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SANDARDIZED CATCH-RATES OF WHITE MARLIN (*KAJIKIA ALBIDA*) FOR THE TAIWANESE DISTANT-WATER TUNA LONGLINE FISHERY IN THE ATLANTIC OCEAN, 1967-2010

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SUMMARY

The catch and effort data of the Taiwanese distant-water tuna longline fishery were standardized for white marlin in the Atlantic Ocean. Two alternative approaches, i.e., generalized linear and additive models, were applied for the standardization, based on the assumption of lognormal error distribution. All the main effects and the interactions considered in the standardization were statistically significant. Results derived from the two modeling approaches were almost identical, regardless of including or not the interaction terms in the models. The standardized CPUE of white marlin for the Taiwanese distant-water longline fishery in the Atlantic Ocean showed a decreasing trend before 1990, but increased substantially in the early 1990s, and then decreased continuously over the past 15 years.

RÉSUMÉ

Les données de prise et d'effort de la pêcherie palangrière thonière du Taipei chinois opérant en eaux lointaines dans l'océan Atlantique ont été standardisées pour le makaire blanc. Deux approches alternatives ont été appliquées (modèle linéaire généralisé et modèle additif) pour la standardisation, sur la base du postulat de distribution d'erreur lognormale. L'ensemble des principaux effets et interactions pris en compte dans la standardisation était statistiquement significatif. Les résultats découlant des deux approches de modélisation étaient presque identiques, indépendamment du fait d'inclure ou non les termes d'interaction dans les modèles. La CPUE standardisée du makaire blanc de la pêcherie palangrière thonière hauturière du Taipei chinois opérant dans l'océan Atlantique dégageait une tendance à la baisse avant 1990, mais a augmenté considérablement au début des années 1990, pour chuter ensuite de manière continue au cours de ces 15 dernières années.

RESUMEN

Se estandarizaron los datos de captura y esfuerzo de la pesquería de palangre de túnidos de aguas distantes de Taipei Chino para la aguja blanca en el océano Atlántico. Para la estandarización se aplicaron dos enfoques alternativos, es decir, modelos lineales generalizados y aditivos, basándose en un supuesto de distribución de error lognormal. Los principales efectos e interacciones considerados en la estandarización fueron estadísticamente significativos. Los resultados derivados de los dos enfoques de modelación fueron casi idénticos, al margen de que se incluyeran o no los términos de interacción en los modelos. La CPUE estandarizada de aguja blanca de la pesquería de palangre de aguas distantes de Taipei Chino en el océano Atlántico mostraba una tendencia decreciente antes de 1990, pero se incrementó notablemente a principios de los noventa, y ha descendido de forma continua durante los 15 últimos años.

KEYWORDS

White marlin, standardized CPUE, GLM, GAM, longline

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1. Introduction

White marlin, *Kajikia albida* (formerly *Tetrapturus Albidus*; Collette *et al*., 2006), is a highly migratory species widely distributed in the Atlantic Ocean (Goodyear, 2003). Several studies have reported that white marlin migrate a long distance more than 1000 km, consisting of both trans-Atlantic and trans-equatorial movements (Orbesen *et al*., 2008). The assessment of white marlin in the Atlantic Ocean was made based on the assumption of a single unit stock (Restrepo *et al*., 2003). Previous stock assessment conducted by the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated that the current status of this population was overfished, with estimated exploitable biomass well below the level needed to maintain maximum sustainable yield, and suffering overfishing (Wells *et al*., 2010; ICCAT, 2012).

White marlin are caught as bycatch species in commercial longline fisheries targeting tunas, supporting economically important recreational fisheries throughout the Atlantic Ocean (Prince and Brown, 1991). The Taiwanese distant-water tuna longline fishery has operated throughout the Atlantic Ocean since the early 1960s, and become one of the major longline fleets thereafter. The fishery targeted solely on albacore tuna (*Thunnus alalunga*) from the beginning through 1980s, but some of fishing effort has shifted to target on bigeye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) since the late 1980s, with the development of the deep longlining (Chang, 2003).

CPUE (catch per unit of effort) of white marlin for the fleets operating in the Atlantic Ocean is standardized for the use of basic input data in stock assessments (ICCAT, 2011). The objective of this study were to provide (1) the spatial and temporal distributions of fishing effort for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean and the nominal catch-rates of white marlin from this fishery, and (2) the standardized CPUE of white marlin derived from statistical models based on the assumption of a single Atlantic-wide stock for this species.

2. Materials and methods

2.1 Fishery data

Task II data (1967-2010) on catch (number of white marlin caught) and effort (number of hooks deployed) of the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean were obtained from the Overseas Fisheries Development Council of the Republic of China (OFDC, Chinese Taipei). Data were aggregated into monthly 5°×5° latitude and longitude grids. CPUE were expressed as the number of fish caught per 1000 hooks.

2.2 Statistical model

Nominal CPUE of white marlin were standardized using two alternative approaches, generalized linear models (GLMs) and generalized additive models (GAMs). The lognormal error distribution was assumed in the standardization. GLMs are the most commonly used approach for standardizing catch and effort data, assuming that the expected value of a transformed response variable is related to a linear combination of exploratory variables, whereas GAM is a semi-parametric extension of GLM with the underlying assumption that the response variable is related to smooth additive functions of the explanatory variables (Maunder and Punt 2004). Year, month, latitude, and longitude were considered in the GLM and GAM analysis as main explanatory variables. The full GLM and GAM models including interactions were expressed as follows:

GLM: WHM ~ Year + Month + Latitude + Longitude;
GLMi: WHM ~ Year + Month + Latitude + Longitude + Interactions;
GAM: WHM ~ Year + s(Month) + s(Latitude) + s(Longitude);
GAMi: WHM ~ Year + s(Month) + s(Latitude) + s(Longitude) + s(Interactions)

where WHM is the nominal CPUE of white marlin with a constant being added to avoid log-transformation problems; s(X) denotes a spline smoother function of the covariate X. No interactions with year effect were considered in GLMs and GAMs for the CPUE standardization (Maunder and Punt 2004).

2.3 Model diagnostic

Various diagnostic plots, e.g. the distribution of residuals and quantile-quantile plots (Q-Q plots), were used to assess the assumption of error models (here assuming lognormal distribution) for standardizing the nominal CPUE of white marlin in the Atlantic Ocean. The improvement of each model that differed in one additional predictor was examined using the change in deviance explained, the proportion of deviance explained to the total explained deviance, the change in R^2, and the Chi-square test.

3. Results and discussion

There were in total 22,719 catch-effort records available for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean for 1967-2010. This fishery operated throughout the entire Atlantic Ocean (**Figure 1**), but shifted to tropical waters to target bigeye and yellowfin tunas since the late 1980s (**Figures A1-A2**). Most of high nominal CPUE of white marlin distributed in temperate waters of the western Atlantic Ocean around 20°N and 20°S (**Figure 2**). The residual distributions from both GLM and GAM analyses appeared normal for all of the four candidate models (**Figure 3**), even if separated by period (results for GLMi were shown in **Figure A3**). The Q-Q plots also confirmed to the greatest extent the assumption of lognormal error distribution for all the models used to standardize the nominal CPUE of white marlin for the fishery (**Figure 4**).

All of the main explanatory variables considered in the modelling and the interactions used in the GLM and GAM analyses were highly significant ($P < 0.01$; **Table 1**). The proportion of deviance explained (i.e. R^2) in the GLM and GAM modelling with all of the predictors were 0.36 and 0.29, respectively. Year, latitude and longitude explained the largest proportion of deviance, accounting for 75.4% in the GLM and 79.7% in the GAM of the total deviance explained (**Table 1**). We inferred based on the results that latitude and longitude were the predominant predictors affecting the nominal CPUE of white marlin, compared to the month effect (**Figure A4**). However, environmental factors (*e.g*. sea surface temperature, chlorophyll-a concentration, and mixed layer depth) could also be important factors to influence the CPUE of white marlin, and should be included in further analyses (see the study conducted by Goodyear, 2003).

Results showed that the standardized CPUE of white marlin derived from the GLM and GAM modeling approaches were almost identical, no matter including or not the interaction terms in the standardization models (**Figure 5**). In general, the standardized CPUE of white marlin for the Taiwanese distant-water longline fishery were high (~0.3 fish per 1000 hooks) in the late 1960s and early 1970s, but decreased sharply in the late 1970s. The standardized CPUE trend seemed to stabilize with a slight increase trend in the 1980s, and then substantially increased in the early 1990s. However, the standardized CPUE of white marlin have dropped continuously since mid-1990s, and reached the lowest level in recent years (less than 0.1 fish per 1000 hooks) (**Figure 5**). We suggest using the standardized CPUE series derived from the GLMi for the white marlin stock assessment (**Table 2**), because this model explained the most deviance among the candidate models.

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Table 1. Analysis table for the models selected to standardize the catch and effort data of Taiwanese distant-water tuna longline fishery for white marlin in the Atlantic Ocean using generalized linear models and generalized additive models.

(a) Generalized linear models

Predictor	*Residual deviance*	*Deviance explained*	*% of total deviance explained*	*P-value*	*R^2*	*Model*
NULL	26598					
+Year	23744	2853	29.9	<0.01	0.107	
+Month	22990	755	7.9	<0.01	0.136	
+Latitude	20278	2711	28.4	<0.01	0.238	
+Longitude	18644	1634	17.1	<0.01	0.299	GLM
+Latitude:Longitude	17054	1590	16.7	<0.01	0.359	GLMi

(b) Generalized additive models

Predictor	*Residual deviance*	*Deviance explained*	*% of total deviance explained*	*P-value*	*R^2*	*Model*
NULL	26598					
+s(Year)	23744	2853	36.8	<0.01	0.107	
+s(Month)	23125	619	8.0	<0.01	0.131	
+s(Latitude)	21503	1622	20.9	<0.01	0.192	
+s(Longitude)	19804	1700	21.9	<0.01	0.255	GAM
+s(Latitude:Longitude)	18852	952	12.3	<0.01	0.291	GAMi

The *P*-values indicate the level of significance based on the Chi-square test.

Table 2. Nominal and standardized CPUE of white marlin for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean.

Year	*Nominal CPUE*	*Standardized CPUE*	*Year*	*Nominal CPUE*	*Standardized CPUE*
1967	0.145	0.165	1989	0.559	0.190
1968	0.631	0.304	1990	0.152	0.128
1969	0.363	0.311	1991	0.047	0.084
1970	0.530	0.324	1992	0.049	0.108
1971	0.323	0.345	1993	0.250	0.226
1972	0.203	0.214	1994	0.285	0.332
1973	0.449	0.259	1995	0.201	0.219
1974	0.492	0.317	1996	0.191	0.214
1975	0.343	0.249	1997	0.158	0.199
1976	0.018	0.094	1998	0.046	0.134
1977	0.009	0.094	1999	0.050	0.131
1978	0.026	0.099	2000	0.056	0.122
1979	0.093	0.119	2001	0.043	0.128
1980	0.182	0.178	2002	0.064	0.137
1981	0.250	0.187	2003	0.039	0.109
1982	0.116	0.147	2004	0.020	0.090
1983	0.118	0.171	2005	0.026	0.099
1984	0.131	0.141	2006	0.027	0.111
1985	0.109	0.142	2007	0.025	0.095
1986	0.234	0.186	2008	0.017	0.084
1987	0.218	0.210	2009	0.011	0.082
1988	0.232	0.178	2010	0.007	0.083

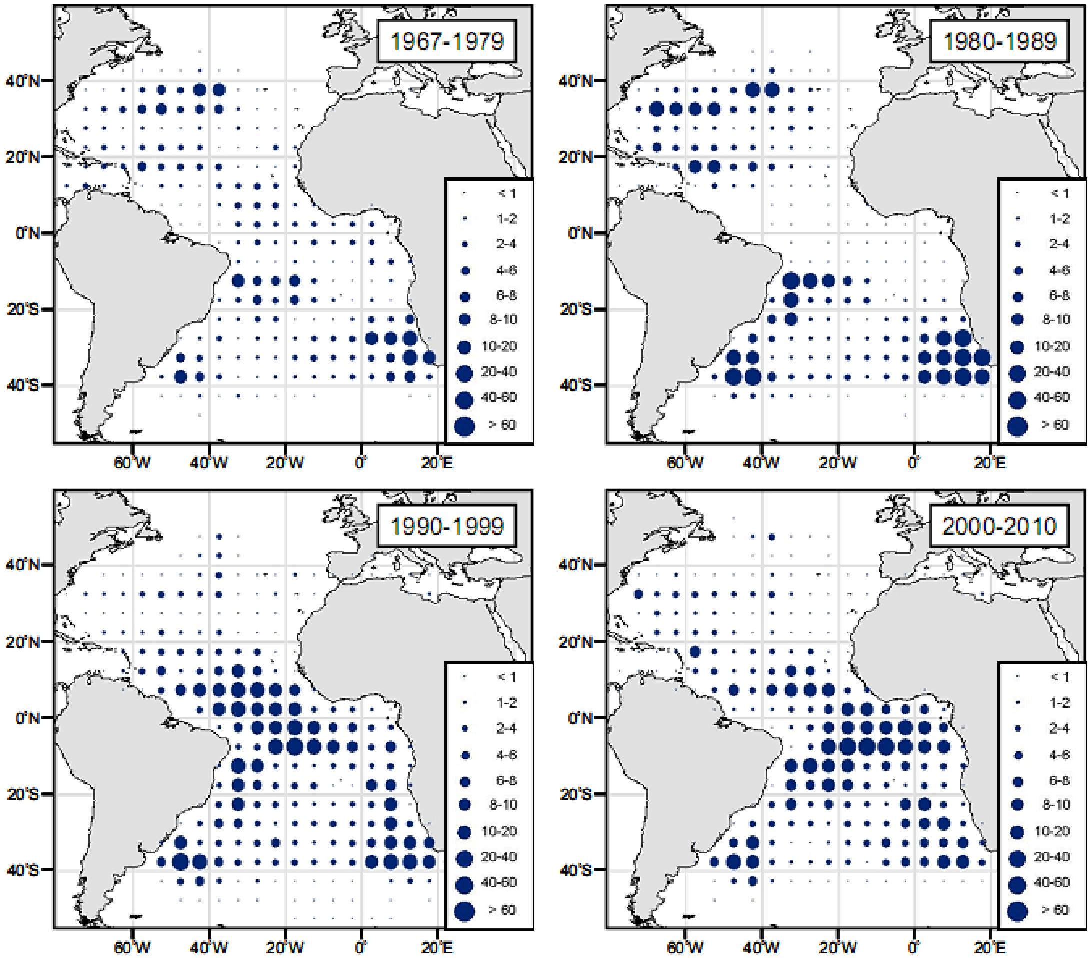

Figure 1. Distributions of fishing effort (10^6 hooks) of the Taiwanese distant-water tuna longline fleet in the Atlantic Ocean for 1967-79, 1980-89, 1990-99, and 2000-10.

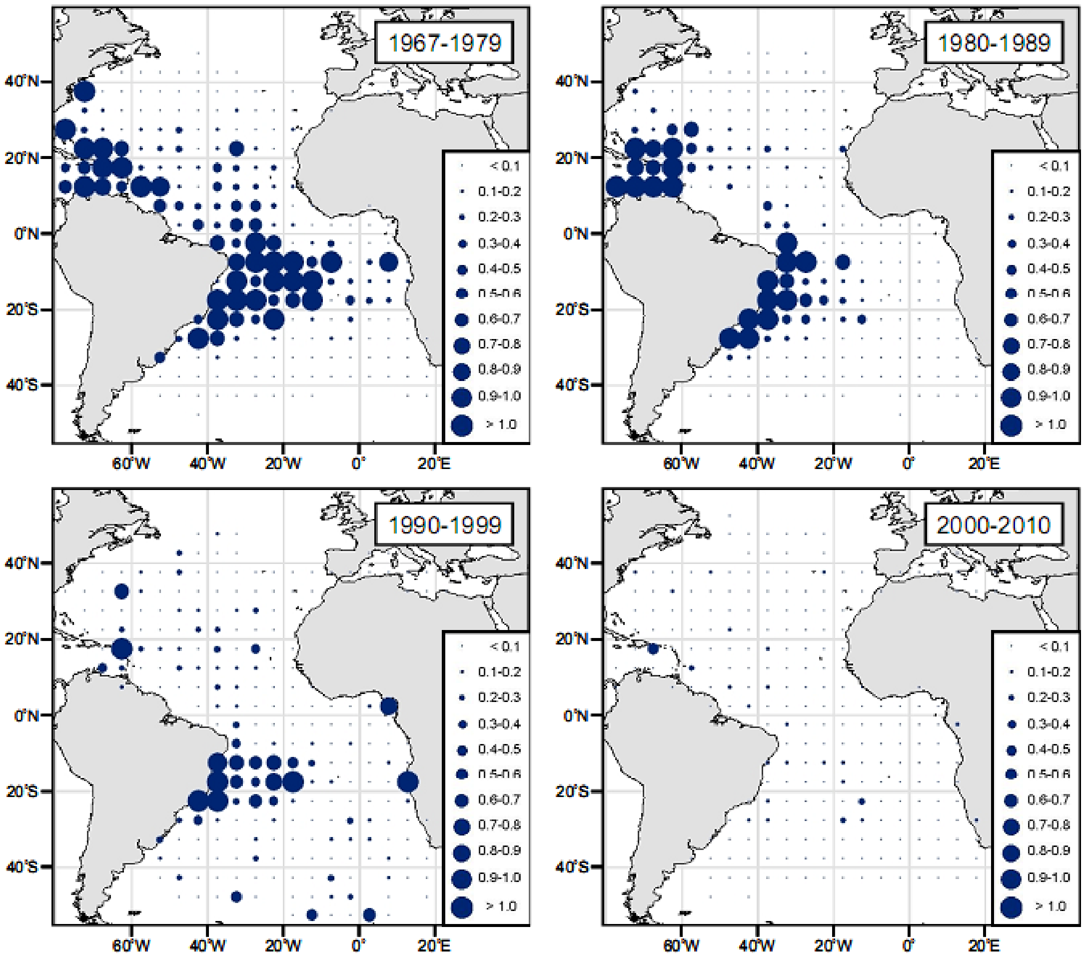

Figure 2. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for white marlin caught in the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean for 1967-79, 1980-89, 1990-99, and 2000-10.

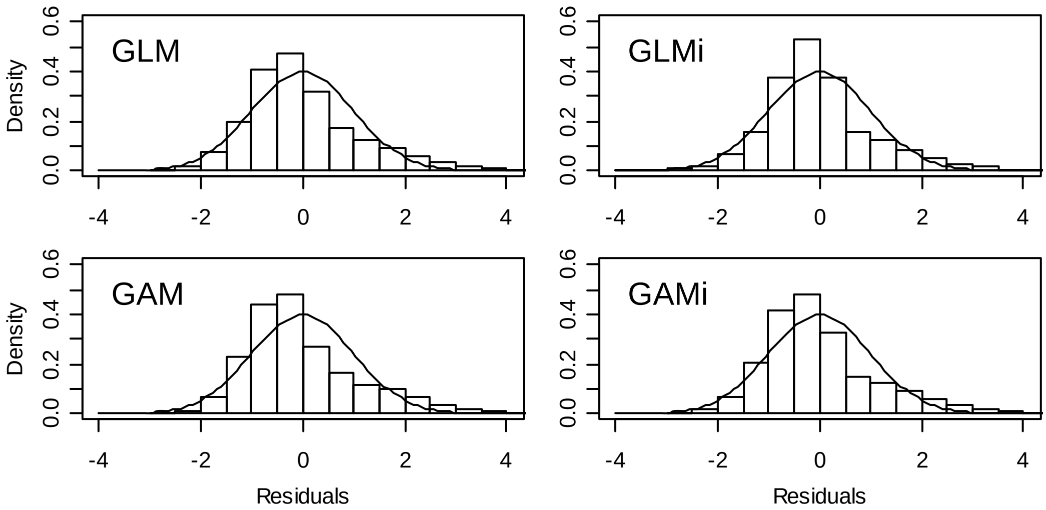

Figure 3. Diagnostic plots (residual distributions) for the GLMs and GAMs used to standardize the catch-rates of white marlin for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean for 1967-2010.

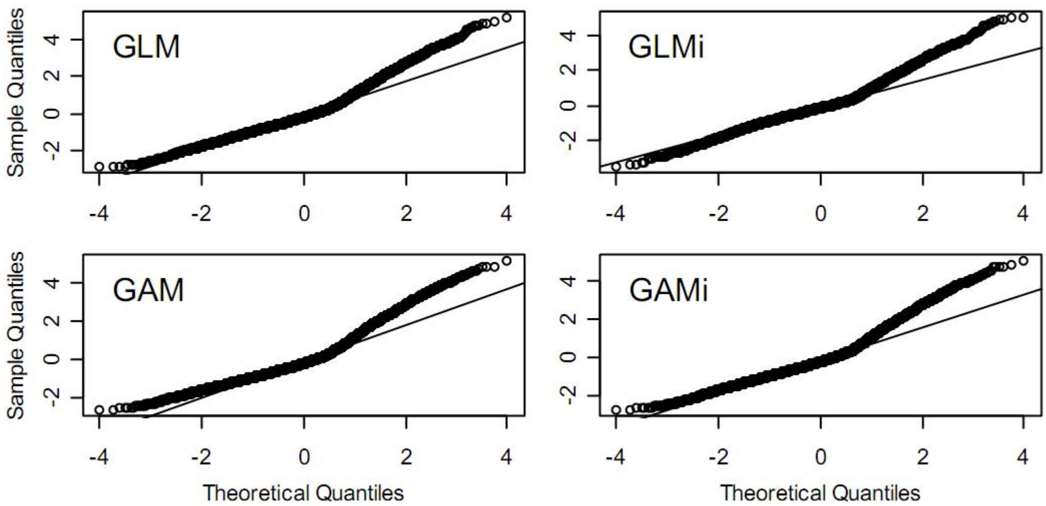

Figure 4. Diagnostic plots (Q-Q plots) for the GLMs and GAMs used to standardize the catch-rates of white marlin for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean for 1967-2010.

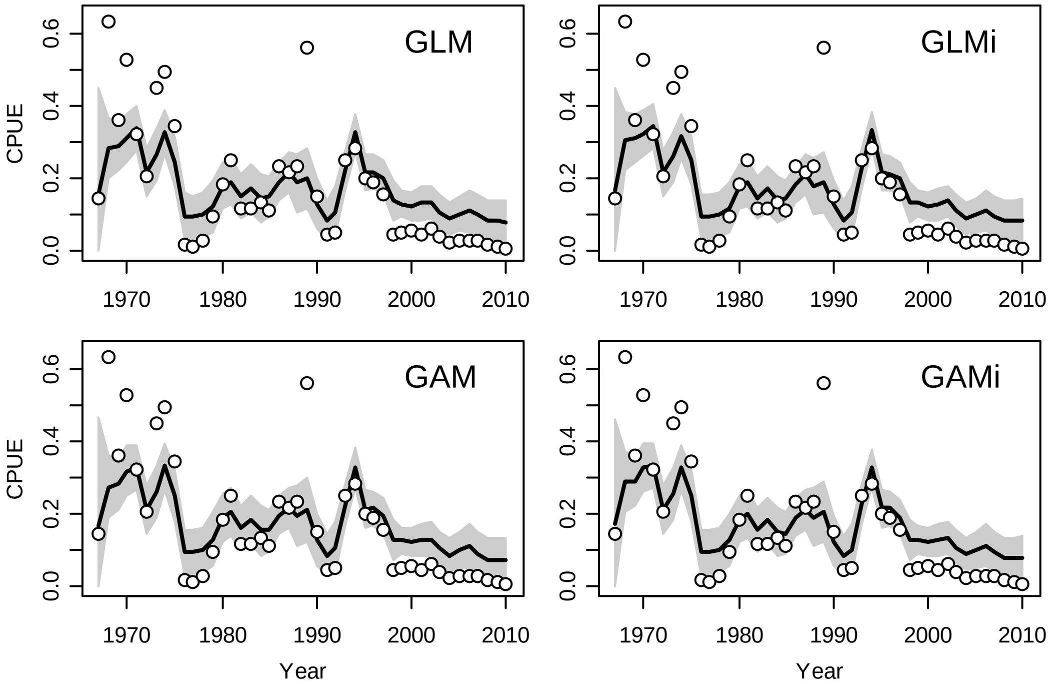

Figure 5. The nominal (open circles) and standardized (black lines) CPUE (number of fish caught per 1000 hooks) of white marlin for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean for 1967-2010 using GLM and GAM modeling approaches. The shadowed areas indicate the point-wise standard errors for the standardized CPUE of white marlin.

Appendix

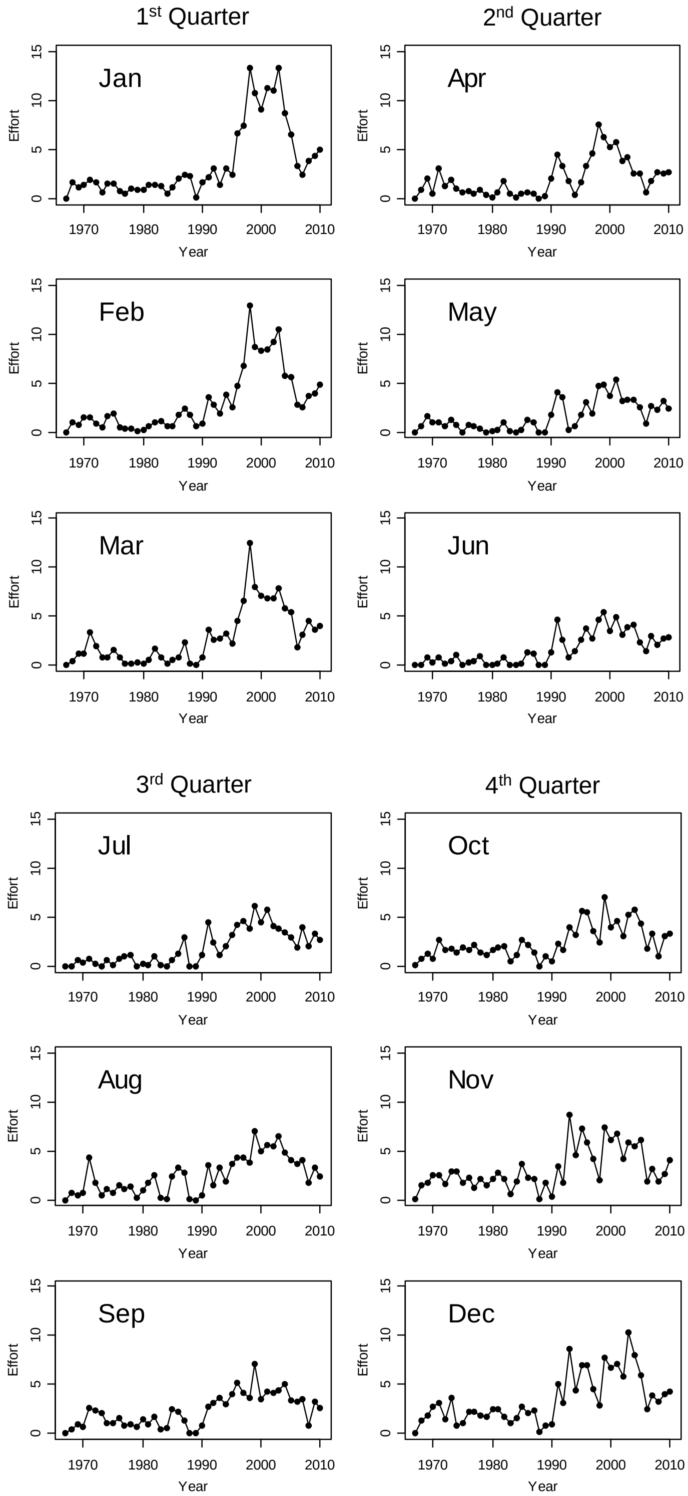

Figure A1. Fishing effort (in 10^6 hooks) of the Taiwanese distant-water longline fishery in the Atlantic Ocean (0-30°S) during 1967-2010 by month.

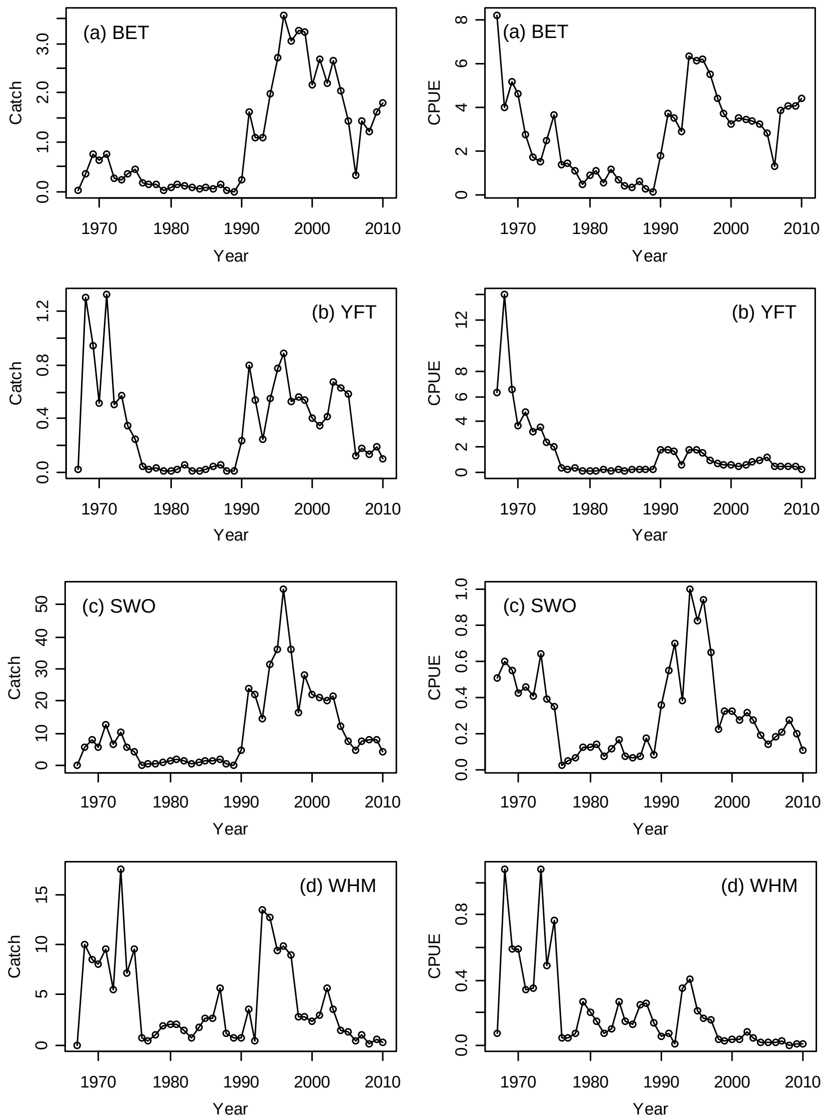

Figure A2. Annual catches (in 10^5 fish) and CPUE (number of fish caught per 1000 hooks) by species: (a) bigeye tuna (BET), (b) yellowfin tuna (YFT), (c) swordfish (SWO), and (d) white marlin (WHM) for the Taiwanese distant-water longline fleet in the Atlantic Ocean (0-30°S).

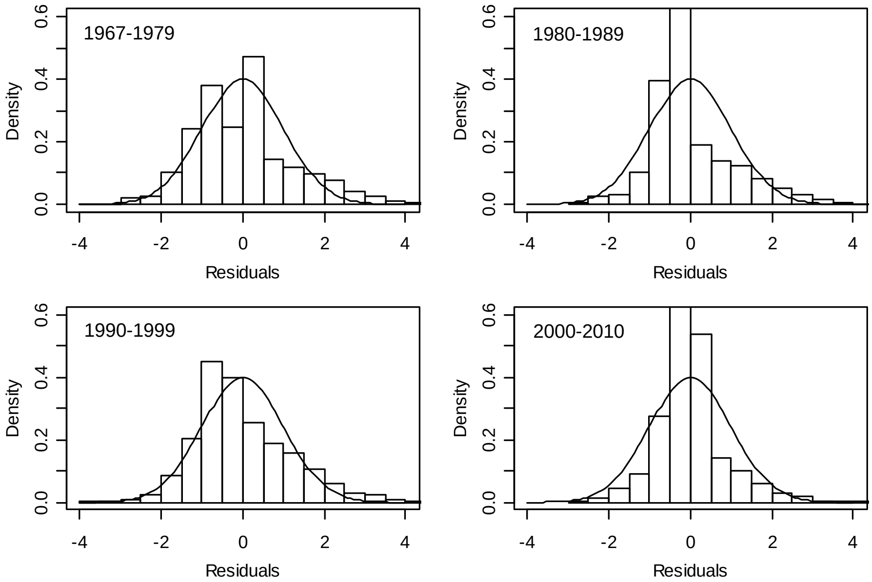

Figure A3. Residual distributions for the selected CPUE standardization model (GLMi) by period, 1967-79, 1980-89, 1990-99, and 2000-10.

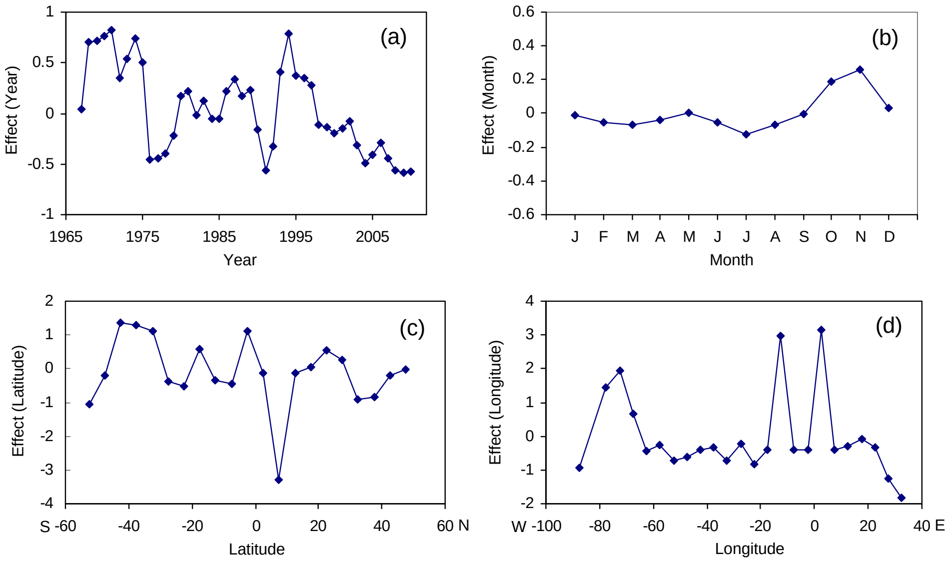

Figure A4. Estimated effects of (a) year, (b) month, (c) latitude, and (d) longitude on the CPUE of white marlin for the selected CPUE standardization model (GLMi).