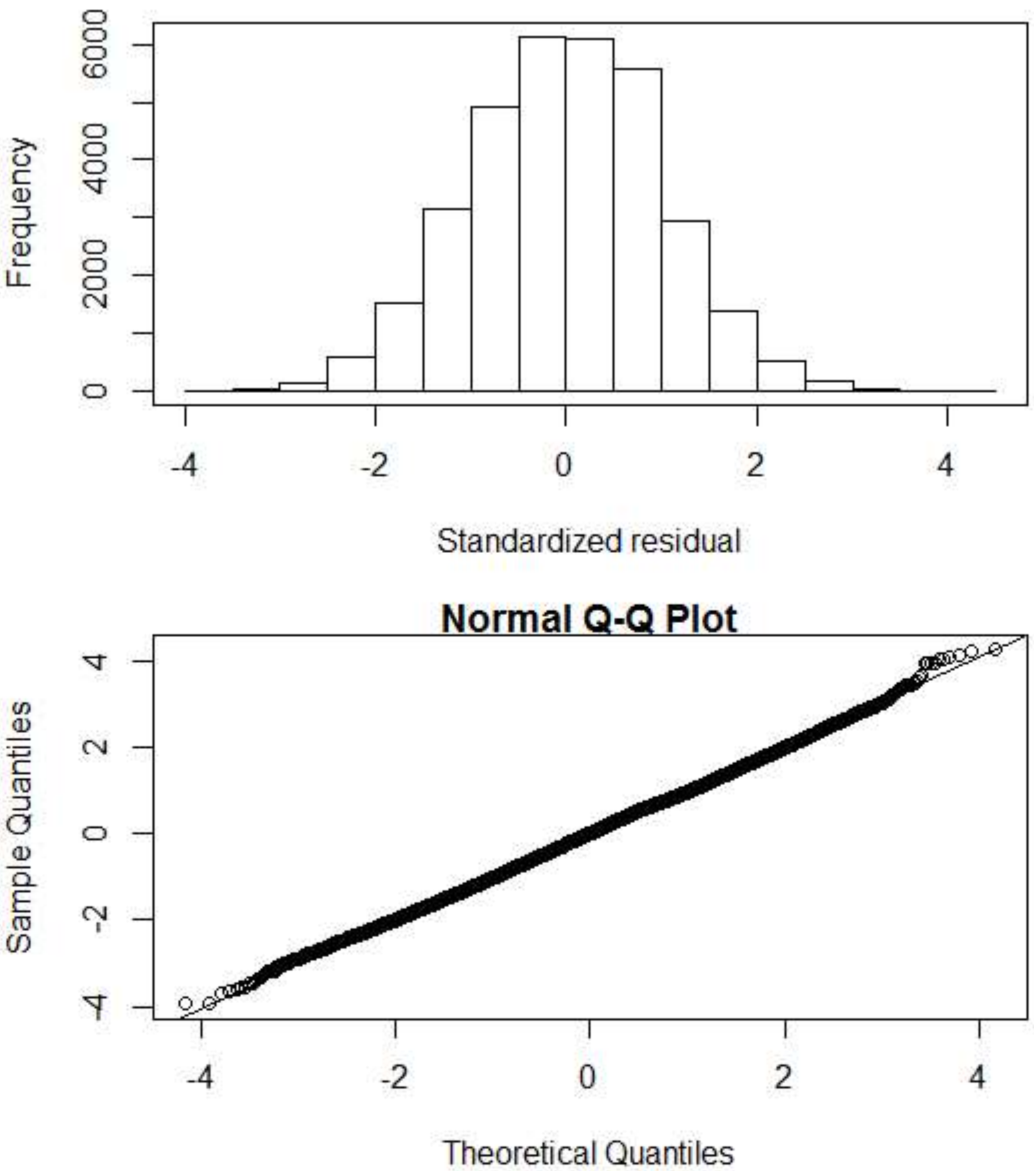

Fig. 3. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1995 to 2011with environmental effects

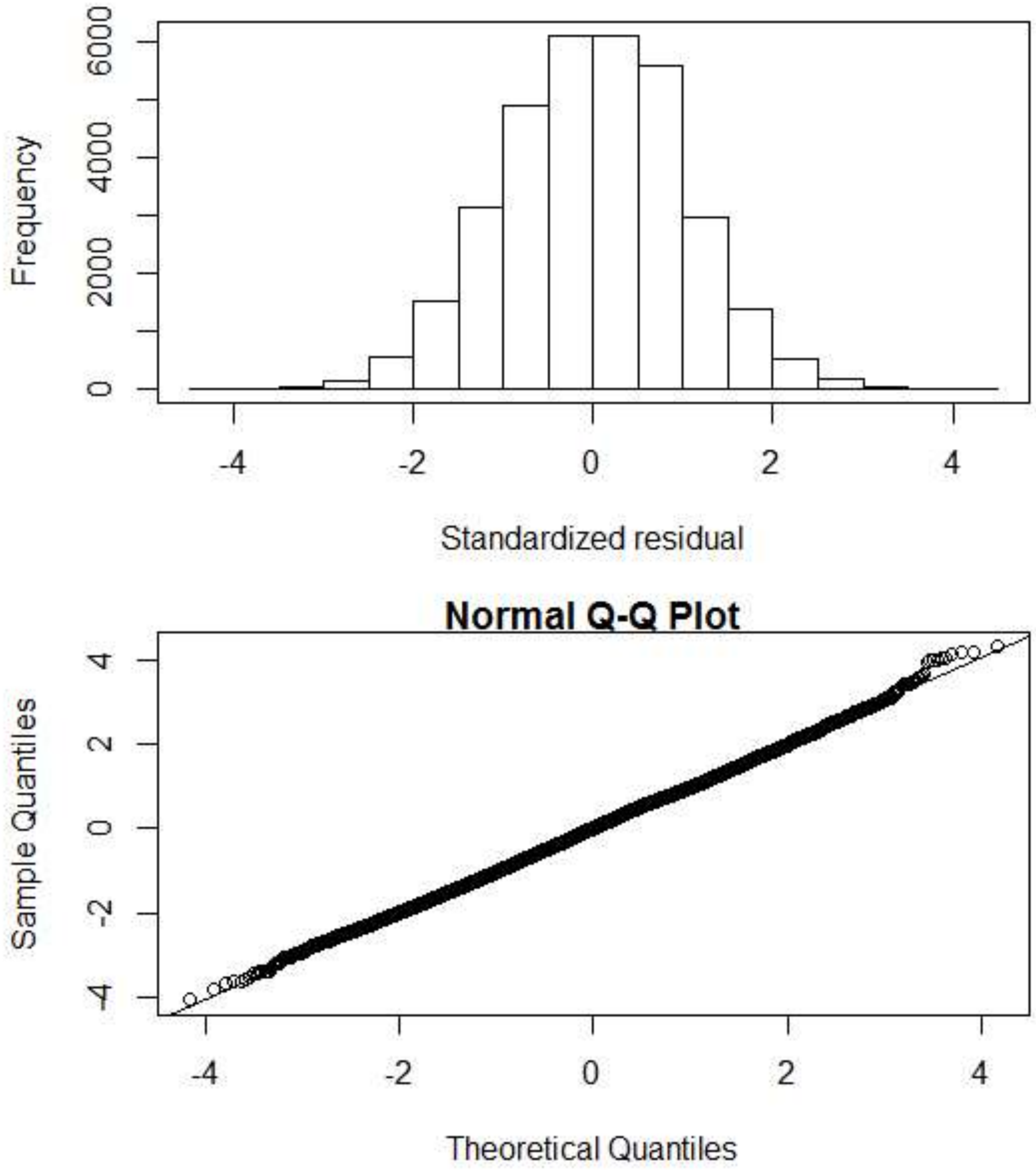

Fig. 4. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1995 to 2011without environmental effects.

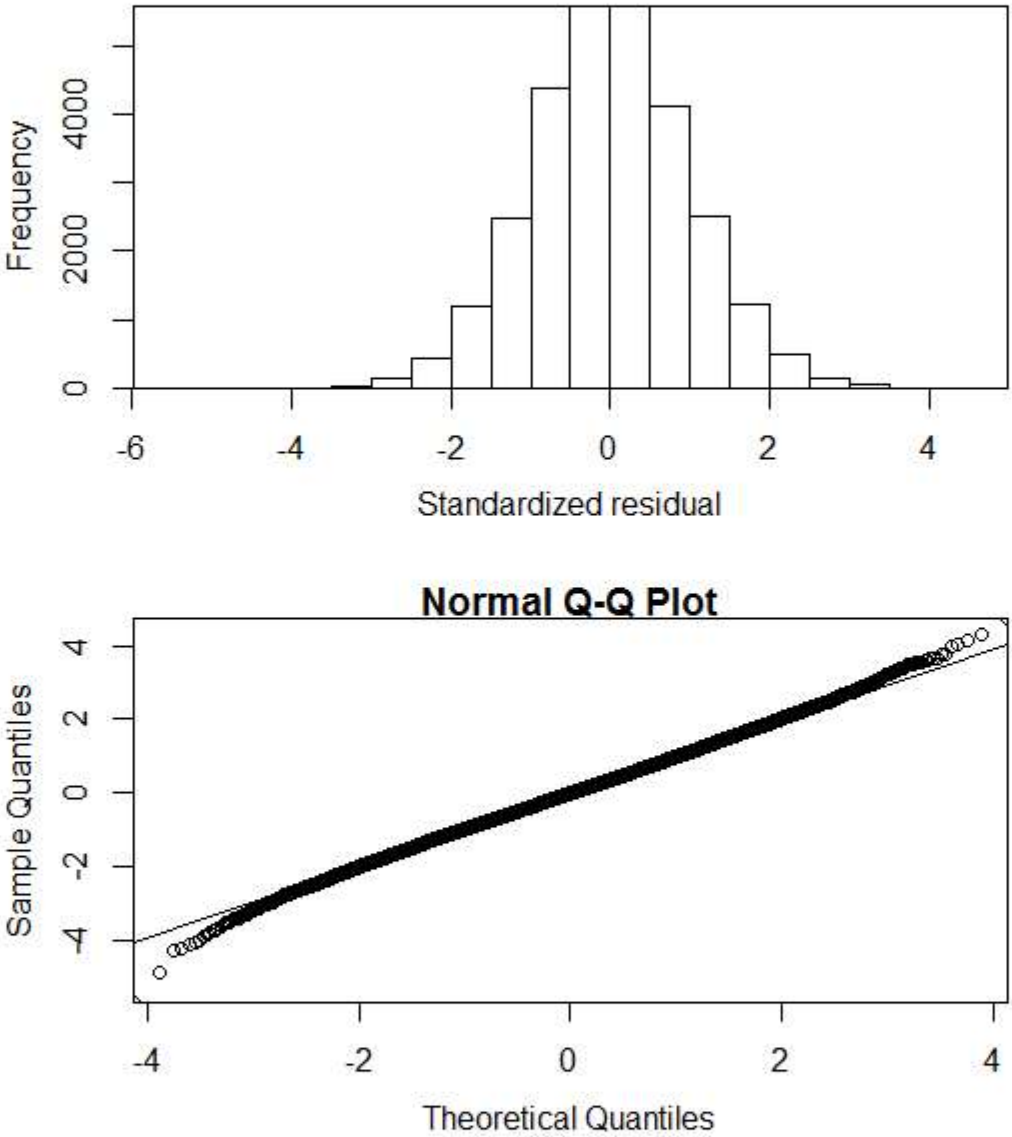

Fig. 5. The distribution and quantile-quantile plot for the residuals obtained from lognormal model based on the data from 1980 to 2011without environmental effects.

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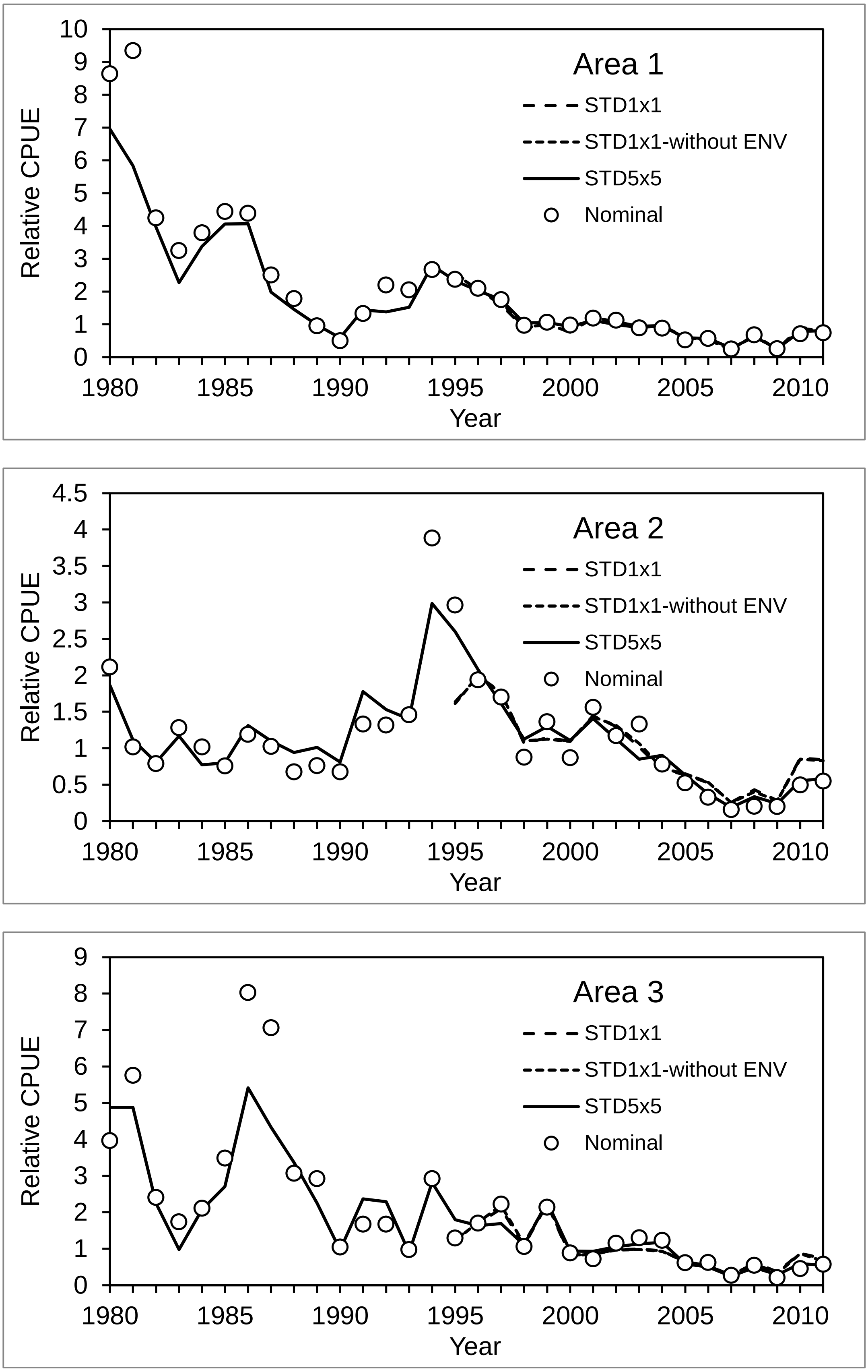

Fig. 6. Area-specific nominal and Standardized CPUE of striped marlin caught by Taiwanese longline fleet.

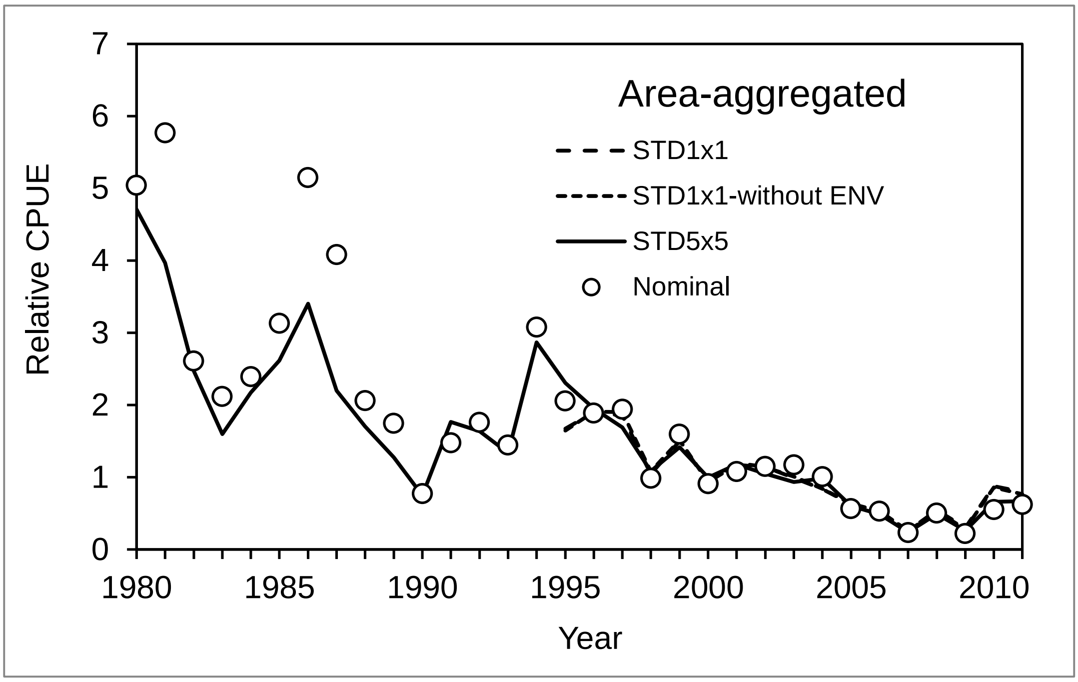

Fig. 7. Area-aggregated nominal and Standardized CPUE of striped marlin caught by Taiwanese longline fleet.

Table 1. The ANOVA table for the lognormal model with environmental effects.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	117	3482.78	29.77	34.84	<.0001
Error	33111	28291.42	0.85		
Corrected Total	33228	31774.20			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	16	2131.95	133.25	155.95	<.0001
M	11	332.95	30.27	35.42	<.0001
A	2	125.43	62.72	73.40	<.0001
CT	4	48.55	12.14	14.20	<.0001
NHBF	2	196.09	98.04	114.75	<.0001
TD	1	20.37	20.37	23.84	<.0001
T15	1	14.47	14.47	16.94	<.0001
Y*A	32	172.76	5.40	6.32	<.0001
M*A	22	259.88	11.81	13.83	<.0001
M*NHBF	22	89.15	4.05	4.74	<.0001
A*NHBF	4	91.16	22.79	26.67	<.0001

Table 2. The ANOVA table for the delta model with environmental effects.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			120189	141725	
Y	16	3382.4	120173	138343	<.0001
M	11	1364.9	120162	136978	<.0001
A	2	808.7	120160	136169	<.0001
CT	4	188.8	120156	135981	<.0001
NHBF	2	19.5	120154	135961	<.0001
TD	1	522.2	120153	135439	<.0001
T15	1	97.5	120152	135341	<.0001
TG15	1	19.9	120151	135321	<.0001
Y*A	32	365.5	120119	134956	<.0001
M*A	22	322.9	120097	134633	<.0001
M*NHBF	22	100	120075	134533	<.0001
A*NHBF	4	53.2	120071	134480	<.0001

Table 3. The ANOVA table for the lognormal model without environmental effects.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	115	3452.97	30.03	35.11	<.0001
Error	33113	28321.23	0.86		
Corrected Total	33228	31774.20			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	16	2131.95	133.25	155.79	<.0001
M	11	332.95	30.27	35.39	<.0001
A	2	125.43	62.72	73.33	<.0001
CT	4	48.55	12.14	14.19	<.0001
NHBF	2	196.09	98.04	114.63	<.0001
Y*A	32	175.65	5.49	6.42	<.0001
M*A	22	260.58	11.84	13.85	<.0001
M*NHBF	22	94.18	4.28	5.01	<.0001
A*NHBF	4	87.58	21.89	25.60	<.0001

Table 4. The ANOVA table for the delta model without environmental effects.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			120189	141725	
Y	16	3382.4	120173	138343	<.0001
M	11	1364.9	120162	136978	<.0001
A	2	808.7	120160	136169	<.0001
CT	4	188.8	120156	135981	<.0001
NHBF	2	19.5	120154	135961	<.0001
Y*A	32	349	120122	135612	<.0001
M*A	22	399.2	120100	135213	<.0001
M*NHBF	22	75.7	120078	135137	<.0001
A*NHBF	4	53.2	120074	135084	<.0001

Table 5. The ANOVA table for the lognormal model based on the data from 1980 to 2011.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	194	11568.71	59.63	54.76	<.0001
Error	28163	30671.39	1.09		
Corrected Total	28357	42240.10			

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Y	31	1031.92	33.29	37.08	<.0001
M	11	465.67	42.33	47.16	<.0001
A	2	2023.12	1011.56	1126.79	<.0001
CT	6	84.25	14.04	15.64	<.0001
T_ALB	2	195.49	97.74	108.88	<.0001
T_BET	2	14.56	7.28	8.11	0.0003
Y*A	62	571.45	9.22	10.27	<.0001
M*A	22	541.06	24.59	27.40	<.0001
M*T_ALB	22	131.26	5.97	6.65	<.0001
M*T_BET	22	44.46	2.02	2.25	0.0007
A*T_ALB	4	93.32	23.33	25.99	<.0001
A*T_BET	4	266.49	66.62	74.21	<.0001
T_ALB*T_BET	4	36.32	9.08	10.11	<.0001

Table 6. The ANOVA table for the delta model based on the data from 1980 to 2011.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL			55873	77445	
Y	31	2251.8	55842	75193	< .0001
M	11	771.65	55831	74422	< .0001
A	2	2632.38	55829	71789	< .0001
CT	6	253.19	55823	71536	< .0001
T_ALB	2	176.04	55821	71360	< .0001
T_BET	2	971.01	55819	70389	< .0001
Y:A	62	629.03	55757	69760	< .0001
M:A	22	340.86	55735	69419	< .0001
M:T_ALB	22	88.21	55713	69331	< .0001
M:T_BET	22	82.82	55691	69248	< .0001
A:T_ALB	4	90.85	55687	69157	< .0001
A:T_BET	4	167.95	55683	68989	< .0001