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STANDARDIZED CPUE OF SWORDFISH (*XIPHIAS GLADIUS*) CAUGHT IN THE TAIWANESE LONGLINE FISHERY IN THE SOUTH ATLANTIC OCEAN FOR 1967-2012, ADDRESSING THE TARGETING CHANGE

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SUMMARY

*Catch and effort data of the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean were standardized for swordfish (*Xiphias gladius*) by applying generalized linear models (GLMs). Two periods (1967-1989 and 1990-1999) and the information on operation type (the number of hooks per basket, HPB) from 2000 were considered in the standardization of CPUE (catch per unit effort) to address the issue of targeting change of this fishery. All the predictor variables, including time, fishing area, and gear configuration were statistically significant. The standardized CPUE of swordfish for 1967-1989 and 1990-1999 were almost identical to the results based on an entire period (1967-2012). However, the relative abundance indices in the late 1990s were sensitive to the inclusion of HPB in the model. In general, the standardized CPUE of swordfish in the South Atlantic Ocean showed a decreasing trend from 1967 through 1990, with a sudden increase during 1991 to 1996, but dropped to a lower level in the late 1990s and slightly decreased from 2000 until 2012.*

RÉSUMÉ

Les données de prise et d'effort de la pêcherie palangrière du Taipei chinois opérant en eaux lointaines dans l'océan Atlantique Sud ont été standardisées pour l'espadon (Xiphias gladius) *en appliquant des modèles linéaires généralisés (GLM). Deux périodes (1967-1989 et 1990-1999) et les informations sur le type d'opération (nombre d'hameçons par panier, HPB) à partir de 2000 ont été prises en compte dans la standardisation de la CPUE (prise par unité d'effort) afin d'aborder la question du changement de ciblage de cette pêcherie. Toute les variables de prédiction, y compris le moment, la zone de pêche et la configuration des engins, étaient statistiquement importantes. La CPUE standardisée de l'espadon pour les périodes 1967-1989 et 1990-1999 était pratiquement identique aux résultats fondés sur l'ensemble de la période (1967-2012). Toutefois, les indices d'abondance relative à la fin des années 90 étaient sensibles à l'inclusion du HPB dans le modèle. En général, la CPUE standardisée de l'espadon dans l'océan Atlantique Sud a dégagé une tendance décroissante de 1967 à 1990 compris : elle a ensuite connu une brusque augmentation de 1991 à 1996, pour chuter à un niveau plus faible à la fin des années 90 et elle a légèrement baissé à partir de 2000 jusqu'en 2012.*

RESUMEN

*Se estandarizaron los datos de captura y esfuerzo de la pesquería de palangre de túnidos en aguas distantes de Taipei Chino en el océano Atlántico sur para el pez espada (*Xiphias gladius*) aplicando modelos lineales generalizados (GLM). Se consideraron dos periodos (1967-1989 y 1990-1999) y la información sobre el tipo de operación (número de anzuelos por cesta-HPB) desde 2000 para estandarizar la CPUE (captura por unidad de esfuerzo) con el fin de abordar la cuestión del cambio de especie objetivo en esta pesquería. Todas las variables de predicción, lo que incluye, periodo, zona de pesca y configuración del arte, fueron estadísticamente significativas. Las CPUE estandarizadas de pez espada para 1967-1989 y 1990-1999 fueron casi idénticas a los resultados basados en el periodo completo (1967-2012). Sin embargo, los índices de abundancia relativa a finales de los noventa fueron sensibles a la inclusión de HPB en el modelo. En general, las CPUE estandarizada de pez espada del Atlántico sur mostraba una tendencia decreciente desde 1967 hasta 1990, seguida de un súbito incremento durante el periodo de 1991 a 1996, pero después descendió a un nivel inferior a finales del os noventa, y descendió ligeramente desde 2000 hasta 2012.*

KEYWORDS

GLM, CPUE standardization, Abundance index, Longline, Targeting change

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1. Introduction

Swordfish (*Xiphias gladius* Linnaeus, 1758) is a cosmopolitan species widely distributed in tropical, subtropical, and temperate waters of three oceans and adjacent seas (ICCAT 2007). In the Atlantic Ocean, swordfish can be harvested in areas between 45°N and 55°S by a large number of countries because of their broad geographical distribution in pelagic, offshore and coastal waters (ICCAT 2010). Most swordfish were caught as a bycatch in longline fisheries that target tunas (*e.g*., Japanese and Taiwanese longline fleets), although small catches of swordfish were taken using other gears, such as gillnets and harpoons. A small proportion of catch was caught by the Brazilian longline vessels targeting swordfish from 1990 onward (ICCAT 2007). Three management units of swordfish in the Atlantic Ocean (the Mediterranean, the North, and the South Atlantic stocks) are defined by the ICCAT for stock assessment and management purpose (ICCAT 2010).

The Taiwanese distant-water tuna longline vessels, one of the world's most important tuna fleets, have operated throughout the Atlantic, Pacific, and Indian Oceans since the late 1960s (Chang *et al*. 2007). The annual catch of swordfish from the Taiwanese tuna longline fishery in the South Atlantic Ocean was about 200~800 tons in the 1980s, but increased to more than 2,500 tons in the early 1990s due to the development of deep longline operations in tropical areas targeting bigeye tuna (*Thunnus obesus*) (**Figure 1**). However, the catch of swordfish from this fishery reduced to around 1,500 tons in the late 1990s and early 2000s owing to the catch regulations by ICCAT. The catch of swordfish was further decreased to 600~700 tons in 2008 and 2009 (**Figure 1**), and about 400 tons in recent two years (2010 and 2011) due to a decrease in fishing effort through the large-scale vessel reduction program (Chang *et al*. 2007).

Catch and effort data of the Taiwanese distant-water tuna longline fishery were standardized for swordfish based on generalized linear models (GLMs) assuming a delta lognormal error distribution with main explanatory variables including year and bimonth, geographical area, and the target species of tunas (Chang *et al*. 2007), and were also analyzed using GLMs and generalized additive models (GAMs) assuming lognormal error distribution (Sun *et al*. 2010; 2013). Alternative area stratifications were considered in the CPUE (catch per unit effort) standardization to evaluate the potential impact on abundance index of swordfish, but all of them led to almost identical results. The abundance indices of swordfish for the South Atlantic stock derived from previous studies suggested a generally decreasing trend from 1968 through 1990, with a notable increase to a higher level during 1991 to 1996, but dropped sharply in the late 1990s (Sun *et al*. 2010; 2013).

The objectives of this study were to assess how the targeting change might influence the swordfish CPUE caught in the Taiwanese distant-water longline fishery in the South Atlantic Ocean by conducting the analysis for two separate periods, and to examine how sensitive the factor of gear configuration is to the choice of analytical framework for standardizing catch and effort data of this fishery for swordfish. The relative abundance index of swordfish developed in this study could be used in the stock assessment.

2. Materials and methods

2.1 Fishery data

Catch and effort data of the Taiwanese distant-water tuna longline fleets in the South Atlantic Ocean were obtained from the Overseas Fisheries Development Council of the Republic of China (OFDC, Taipei) for 1967-2012 (Task II) and 1995-2012 (because information on hooks per basket, HPB, was available from 1995). Both data sets contain information on time (year and month), fishing locations (in 5° longitude and latitude), number of hooks, and the catch of tunas and swordfish. However, information on gear configuration (*i.e.*, HPB) was only available from the logbooks since 1995. Both of the data sets were grouped into 5° grids of latitude and longitude for each month for the analysis. CPUE of swordfish were expressed as the number of fish caught per 1000 hooks in this study.

2.2 Catch composition

Catch composition can be used to separate a tuna longline fishery that targets different species (Lee *et al*. 2005). For example, the proportion of bigeye tuna in the catch might increase when the targeting species changes from albacore to bigeye tuna. The Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean was thus separated into two periods to address the targeting change based on the catch ratios defined as follows:

ALB = ALB/(ALB+BET+SWO)
BET = BET/(ALB+BET+SWO)
SWO = SWO/(ALB+BET+SWO)

where ALB, BET, and SWO are the catches of albacore, bigeye tuna, and swordfish for each year respectively.

2.3 Statistical models

Generalized linear models (GLMs; Nelder and Wedderburn 1972) are commonly used methods for standardizing fishery data (Maunder and Punt, 2004). This standard approach was thus applied to standardize catch and effort data of the Taiwanese distant-water tuna longline fishery for swordfish in the South Atlantic Ocean in this study. A lognormal error distribution with an identity link was assumed to model the swordfish CPUE data. A small constant (10% of the grand mean) was added to avoid log-transformation problems. The full GLM used in this study can be written as:

GLM: $CPUE_{SWO}$ ~ Year + Season + Area + Season:Area (for 1967-2012, 1967-1989 and 1990-1999);

GLM: $CPUE_{SWO}$ ~ Year + Season + Area + Season:Area + HPB (for 2000-2012);

where $CPUE_{SWO}$ is the CPUE of swordfish with a small constant added. Year, season, and area are the temporal and spatial effects. A new area stratification based on fishing effort distributions of the Taiwanese tuna longline fishery and nominal CPUE distributions of swordfish in the South Atlantic Ocean was used in GLM analysis (**Figures 2 and 3**). Information on gear configuration (*i.e.*, HPB) was available from logbook data since 1995, but included in the GLM analysis for 2000-2012 because only few HPB data were collected before 2000. The impact of HPB was considered in the CPUE standardization of swordfish because potential relationship between the targeting change and swordfish CPUE was suggested by previous studies (Chang *et al*. 2007; Sun *et al*. 2010; Sun *et al*. 2012).

A forward stepwise technique was used to identify the appropriate set of explanatory variables for each model of the GLM and GAM analyses. A Chi-square (χ^2) analysis was used to evaluate the significance of each predictor variable. Diagnostic plots, *i.e.*, the distribution of residuals and quantile-quantile (Q-Q) plots, were used to assess the model fits and the assumption of error models. Alternative models with the inclusion of target species were evaluated using the Akaike information criterion (AIC) and the pseudo-coefficient of determination (R^2).

Relative abundance indices of swordfish were developed using least-square means (LS means) for the year effect. The LS means are marginal means over a balanced population predicted from a linear model at combinations of specified factors. Unspecified factors and covariates are handled by summarizing the predictions over those factors and variables. All of the analyses were conducted by using R version 2.15.1.

3. Results and discussion

There were 15,774 catch and effort records (Task II) for 1967-2012, and 3,682 records with gear configuration information (HPB) for 2000-2012 used in the GLM analyses. The fishing ground of the Taiwanese tuna longline fishery was throughout the South Atlantic Ocean before 1989, but shifted to tropical waters of the Atlantic Ocean since 1990 (**Figure 2**) due to the targeting change from albacore to bigeye tuna. Therefore, the catch of bigeye tuna substantially increased since 1990.

High CPUE of swordfish occurred in tropical waters of the central Atlantic Ocean (**Figure 3**), suggesting that spatial covariates are likely to be an important factor in determining catchability of swordfish in the Taiwanese longline fishery. There was no substantial seasonal variation in nominal CPUE distributions, but there seems a shift in the fishing grounds of this fishery in recent years, with substantially higher CPUE of swordfish occurring in tropical areas (5°N~10°S). A new area classification was therefore used in this study based on the spatial and temporal variations of the swordfish nominal CPUE distributions (**Figure 3**).

The catch ratios of albacore were higher than 90% for the Taiwanese tuna longline fishery before 1989 but dropped to 60~70% after 1990, while the catch ratios of bigeye tuna suddenly increased to 30~40% with a slightly increasing trend since 1990 (**Figure 4**). The fishery was therefore separated at 1990 into two periods for this fishery to conduct the standardization of swordfish CPUE. The catch ratios of swordfish were slightly increasing during the early 1990s with the increase of bigeye tuna catch, but dropped slightly thereafter until 2006 and increased in recent two years 2011-2012 (**Figure 4**).

The distributions of residuals in a log-scale from the GLM analyses based on a lognormal error model appeared normal (**Figure 5**). This assumption of lognormal error distributions was further confirmed according to the Q-Q plots (**Figure 6**). Deviance tables were used to summarize the model selection process for the GLM analyses for 1967-2012, 1967-1989, 1990-1999, and 2000-2012, respectively (**Table 1**). All the explanatory variables considered in the model were statistically significant at $\alpha = 0.01$. Effects of year, area in the GLM accounted for the largest proportions of the explained deviance of the models 1967-2012, 1967-1989, and 1990-1999 with R^2 ranging from 0.284 to 0.324.

The effect of gear configuration was also statistically significant in the GLM analysis, with R^2 increasing from 0.122 to 0.137 with the inclusion of this covariate in the model (**Table 1**). The inclusion of this factor could capture potential changes in the development of deep longline operations targeting bigeye tuna in tropical areas since the 1990s. This is expected because the inclusion of gear configuration increased substantially the explained deviance in the GLM analysis (**Table 1**). The R^2 and AIC values indicated that the full models (including the variable of HPB for the model 2000-2012) provided the best fits to the data (**Table 1**).

In general, the relative abundance indices of swordfish developed in this study were insensitive to the separation of two periods, 1967-1989 and 1990-1999 (upper panel in **Figure 7**). Standardized CPUE of swordfish with HPB information included in the model (2000-2012) was slightly higher than that derived from the models without HPB (lower panel in **Figure 7**). We suggest the standardized CPUE of swordfish from the model with HPB included to be used as a relative abundance index in the stock assessments.

In summary, the trend in standardized CPUE of swordfish was consistent with that derived from the previous study by Sun *et al*. (2010; 2013). The standardized CPUE of swordfish showed a decreasing trend from 1967 through 1990, but increased to a relatively high level during 1991 to 1997, and sharply decreased in the late 1990s, and slightly decreased from 2000 until 2012 (**Figure 7; Table 2**).

References

Chang, S.K., Lee, H.H., and Liu, H.I. 2007, Standardization of South Atlantic swordfish by-catch rate for Taiwanese longline fleet. Col. Vol. Sci. Pap. ICCAT, 60: 1974-1985.

ICCAT. 2007, Report of the 2006 Atlantic swordfish stock assessment session. Col. Vol. Sci. Pap. ICCAT, 60: 1787-1896.

ICCAT. 2010, Report of the 2009 Atlantic swordfish stock assessment session. Col. Vol. Sci. Pap. ICCAT, 65: 1-123.

Lee, Y.C., Nishida, T., Mohri, M. 2005. Separation of the Taiwanese regular and deep tuna longliners in the Indian Ocean using bigeye tuna catch ratios. Fish. Sci., 71: 1256-1263.

Maunder, M.N. and Punt, A.E. 2004, Standardizing catch and effort data: a review of recent approaches. Fish. Res., 70: 141-159.

Nelder, J.A. and Wedderburn, R.W.M. 1972, Generalised linear models. J. R. Statist. Soc. A, 137: 370-384.

Sun, C.L., Chang, Y.J., Yeh, S.Z., and Wu, W.J. 2010, Standardizing catch and effort data for South Atlantic swordfish of the Taiwanese longline fishery. Col. Vol. Sci. Pap. ICCAT, 65: 249-263.

Sun, C.L., Su, N.J., Yeh, S.Z. 2012, CPUE standardization of blue marlin (*Makaira nigricans*) for the Taiwanese longline fishery in the Atlantic Ocean. Col. Vol. Sci. Pap. ICCAT, 68: 1470-1478.

Sun, C.L., Su, N.J., Yeh, S.Z. 2013. Standardizing catch and effort data of the Taiwanese distant-water longline fishery in the South Atlantic Ocean for swordfish (*Xiphias gladius*). Atlantic swordfish data preparatory meeting, International Commission for the Conservation of Atlantic Tunas (ICCAT). 3-10 June 2013, Madrid, Spain. 14 pp.

Table 1. Deviance tables and AIC values for the models selected to standardize the catch and effort data of the Taiwanese distant-water tuna longline fishery for swordfish in the South Atlantic Ocean for 1967-2012, 1967-1989, 1990-1999, and 2000-2012. The area stratification used in GLM is shown in **Figure 2**. HPB denotes the number of hooks per basket.

	Degree of freedom	*Residual deviance*	*Deviance explained*	R^2	$P(\chi^2)$	*AIC*
1967-2012						
NULL	15767	22105				
+Year	15722	19512	2593	0.117	<0.01	48201
+Season	15719	19492	20	0.118	<0.01	48191
+Area	15716	15995	3496	0.276	<0.01	45079
+Season:Area	15707	15834	161	**0.284**	<0.01	44938
1967-1989						
NULL	5786	7148.4				
+Year	5764	6173.4	975	0.136	<0.01	16845
+Season	5761	6161.6	12	0.138	<0.01	16840
+Area	5758	4905.3	1256	0.314	<0.01	15526
+Season:Area	5749	4830.1	75	**0.324**	<0.01	15455
1990-1999						
NULL	3741	6267				
+Year	3732	5869	398	0.063	<0.01	12326
+Season	3729	5855	15	0.066	<0.01	12322
+Area	3726	4418	1437	0.295	<0.01	11275
+Season:Area	3717	4376	42	**0.302**	<0.01	11257
2000-2012						
NULL	11798	12292				
+Year	11786	11982	310	0.025	<0.01	33693
+Season	11783	11878	103	0.034	<0.01	33597
+Area	11780	10894	984	0.114	<0.01	32583
+Season:Area	11771	10795	99	0.122	<0.01	32493
+HPB	11755	10607	188	**0.137**	<0.01	32318

Table 2. Standardized CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean for 1967-1989, 1990-1999, and 2000-2012.

Year	*CPUE*	*SE*	*Year*	*CPUE*	*SE*
1967	0.111	0.282	1990	0.211	0.075
1968	0.189	0.091	1991	0.382	0.067
1969	0.246	0.073	1992	0.413	0.081
1970	0.185	0.061	1993	0.287	0.064
1971	0.233	0.068	1994	0.404	0.060
1972	0.238	0.094	1995	0.277	0.053
1973	0.242	0.092	1996	0.307	0.049
1974	0.211	0.072	1997	0.224	0.048
1975	0.145	0.075	1998	0.126	0.061
1976	0.072	0.072	1999	0.158	0.042
1977	0.071	0.068	2000	0.192	0.051
1978	0.084	0.078	2001	0.169	0.050
1979	0.084	0.101	2002	0.166	0.048
1980	0.143	0.085	2003	0.160	0.051
1981	0.153	0.076	2004	0.127	0.046
1982	0.133	0.072	2005	0.119	0.047
1983	0.131	0.069	2006	0.161	0.050
1984	0.100	0.062	2007	0.132	0.048
1985	0.086	0.061	2008	0.148	0.050
1986	0.098	0.060	2009	0.120	0.049
1987	0.096	0.081	2010	0.102	0.050
1988	0.076	0.161	2011	0.109	0.048
1989	0.072	0.186	2012	0.103	0.052

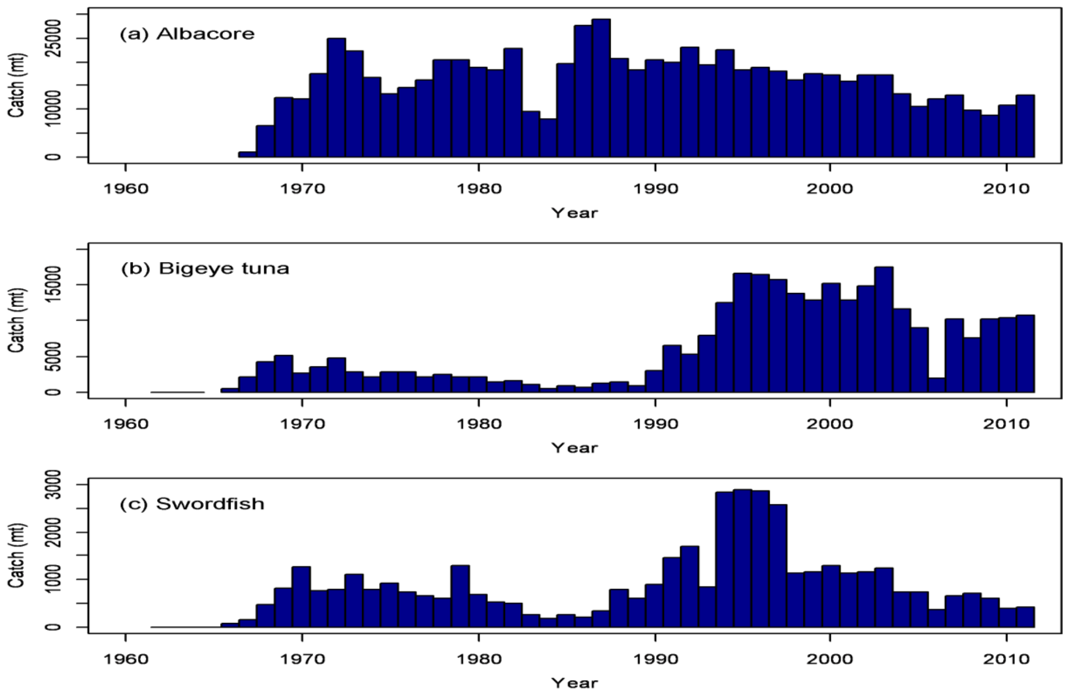

Figure 1. Annual catches of (a) albacore, (b) bigeye tuna, and (c) swordfish for the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean.

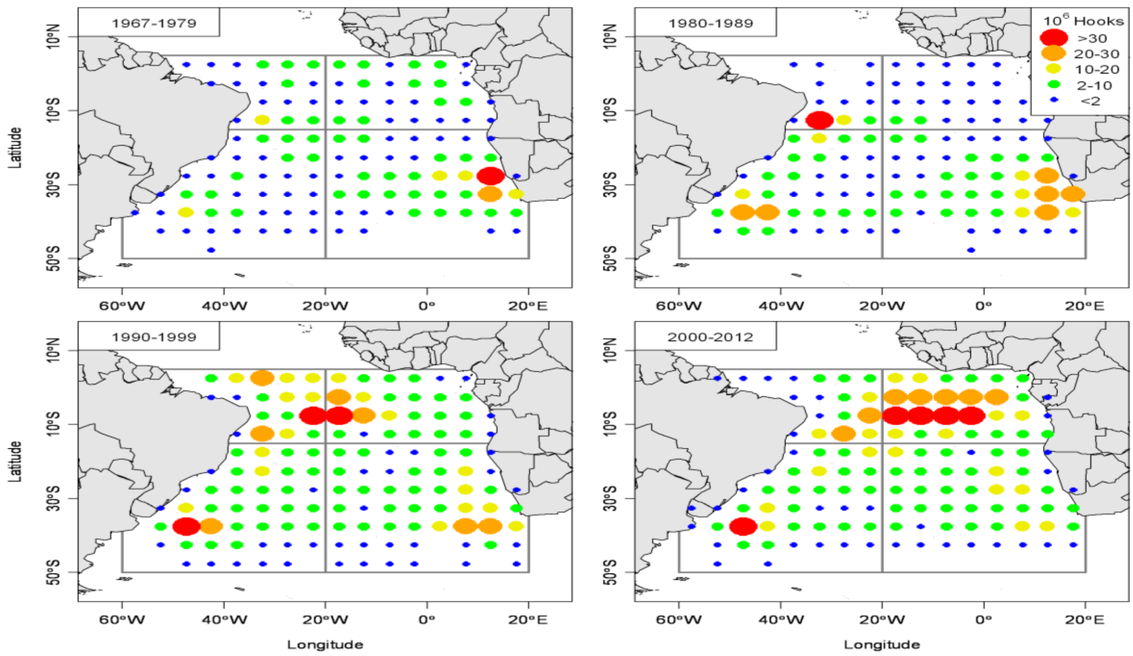

Figure 2. Distributions of fishing effort (in hooks) of the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean for 1967-1979, 1980-1989, 1990-1999, and 2000-2012. The area stratification of the South Atlantic Ocean was used in the GLM.

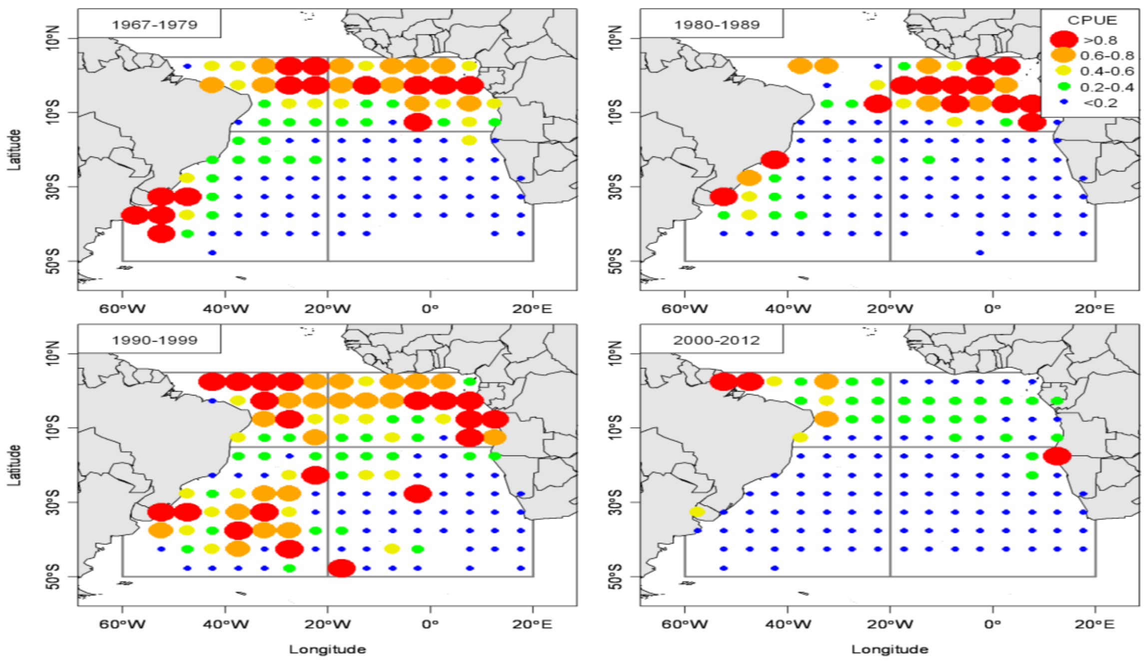

Figure 3. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean for 1967-1979, 1980-1989, 1990-1999, and 2000-2012.

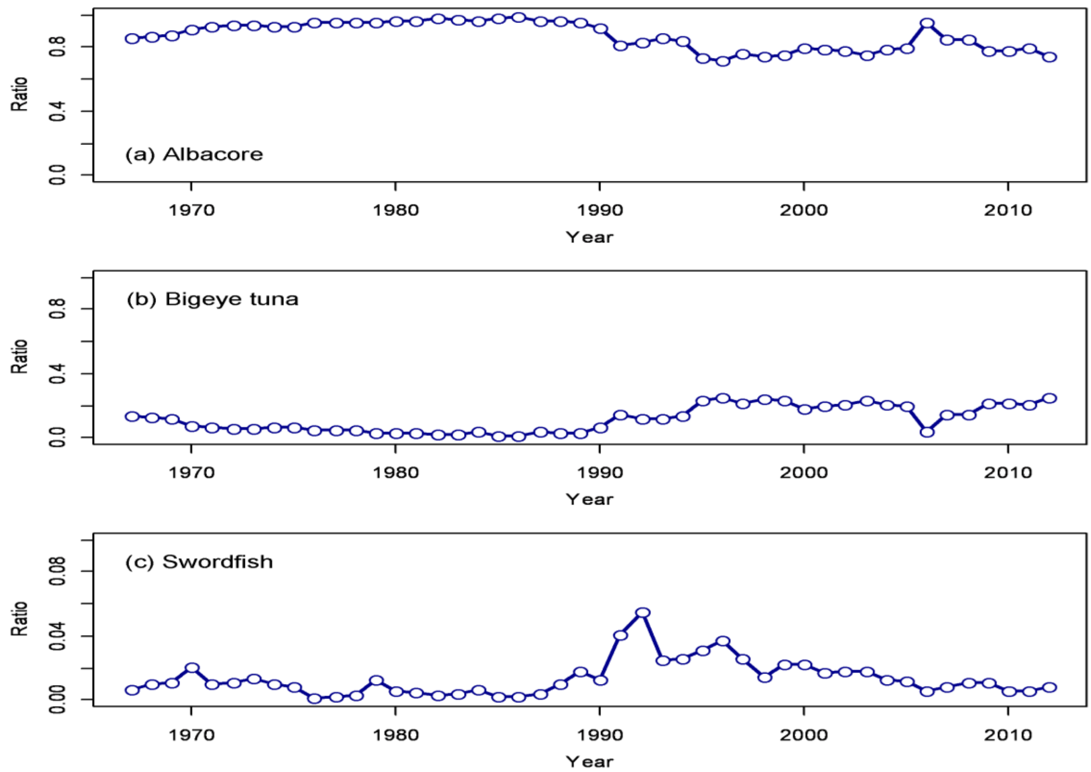

Figure 4. Catch ratios of (a) albacore, (b) bigeye tuna, and (c) swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean.

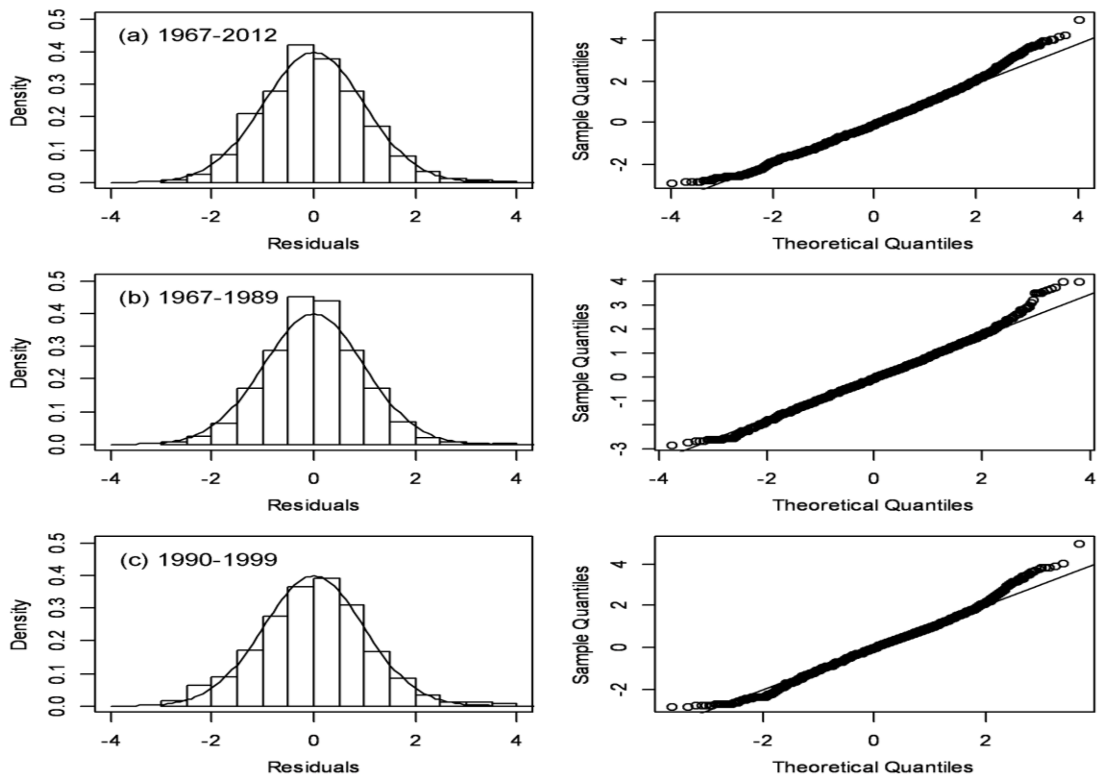

Figure 5. Diagnostic plots (residual distributions and Q-Q plots) for the GLM analyses for (a) 1967-2012, (b) 1967-1989, and (c) 1990-1999.

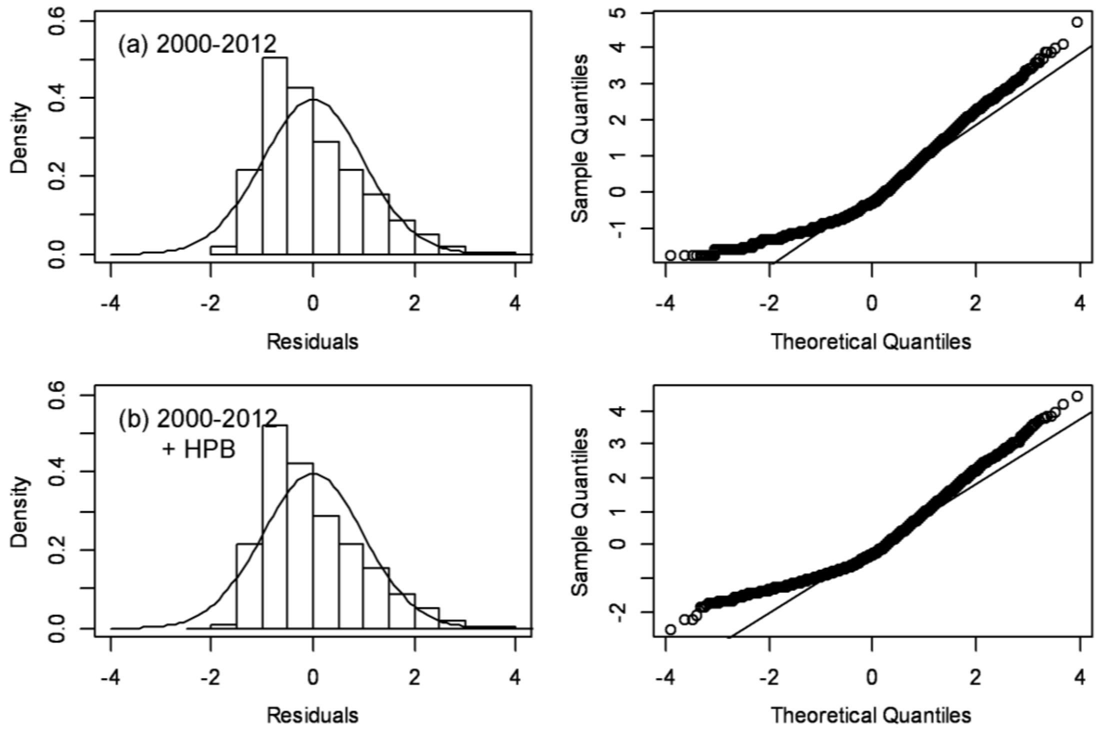

Figure 6. Diagnostic plots (residual distributions and Q-Q plots) for the GLM analyses for (a) 2000-2012 and (b) 2000-2012 with hooks per basket (HPB) information.

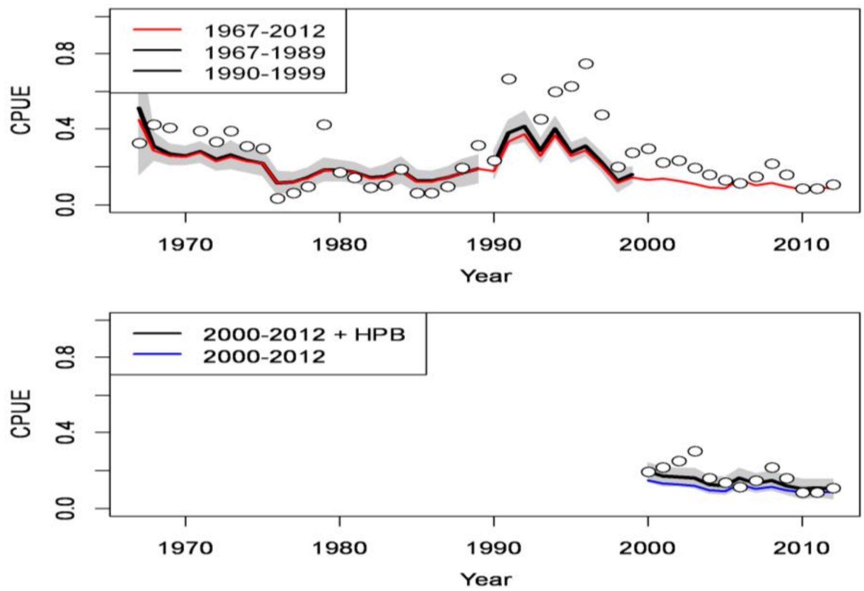

Figure 7. Nominal (open circles) and standardized (lines) CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean. The shaded areas indicate confidence intervals for the standardized CPUE.