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STANDARDIZING CATCH AND EFFORT OF THE TAIWANESE DISTANT-WATER TUNA LONGLINE FISHERY IN THE SOUTH ATLANTIC OCEAN FOR SWORDFISH (*XIPHIAS GLADIUS*), 1968-2015

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SUMMARY

*Catch and effort data of the Chinese Taipei distant-water tuna longline fishery in the South Atlantic Ocean were standardized for swordfish (*Xiphias gladius*) by applying a generalized linear model (GLM). Four periods (1968-2015, 1968-1990, 1991-2015 and 1998-2015) and the information on operation type (i.e. number of hooks per basket, HPB) 1998-2015 were considered in the standardization of CPUE (catch per unit effort) for swordfish to address the issue of targeting change for this fishery. The standardized CPUE of swordfish for 1968-1990 and 1991-2015 were almost identical to the results based on the model applied for the entire period (1968-2015). Inclusion of HPB in the model for 1998-2015 produced similar and consistent trends, with a slight difference in the late 1990s, to that for the 1968-2015. In general, the standardized CPUE series for the South Atlantic swordfish showed a decreasing trend through the 1970s, and relatively stabilized during the 1980s, and then decreased from the early 1990s, with a drop to a lower level in the late 1990s, and stabilized from 1998 until present.*

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 un modèle linéaire généralisé (GLM). Quatre périodes (1968-2015, 1968-1990, 1991-2015 et 1998-2015) et des informations sur le type d'opération (à savoir le nombre d'hameçons par panier (HPB), pour le modèle de 1998-2015) ont été prises en compte dans la standardisation de la CPUE (capture par unité d'effort) afin de tenir compte du changement de ciblage de cette pêcherie. La CPUE standardisée de l'espadon pour les périodes 1968-1990 et 1991-2015 était pratiquement identique aux résultats fondés sur le modèle appliqué à l'ensemble de la période (1968-2015). L'inclusion du HPB dans le modèle pour 1998-2015 a produit des tendances similaires et constantes, avec une légère différence à la fin des années 90, par rapport à celle de 1968-2015. En général, les séries de CPUE standardisée de l'espadon de l'Atlantique Sud affichaient une tendance à la baisse au cours des années 70 et se sont relativement stabilisées au cours des années 80 avant de diminuer depuis le début des années 90, de connaître une chute à un niveau inférieur à la fin des années 90, et de se stabiliser à partir de 1998 jusqu'à présent.*

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 un modelo lineal generalizado (GLM). Se consideraron cuatro periodos (1968-2015, 1968-1990, 1991-2015 y 1998-2015) y la información sobre el tipo de operación (es decir, el número de anzuelos por cesta (HPB)) para 1998-2015) se consideró en la estandarización de la CPUE (captura por unidad de esfuerzo) para el pez espada con el fin de tener en cuenta el problema del cambio en la estrategia de pesca en función de la especie objetivo en esta pesquería. Las CPUE estandarizadas de pez espada para 1968-1990 y 1991-2015 fueron casi idénticas a los resultados basados en el modelo aplicado al periodo completo (1968-2015). La inclusión de HPB en el modelo para 1998-2015 produjo tendencias similares y constantes, con una ligera diferencia a finales de los 90, a las del periodo 1968-2015. En general, la serie de CPUE estandarizada para el pez espada en el Atlántico sur mostraba una tendencia descendente durante los 70, y se estabilizaba relativamente durante los 80, descendiendo posteriormente desde principios de los 90, con una caída a un nivel menor a finales de los 90, y se ha estabilizado desde 1998 hasta el presente.*

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KEYWORDS

GLM, CPUE standardization, swordfish, index, longline, targeting change

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, coastal and offshore waters (ICCAT 2010). Most swordfish were caught as a bycatch in longline fisheries that target tunas (*e.g*., the 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 2014). 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 (Neilson *et al*. 2013).

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 suddenly increased to more than 2,500 tons in the early 1990s due to the development of deep longlining operations in tropical areas that target bigeye tuna (*Thunnus obesus*) (**Figure 1**). However, the catch of swordfish from this fishery reduced to around 1,500 tons in the late 1990s to 2000s due to the catch regulations by ICCAT. The catch of swordfish was further decreased to 600~700 tons in 2008 and 2009, and about 400 tons in recent years, because of the decrease in fishing effort through the implementation of 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 a generalized linear model (GLM) by assuming a delta lognormal error distribution with main explanatory variables including year and bi-month, geographical area, and 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 the early 1990s from 1991 to 1996, but dropped sharply in the late 1990s (Sun *et al*. 2014).

The objectives of this study were to assess how the targeting change might influence the swordfish CPUE caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean by conducting the analysis for four 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 stock assessments and population modeling.

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 1968-2015 (Task II) and 1995-2015 (because the 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 from the middle of the 1990s. The two data sets were further grouped into 5° grids of latitude and longitude in each month for analyses. 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 of tunas (see 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 at 1990 to address the targeting change based on catch data and the catch ratios as defined as follows:

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

where ALB, BET, and SWO are catches in number of albacore, bigeye tuna, and swordfish by 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 to develop relative abundance indices in this study can be written as:

$CPUE_{SWO}$ ~ Year + Season + Area + Season:Area (for 1968-2015, 1968-1990, 1991-2015);

$CPUE_{SWO}$ ~ Year + Season + Area + Season:Area + HPB (for 1998-2015);

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 (**Figure 1)**. Information on gear configuration (*i.e.*, HPB) was available from logbook data since 1995. Therefore a model for 1998-2015 was considered in the GLM analysis because of the availability of this variable and a TAC regulation at 14,620 mt starting from 1998 (Neilson *et al*. 2013). The impact of HPB was considered in the CPUE standardization because there is a potential relationship between the targeting change and catch rates of bycatch species as suggested by previous studies (*e.g*., Chang *et al*. 2007; Sun *et al*. 2012).

A forward stepwise technique was used to identify the appropriate set of explanatory variables for each model of the GLM 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 applied to assess the model fits and the assumption of error models. Alternative models and the inclusion of gear configuration were further evaluated using the Akaike information criterion (AIC) and deviance explained, *i.e.* 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.

3. Results and Discussion

There were 19,972 catch and effort records (Task II) for 1968-2015, and 15,005 records with gear configuration information (HPB) for 1998-2015 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 1**), due to the targeting changed from albacore to bigeye tuna. Therefore, the catch of bigeye tuna from this fishery increased substantially since the early 1990s (**Figure 2**).

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% since 1990, with a slightly increasing trend during the 1990s (**Figure 3**). The fishery was therefore separated at 1990 into two periods for this fishery to conduct the CPUE standardization for swordfish. The catch ratios of swordfish were increasing during the early 1990s, with the increase of bigeye tuna catch, but dropped slightly thereafter until 2006, and stabilized during the last decade until present (**Figure 3**).

High CPUE of swordfish occurred in tropical waters of the central Atlantic Ocean (**Figure 4**), suggesting that spatial covariates are likely to be an important factor in determining catchability of swordfish caught in the Taiwanese tuna 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 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 1968-2015, 1968-1990, 1991-2015 and 1998-2015, respectively (see **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 for the models of 1968-2015, 1968-1990 and 1991-2015, with R^2 ranging from 0.247 to 0.322.

When gear configuration was included in the model, the effect of this covariate was statistically significant in the GLM analysis, although to be a minor effect increasing R^2 from 0.123 to 0.134 (**Table 1**). The inclusion of this factor could capture potential changes in the development of deep longlining operations that target bigeye tuna in tropical areas since the early 1990s. This is expected because the inclusion of gear configuration also led to an increase in deviance explained in the GLM analysis. The R^2 and AIC values indicated that the full models (with HPB included in the model of 1998-2015) provided the best fits to the data (**Table 1**).

The relative abundance indices of swordfish developed in this study were, in general, somewhat insensitive to the separation of two periods, 1968-1990 and 1991-2015 (**Figure 7**). The trend in standardized CPUE of swordfish with HPB information included in the model for 1998-2015 was slightly different from those derived from the models without HPB (1991-2015). Given statistical significance of HPB in the model, we suggest that the standardized CPUE of swordfish should be developed with the inclusion of HPB in the model and used as relative abundance indices in population modeling and assessments.

In summary, the trend in standardized CPUE of swordfish was consistent with that derived from the previous study by Sun *et al*. (2010; 2014). The standardized CPUE for the South Atlantic swordfish showed a decreasing trend through the 1970s, and stabilized relatively during the 1980s and decreased from the early 1990s, with a drop to a lower level in the late 1990s, and then the trend stabilized from 1998 until present (**Figure 7**).

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Table 1. Deviance tables and AIC values for the models selected to standardize CPUE of swordfish for the Taiwanese distant-water longline fishery in the South Atlantic Ocean. Area stratification used in GLM is shown in **Figure 1**. HPB denotes the number of hooks per basket.

Model	**Res. D.F.**	**Res. Dev**	**Dev. Exp.**	R^2	***p*-value**	**AIC**
1968-2015						
NULL	19965	27073				62745
+Year	19918	23605	3468	0.128	<0.001	60102
+Season	19915	23583	22	0.129	<0.001	60090
+Area	19912	20205	3379	0.254	<0.001	57008
+Season:Area	19903	20031	174	0.260	<0.001	56854
1968-1990						
NULL	5993	7455				18322
+Year	5971	6482	973	0.130	<0.001	17528
+Season	5968	6471	11	0.132	0.005	17524
+Area	5965	5129	1342	0.312	<0.001	16136
+ Season:Area	5956	5055	75	0.322	<0.001	16066
1991-2015						
NULL	13971	19563				44358
+Year	13947	17123	2440	0.125	<0.001	42544
+Season	13944	17094	29	0.126	<0.001	42527
+Area	13941	14804	2290	0.243	<0.001	40523
+ Season:Area	13932	14729	75	0.247	<0.001	40470
1998-2015+HPB						
NULL	15004	17867				45206
+Year	14987	17360	508	0.028	<0.001	44807
+Season	14984	17257	102	0.034	<0.001	44725
+Area	14981	15813	1445	0.115	<0.001	43419
+ Season:Area	14972	15664	149	0.123	<0.001	43295
+HPB	14958	15471	193	0.134	<0.001	43137

Table 2. Standardized CPUE of swordfish for the Taiwanese distant-water longline fishery in the South Atlantic Ocean from models of 1968-1990, 1991-2015 and 1998-2015+ HPB.

Year	Std.CPUE	CV	Year	Std.CPUE	CV
Model 1968-1990			**Model 1998-2015+HPB**		
1968	0.311	7.492	1998	0.167	6.041
1969	0.270	5.357	1999	0.126	4.721
1970	0.262	4.995	2000	0.139	4.492
1971	0.282	5.435	2001	0.120	4.079
1972	0.241	5.546	2002	0.118	3.765
1973	0.267	7.215	2003	0.112	4.173
1974	0.236	5.915	2004	0.088	3.451
1975	0.222	6.312	2005	0.082	3.552
1976	0.117	5.848	2006	0.115	4.032
1977	0.121	5.350	2007	0.092	3.746
1978	0.144	5.143	2008	0.105	4.001
1979	0.187	6.052	2009	0.084	3.849
1980	0.182	5.309	2010	0.071	3.962
1981	0.175	5.168	2011	0.076	3.662
1982	0.142	4.936	2012	0.073	3.929
1983	0.149	6.171	2013	0.093	4.156
1984	0.186	6.829	2014	0.078	4.226
1985	0.126	5.827	2015	0.087	4.446
1986	0.124	5.248			
1987	0.146	5.339			
1988	0.170	7.238			
1989	0.189	7.328			
1990	0.175	6.252			
Model 1991-2015					
1991	0.320	6.147			
1992	0.380	7.460			
1993	0.246	5.872			
1994	0.356	5.507			
1995	0.251	4.889			
1996	0.290	4.520			
1997	0.202	4.467			

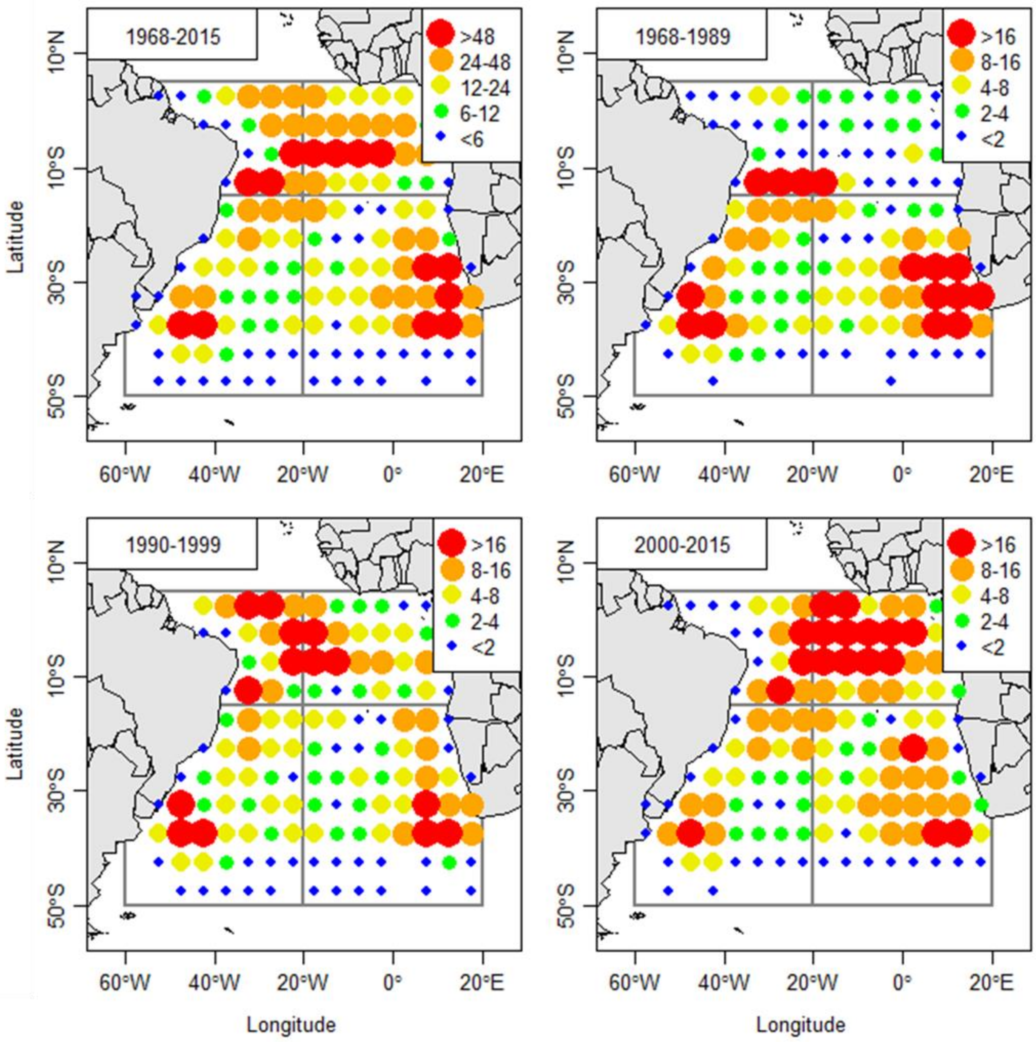

Figure 1. Distributions of fishing effort (in 10^6 hooks) for the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean for 1968-2015 and by period of 1968-1989, 1990-1999 and 2000-2015. The area stratification of the South Atlantic Ocean was used in the GLM analyses.

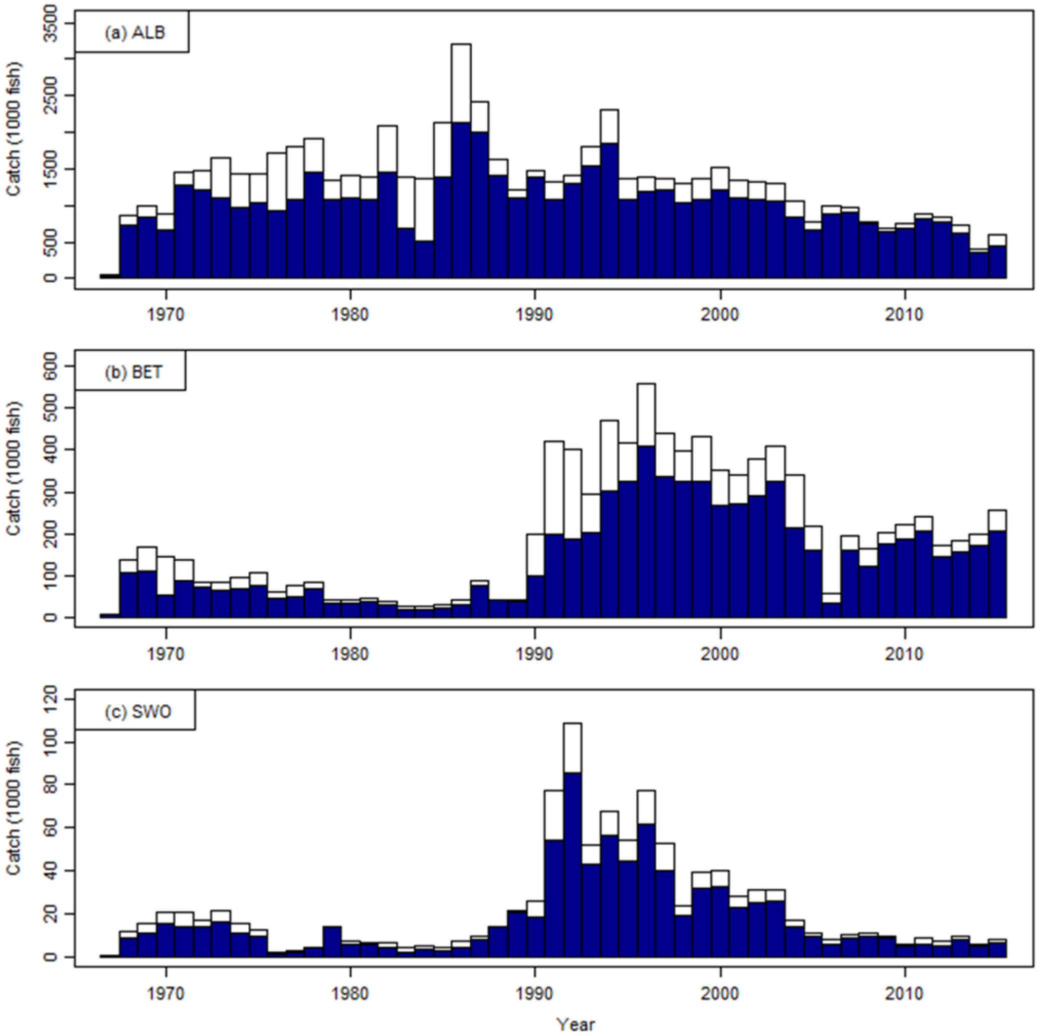

Figure 2. Annual catches in number of (a) albacore, (b) bigeye tuna and (c) swordfish caught in the Taiwanese distant-water tuna longline fishery in the South (solid bars) and North (white bars) Atlantic Ocean.

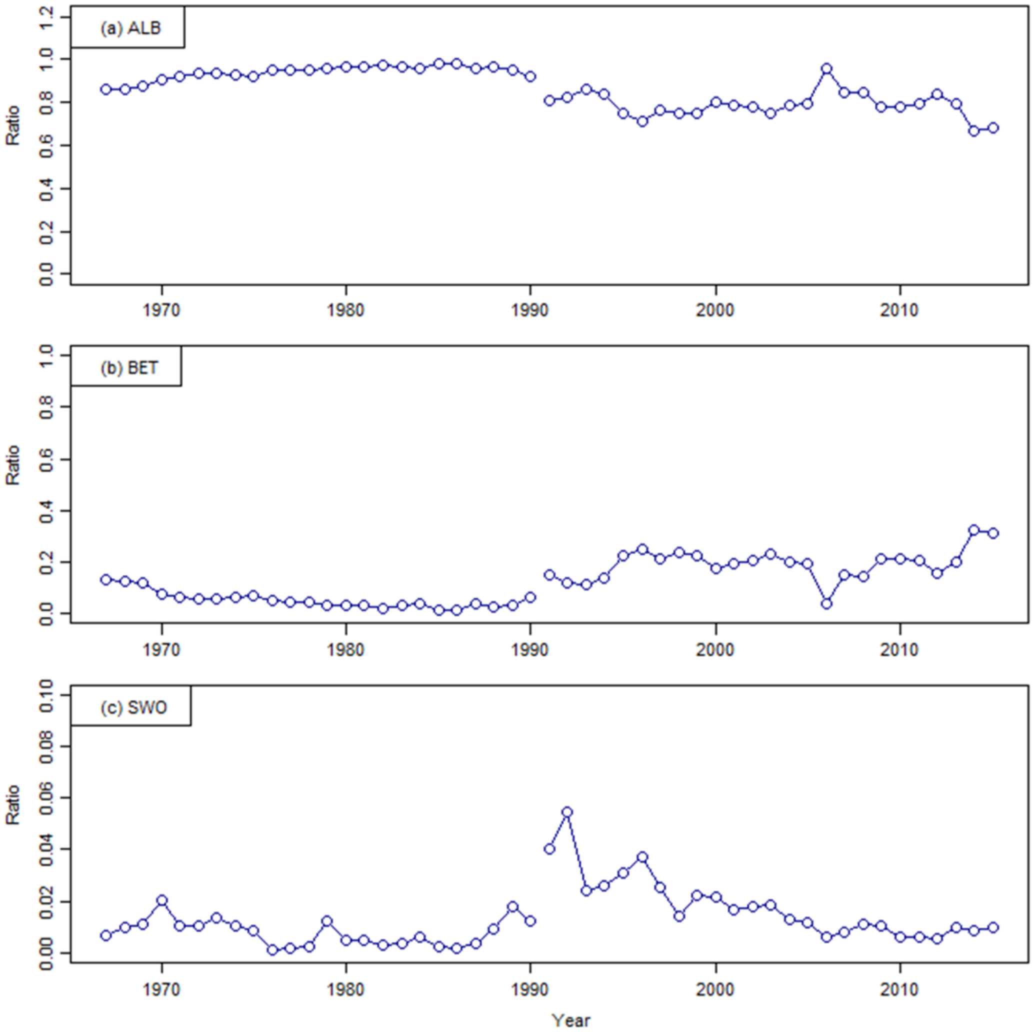

Figure 3. Catch ratios by species for (a) albacore, (b) bigeye tuna and (c) swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean.

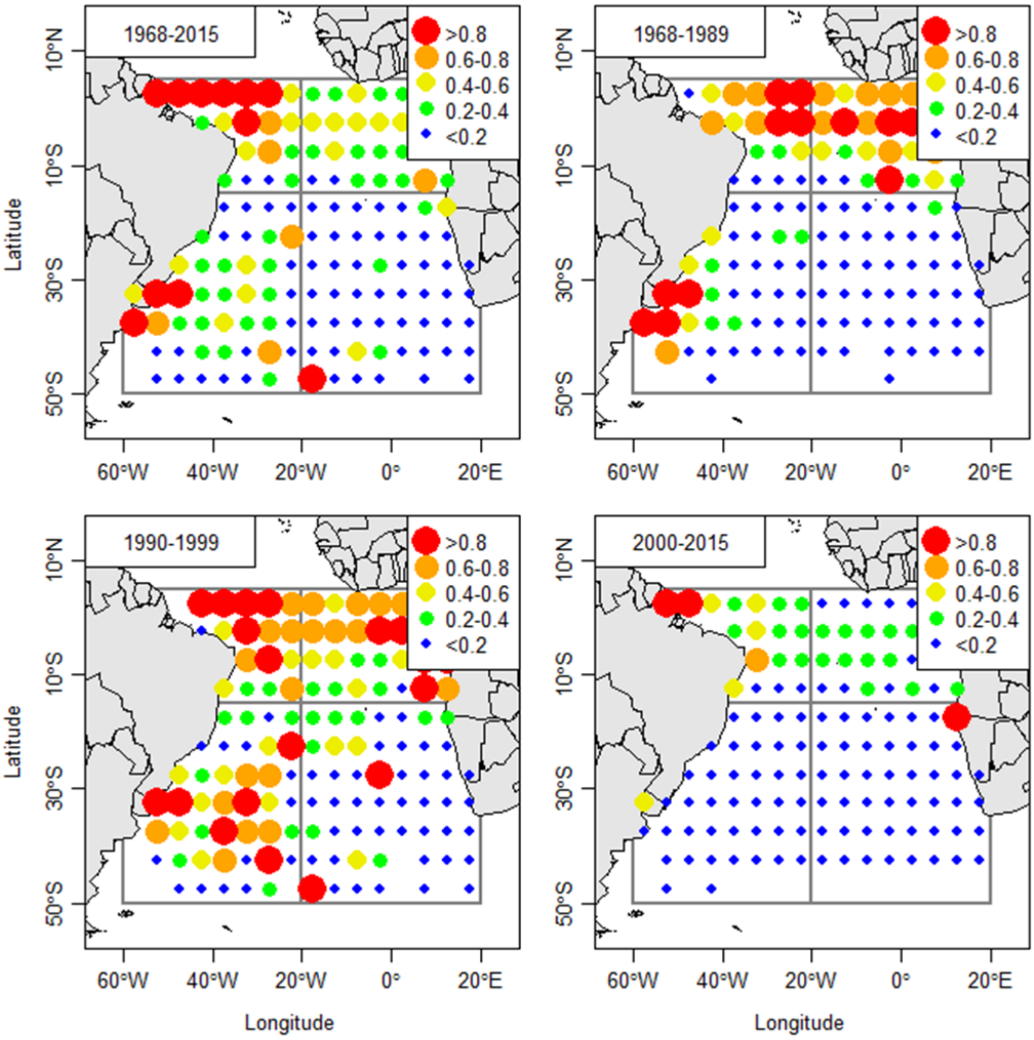

Figure 4. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean for 1968-2015, 1968-1989, 1990-1999 and 2000-2015.

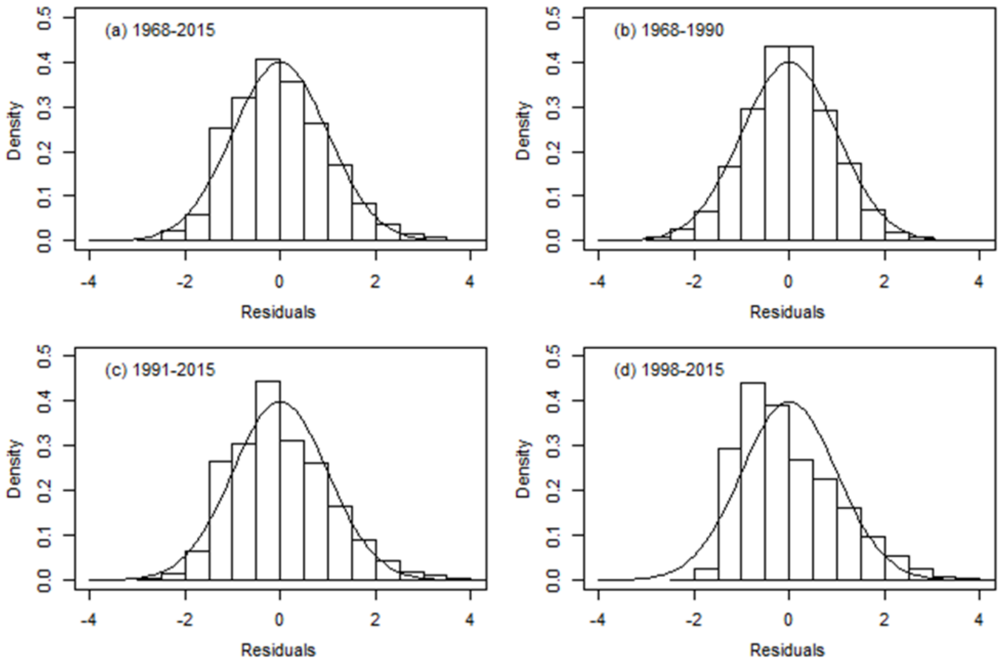

Figure 5. Diagnostic plots of residual distribution for the models of (a) 1968-2015, (b) 1968-1990, (c) 1991-2015 and (d) 1998-2015+HPB in the GLM analyses.

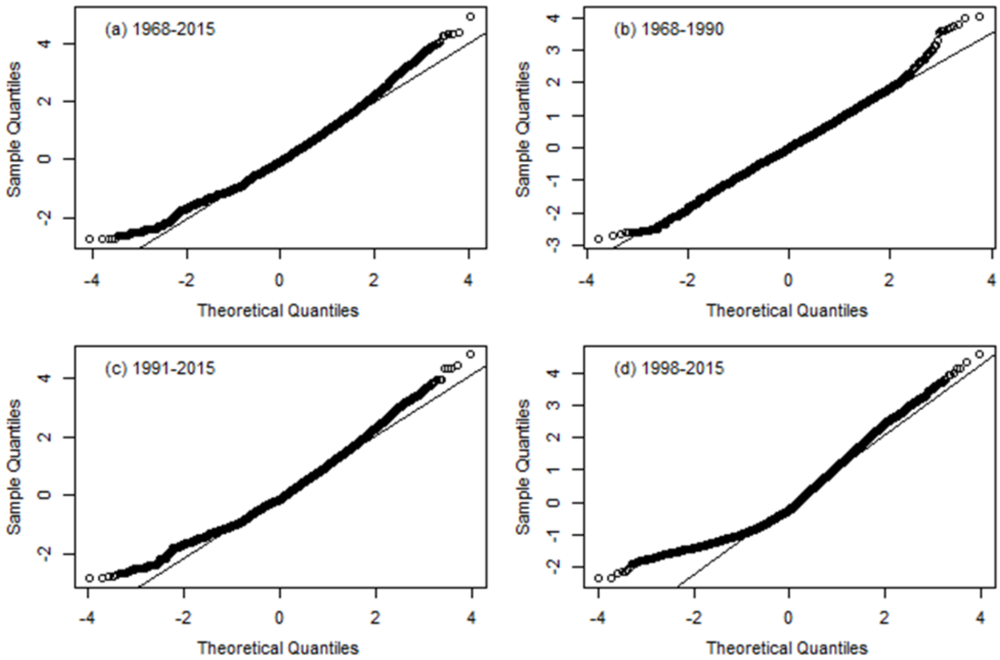

Figure 6. Diagnostic Q-Q plots for the models of (a) 1968-2015, (b) 1968-1990, (c) 1991-2015 and (d) 1998-2015+HPB in the GLM analyses.

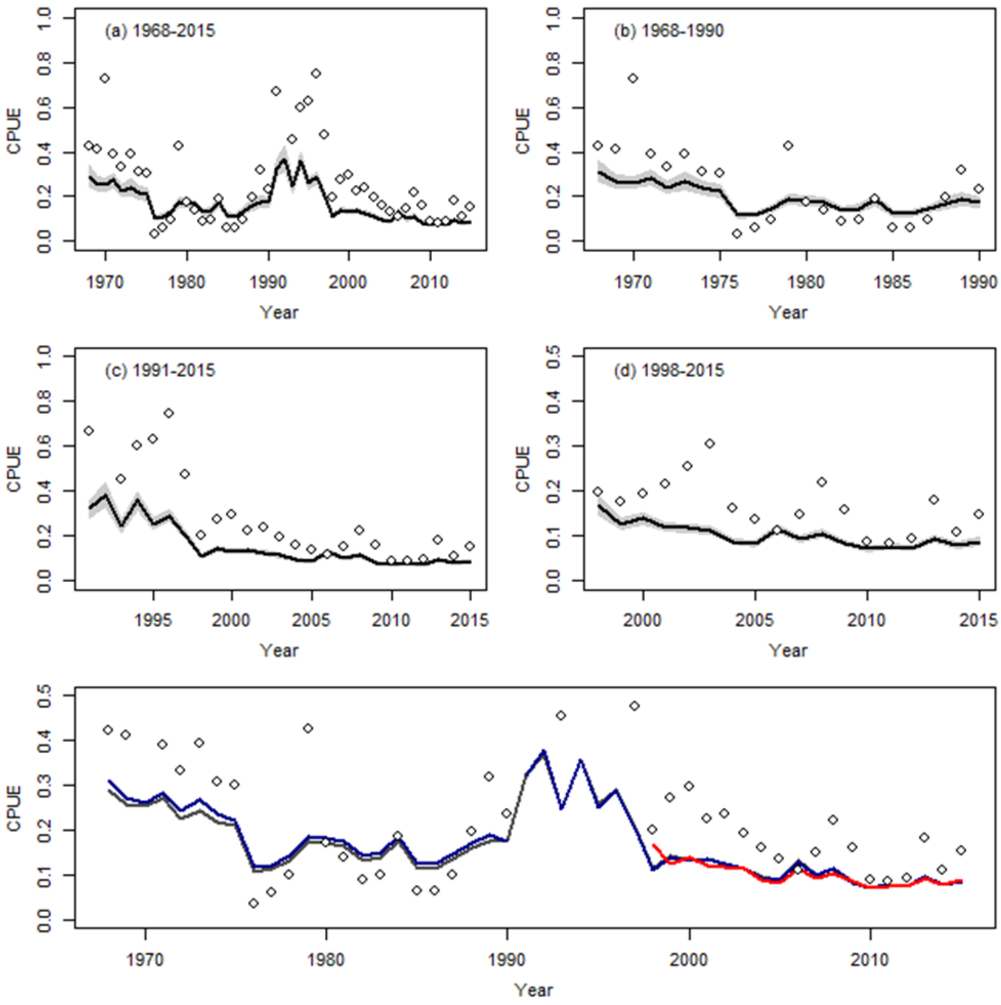

Figure 7. Nominal (open circles) and standardized (lines) CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery in the South Atlantic Ocean. Results are shown for various models and a comparison among models (lower panel). The shaded areas indicate 95% confidence intervals for the estimates of standardized CPUE.