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CPUE STANDARDIZATION OF SWORDFISH (*XIPHIAS GLADIUS*) FOR THE TAIWANESE TUNA LONGLINE FISHERY IN THE NORTH ATLANTIC OCEAN FOR 1968-2015

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SUMMARY

*Catch and effort data of swordfish (*Xiphias gladius*) for the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean were standardized for 1968-2015 and by period using a generalized linear model (GLM). Four periods of 1968-2015, 1968-1989, 1990-2015 and 1997-2015 and information on operation type (the number of hooks per basket, HPB, for the model of 1997-2015) were considered in the standardization of CPUE (catch per unit effort) to address the issue of targeting change in this fishery. Abundance indices developed for swordfish for 1968-1989, 1990-2015 and 1997-2015 showed almost identical trends to those derived from the model of entire period (1968-2015). Results were insensitive to the inclusion of gear configuration (HPB) in the model as an explanatory variable. The standardized CPUE trend of swordfish started to decrease in the early 1970s, with another following slight decrease during the 1980s, but suddenly increased to a higher level during the early 1990s due to the targeting change and dropped sharply in the late 1990s, and then the trend stabilized from 1997 until present.*

RÉSUMÉ

*Les données de prise et d'effort de la pêcherie palangrière d'espadon (*Xiphias gladius*) du Taipei chinois opérant en eaux lointaines dans l'océan Atlantique Nord ont été standardisées pour 1968-2015 et par période en appliquant un modèle linéaire généralisé (GLM). Quatre périodes de 1968-2015, 1968-1989, 1990-2015 et 1997-2015 et des informations sur le type d'opération (le nombre d'hameçons par panier (HPB), pour le modèle de 1997-2015) 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. Les indices d'abondance développés pour l'espadon pour 1968-1989, 1990-2015 et 1997-2015 ont montré des tendances presque identiques à celles obtenues à partir du modèle de l'ensemble de la période (1968-2015). Les résultats n'étaient pas sensibles à l'inclusion de la configuration de l'engin (HPB) dans le modèle en tant que variable explicative. La tendance de la CPUE standardisée de l'espadon a commencé à diminuer au début des années 70, suivie d'une autre légère diminution au cours des années 80, mais a soudainement augmenté pour atteindre un niveau plus élevé au début des années 90 en raison du changement de ciblage et a fortement chuté à la fin des années 90, avant de se stabiliser depuis 1997 à aujourd'hui.*

RESUMEN

Se estandarizaron los datos de captura y esfuerzo del pez espada (Xiphias gladius) p*ara la pesquería atunera de palangre de aguas distantes de Taipei Chino en el Atlántico norte para el periodo 1968-2015 y por periodo utilizando un modelo lineal generalizado (GLM). Se consideraron cuatro periodos 1968-2015, 1968-1989, 1990-2015 y 1997-2015 y la información sobre el tipo de operación (el número de anzuelos por cesta (HPB) para el modelo de 1997-2015) en la estandarización de la CPUE (captura por unidad de esfuerzo) 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. Los índices de abundancia desarrollados para el pez espada para 1968-1989 y 1990-2015 presentaban tendencias casi idénticas a las derivadas del modelo para todo el periodo (1968-2015). Los resultados eran insensibles a la inclusión de la configuración del arte (HPB) en el modelo como variable explicativa. La tendencia de la CPUE estandarizada de pez espada empezaba a descender a principios de los 70, con un ligero descenso durante los 80, pero de repente aumentaron a un mayor nivel durante principios de los 90 debido al cambio en la especie objetivo y cayeron abruptamente a finales de los noventa y posteriormente la tendencia se ha estabilizado desde 1997 hasta el presente.*

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KEYWORDS

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

1. Introduction

Swordfish (*Xiphias gladius*) is a cosmopolitan highly migratory species widely distributed in the three oceans. Many countries fish for swordfish because of their highly economic values and relatively broad geographical distribution in pelagic and coastal waters. In the Atlantic Ocean, three management units, the Mediterranean and the North and South Atlantic stocks separated at 5°N, were defined and used by the International Commission for the Conservation of Atlantic Tuna (ICCAT) to carry out regular assessments and management (Kasapidis *et al*. 2006; Neilson *et al*. 2013). The separation for Mediterranean stock and the existence of two stocks of swordfish in the North and South Atlantic Ocean have been further confirmed by studies using mitochondrial DNA analysis (Alvarado Bremer *et al*. 1999; Alvarado Bremer *et al*. 2005).

The Taiwanese distant-water tuna longline fleets started to operate in the Atlantic Ocean since the early 1960s, and have operated throughout the Atlantic Ocean from the 1990s, targeting albacore (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*) (**Figure 1**). Although some small longliners targeted this species seasonally for the fresh fish market, swordfish is considered one of the most important bycatch species in this fishery (Chang *et al*. 2007). Despite most swordfish were caught in the South Atlantic Ocean, annual catches of swordfish for the northern stock were about 200 tons in average before 1990, but increased to more than 500 tons in the early 1990s due to the development of deep longline operation for bigeye tuna in tropical waters (Sun *et al*. 2010a). However, the catch of swordfish has decreased since 1998, with an average of more than 100 tons during 2004 to 2015, as a result of enhanced catch regulation for this species (ICCAT, 2010; 2014).

CPUE (catch per unit effort) standardization of swordfish for the Taiwanese distant-water tuna longline fleets has been carried out in several studies. For example, catch and effort data of this fishery were standardized based on generalized linear models (GLMs) assuming a delta lognormal error distribution (Chang *et al*. 2007), and that based on both GLMs and GAMs (generalized additive models) with a lognormal error distribution (Sun *et al*. 2010b). Alternative area stratification was considered in the CPEU standardization, but led to almost identical results (Sun *et al*. 2010b). However, most of these studies focused on the southern Atlantic stock of swordfish. The abundance index of swordfish in the North Atlantic Ocean from previous studies (Sun *et al*. 2010a; 2014) suggested a 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 and then stabilized from 2000 to 2010.

The objectives of this study were to assess how the targeting change might influence the swordfish CPUE for the Taiwanese distant-water tuna longline fishery in the North 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 swordfish for this fishery. The relative abundance index of swordfish developed in this study could be used in the stock assessment modeling, which provides suggestions for decision making and management purposes.

2. Materials and methods

2.1 Fishery data

Catch and effort data, expressed as the number of fish caught and the number of hooks employed, respectively, were obtained for the Taiwanese distant-water longline fishery in the North Atlantic Ocean from the Overseas Fisheries Development Council of the Republic of China (OFDC, Taipei). The tuna catch by this fishery consists of three species, albacore, bigeye tuna, and yellowfin tuna (*Thunnus albacares*). This fishery also captures swordfish, billfishes and sharks, but these latter two species are not considered in the analyses.

This data set contains information on time (year and month), fishing location (5º latitude and longitude), catch in number of fish caught, and effort in number of hooks. However, information on gear configuration (*i.e*., number of hooks per basket, HPB) is available from daily logbook data since 1995. Therefore, two data sets (1968-2015 without HPB information and 1995-2015 with HPB information included) were used in the GLM analyses, both of which were aggregated into monthly 5°×5° grids. CPUE of swordfish is expressed as the number of fish caught per 1000 hooks in this study.

2.2 Catch composition

Catch composition can be used to separate tuna longline fisheries that target different tuna 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 North Atlantic Ocean was separated into two periods to address the targeting change based on the catch ratios that are 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 model

A generalized linear model (GLM; Nelder and Wedderburn 1972), assuming a lognormal error distribution, was applied to standardize the catch and effort data of the Taiwanese distant-water longline fishery for swordfish. GLMs are the most commonly used approach for standardizing fishery data with the assumption that the expected value of a log-transformed response variable is related to a linear combination of multiple exploratory variables (Maunder and Punt 2004). Time (year and season), three geographic fishing areas, interaction between season and area and gear configuration (HPB) were included in the GLM analyses as main explanatory variables. The full GLM with interactions can be expressed as follows:

$CPUE_{SWO}$ ~ Year + Season + Area + Season:Area + HPB;

where $CPUE_{SWO}$ is nominal CPUE of swordfish with a small constant (10% of the grand mean) added to avoid taking the logarithm of zero. Year, season, and area are temporal and spatial effects. The area stratification used in GLM analysis was shown in **Figure 1**. No interactions with the year effect were considered in the GLM analyses (Maunder and Punt 2004). Models were developed for 1968-2015 and by periods separated at 1990 (*i.e*. 1968-1989 and 1990-2015) due to the targeting change on bigeye tuna.

A model for 1997-2015 was considered because the availability of HPB and a TAC regulation at 11,300 mt starting from 1997 (Neilson et al. 2013). The effect of gear configuration (HPB) was included in the models because their likely impacts on swordfish CPUE are recognized by previous studies (Sun *et al*. 2010a; 2014).

Alternative diagnostic analyses, *e.g*., the distributions of residuals and the quantile-quantile (Q-Q) plots, were used to examine the error models (assuming a lognormal distribution) in the GLM analyses. Standard methods, such as changes in residual deviance and the Akaike Information Criterion (AIC) values were used to compare alternative model structures of the GLMs.

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 in total 8,390 catch and effort records (Task II) for 1968-2015, and 4,995 records with information on gear configuration (HPB) for 1997-2015 used in the GLM analyses. The fishing ground of the Taiwanese tuna longline fishery was in the central North Atlantic Ocean before 1989, but shifted to tropical waters of the Atlantic Ocean since 1990 (**Figure 1**) due to the targeting changed from albacore in temperate waters to bigeye tuna in tropical Atlantic Ocean (**Figure 2**).

The catch ratios of albacore were higher than 90% for the Taiwanese tuna longline fishery before 1989 but dropped to about 60% after 1990, while the catch ratios of bigeye tuna suddenly increased to about 40% with a slightly increasing trend since 1990 (**Figure 3**). The fishery was therefore separated at 1990 into two periods. The catch ratios of swordfish were also increasing during the early 1990s, but dropped thereafter and remained relative stable during the last decade until recent years (**Figure 3**).

However, high CPUE of swordfish generally 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 the Taiwanese tuna longline fishery for swordfish. The area classification was thus used in the GLM analyses based on the fishing effort and nominal CPUE distributions of swordfish (**Figures 1 and 4**).

The deviance tables (**Table 1**) summarized the model selection process for the GLM analyses for 1968-2015, 1968-1989, 1990-2015 and 1997-2015 (with HPB included). All the explanatory variables and the interaction term considered in the models were statistically significant ($P < 0.01$). The distributions of residuals appeared to be normal in a log-scale for all GLM analyses based on an assumption of lognormal error distribution (**Figure 5**). This assumption was further confirmed according to the Q-Q plots (**Figure 6**).

Effects of year, area in the GLM accounted for the largest proportions of the explained deviance of the models 1968-2015, 1968-1989 and 1990-2015, with R^2 ranging from 0.264 to 0.278 (**Table 1**). The effect of gear configuration was also statistically significant in the GLM analysis, which might imply that the inclusion of this factor could capture some of the potential change in the development of deep longlining operations that target bigeye tuna in tropical areas since the 1990s, although R^2 increased slightly from 0.208 to 0.227 when this covariate was included in the model (**Table 1**).

The AIC values also indicated that the full models with HPB provided best fits to the data. We therefore suggest that the relative abundance index for swordfish in the North Atlantic Ocean should be developed based on the full model with the inclusion of HPB when more operation records with HPB are available from 1997 (**Table 1**). The trend in standardized CPUE of swordfish with HPB included in the model showed a negligible difference from those derived from the model of 1990-2015 without HPB included (**Figure 7**).

In general, the standardized CPUE of swordfish in the North Atlantic Ocean showed a decreasing trend in the early 1970s, but slightly increased from the late 1970s through the 1980s, and then suddenly increased to a higher level from 1990 to the middle 1990s, followed by a sharp decrease in the late 1990s. However, the trend of standardized swordfish CPUE was stabilized from 1997 until present, with slightly higher estimates in 2006 and 2011-2012 (**Figure 7**). The substantial decrease in standardized CPUE of swordfish in the late 1990s may result from the ICCAT recommendation to limit the catch of swordfish, which may cause the fishermen to release or discard the fish (Chang *et al.* 2007; Neilson *et al*. 2013; Sun *et al*. 2014).

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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 North 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	8388	13331				27697
+Year	8341	11176	2155	0.162	<0.001	26312
+Season	8338	11064	112	0.170	<0.001	26233
+Area	8336	9907	1158	0.257	<0.001	25310
+Season:Area	8330	9768	139	0.267	<0.001	25203
1968-1989						
NULL	3248	4211				10067
+Year	3227	3334	878	0.208	<0.001	9350
+Season	3224	3280	54	0.221	<0.001	9303
+Area	3222	3122	157	0.259	<0.001	9147
+ Season:Area	3216	3099	24	0.264	<0.001	9134
1990-2015						
NULL	5139	9110				17532
+Year	5114	7843	1267	0.139	<0.001	16812
+Season	5111	7711	132	0.154	<0.001	16731
+Area	5109	6691	1020	0.266	<0.001	16006
+ Season:Area	5103	6575	116	0.278	<0.001	15928
1997-2015+HPB						
NULL	4781	7409				15668
+Year	4763	6901	508	0.069	<0.001	15365
+Season	4760	6584	317	0.111	<0.001	15146
+Area	4758	6168	415	0.167	<0.001	14838
+ Season:Area	4752	6062	107	0.182	<0.001	14767
+HPB	4739	5874	188	0.207	<0.001	14642

Table 2. Standardized CPUE of swordfish for the Taiwanese distant-water longline fishery in the North Atlantic Ocean from models of 1968-1989, 1990-2015 and 1997-2015+ HPB.

Year	Std.CPUE	CV	Year	Std.CPUE	CV
Model 1968-1989			**Model 1997-2015+HPB**		
1968	0.168	9.908	1997	0.176	10.772
1969	0.221	7.999	1998	0.164	12.584
1970	0.164	6.606	1999	0.063	8.265
1971	0.212	7.367	2000	0.071	10.729
1972	0.217	10.286	2001	0.082	9.377
1973	0.221	10.085	2002	0.089	7.943
1974	0.191	7.892	2003	0.076	8.821
1975	0.127	8.235	2004	0.048	7.126
1976	0.058	7.823	2005	0.064	7.193
1977	0.058	7.414	2006	0.112	7.267
1978	0.069	8.550	2007	0.064	8.778
1979	0.069	11.093	2008	0.043	8.918
1980	0.126	9.283	2009	0.052	9.404
1981	0.137	8.286	2010	0.039	8.592
1982	0.117	7.810	2011	0.091	8.585
1983	0.117	7.474	2012	0.101	9.647
1984	0.086	6.776	2013	0.069	10.175
1985	0.073	6.599	2014	0.075	11.648
1986	0.084	6.565	2015	0.073	8.835
1987	0.081	8.901			
1988	0.062	17.851			
1989	0.056	20.800			
Model 1990-2015					
1990	0.185	14.839			
1991	0.134	9.633			
1992	0.274	13.758			
1993	0.181	11.862			
1994	0.148	8.827			
1995	0.155	9.166			
1996	0.256	7.928			

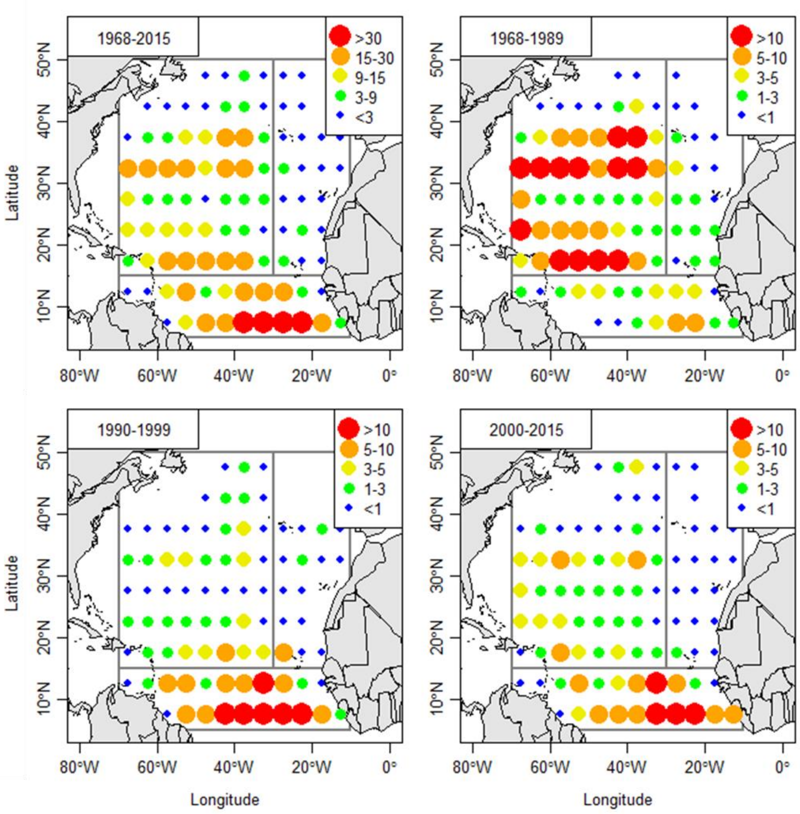

Figure 1. Distributions of fishing effort (in 10^6 hooks) for the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean for periods of 1968-2015, 1968-1989, 1990-1999 and 2000-2015. The area stratification of the North Atlantic Ocean was used in the GLM analyses.

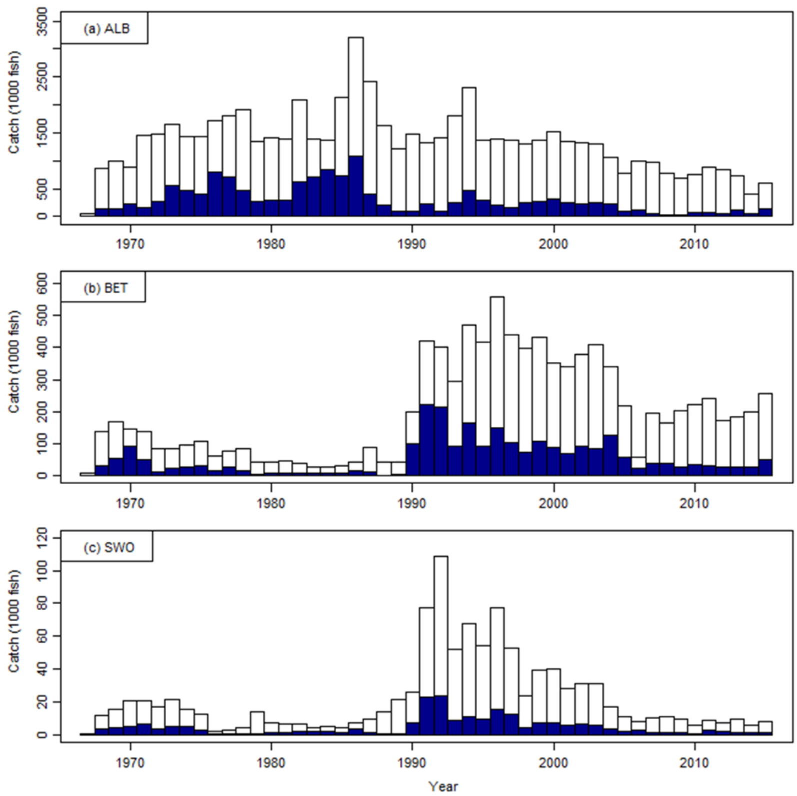

Figure 2. Annual catches in number of (a) albacore, (b) bigeye tuna and (c) swordfish caught in the Taiwanese distant-water tuna longline fishery in the North (solid bars) and South (white bars) Atlantic Ocean.

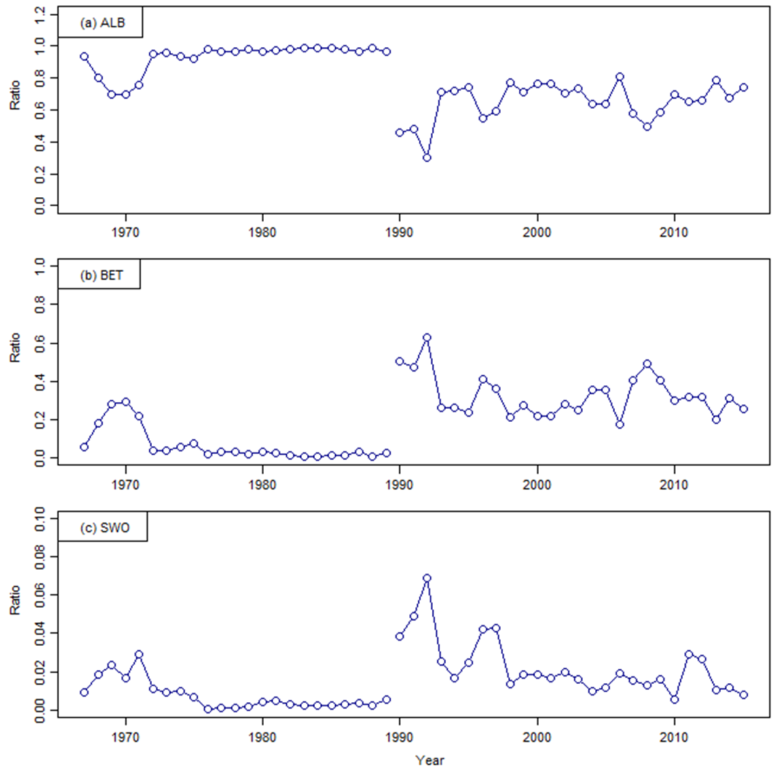

Figure 3. Catch ratios by species for (a) albacore, (b) bigeye tuna and (c) swordfish caught in the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean.

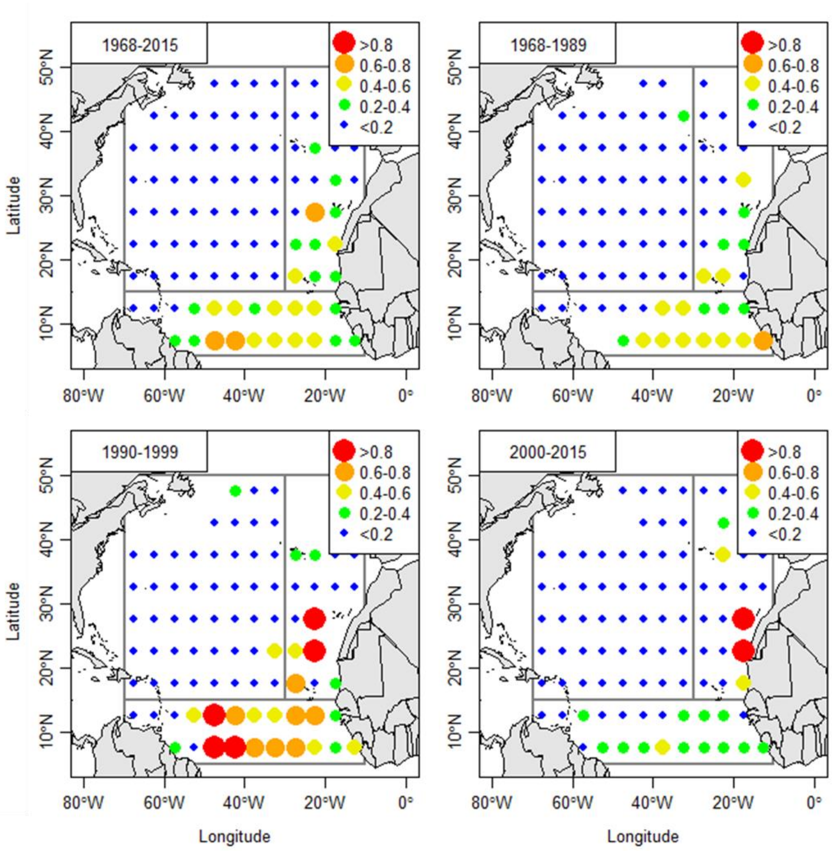

Figure 4. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for swordfish caught in the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean for 1968-2015 and 3 periods of 1968-1989, 1990-1999 and 2000-2015.

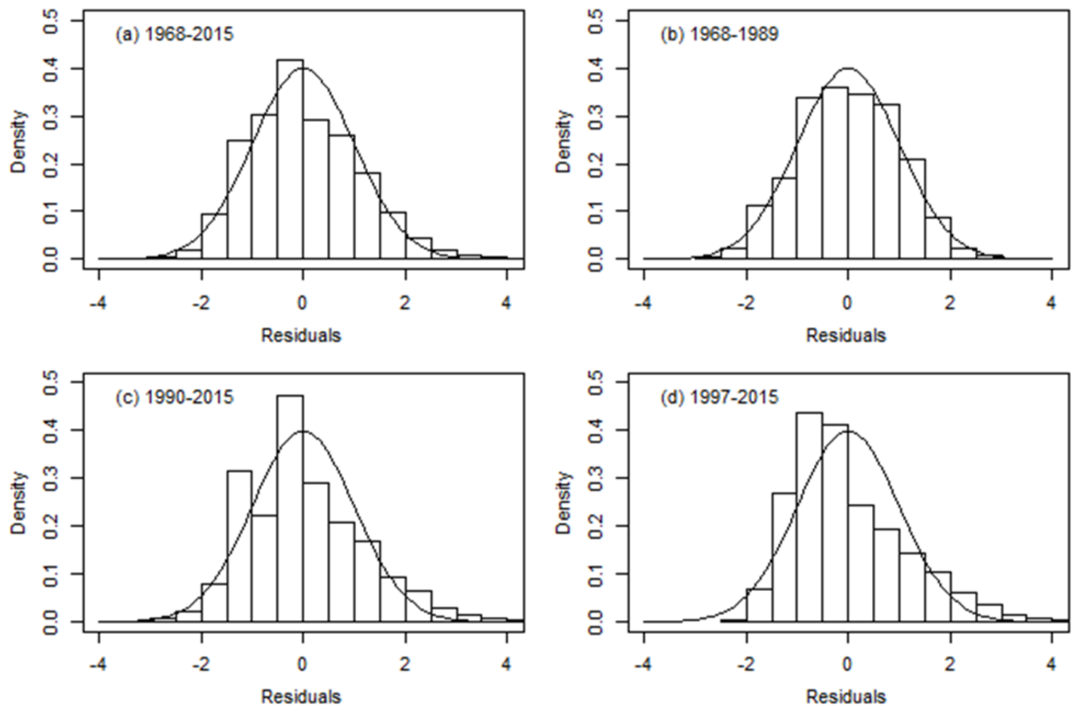

Figure 5. Diagnostic plots of residual distribution for the models of (a) 1968-2015, (b) 1968-1989, (c) 1990-2015 and (d) 1997-2015+HPB in the GLM analyses.

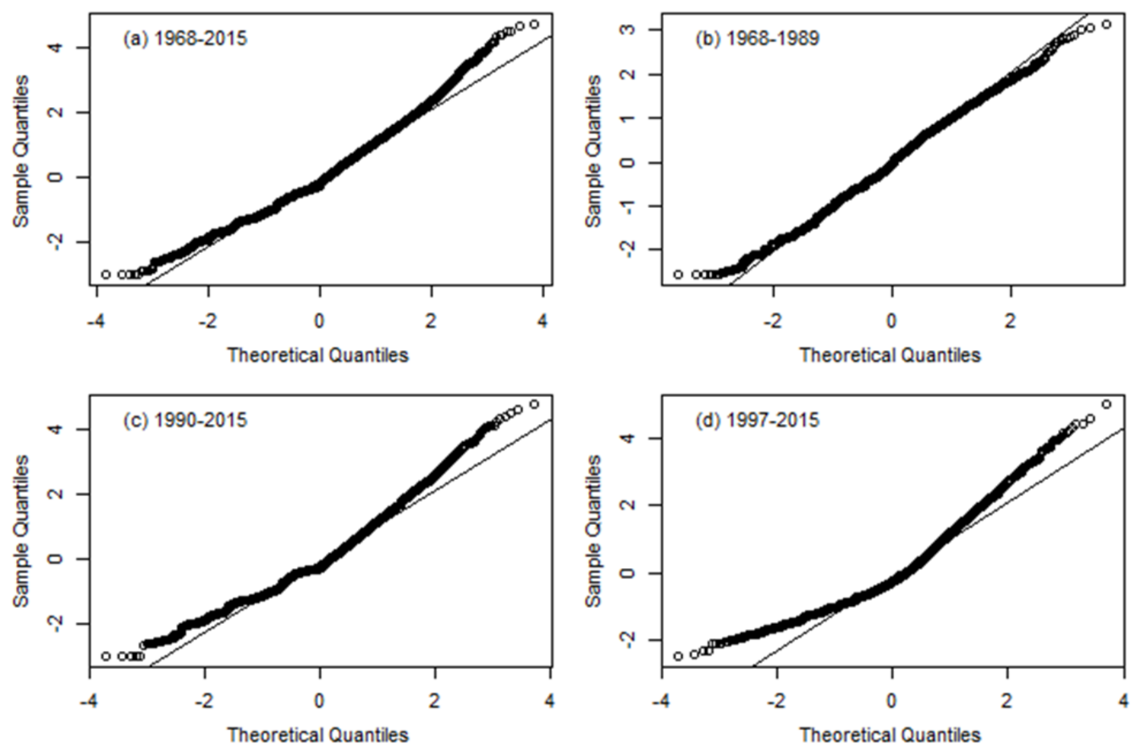

Figure 6. Diagnostic Q-Q plots for the models of (a) 1968-2015, (b) 1968-1989, (c) 1990-2015 and (d) 1997-2015+HPB in the GLM analyses.

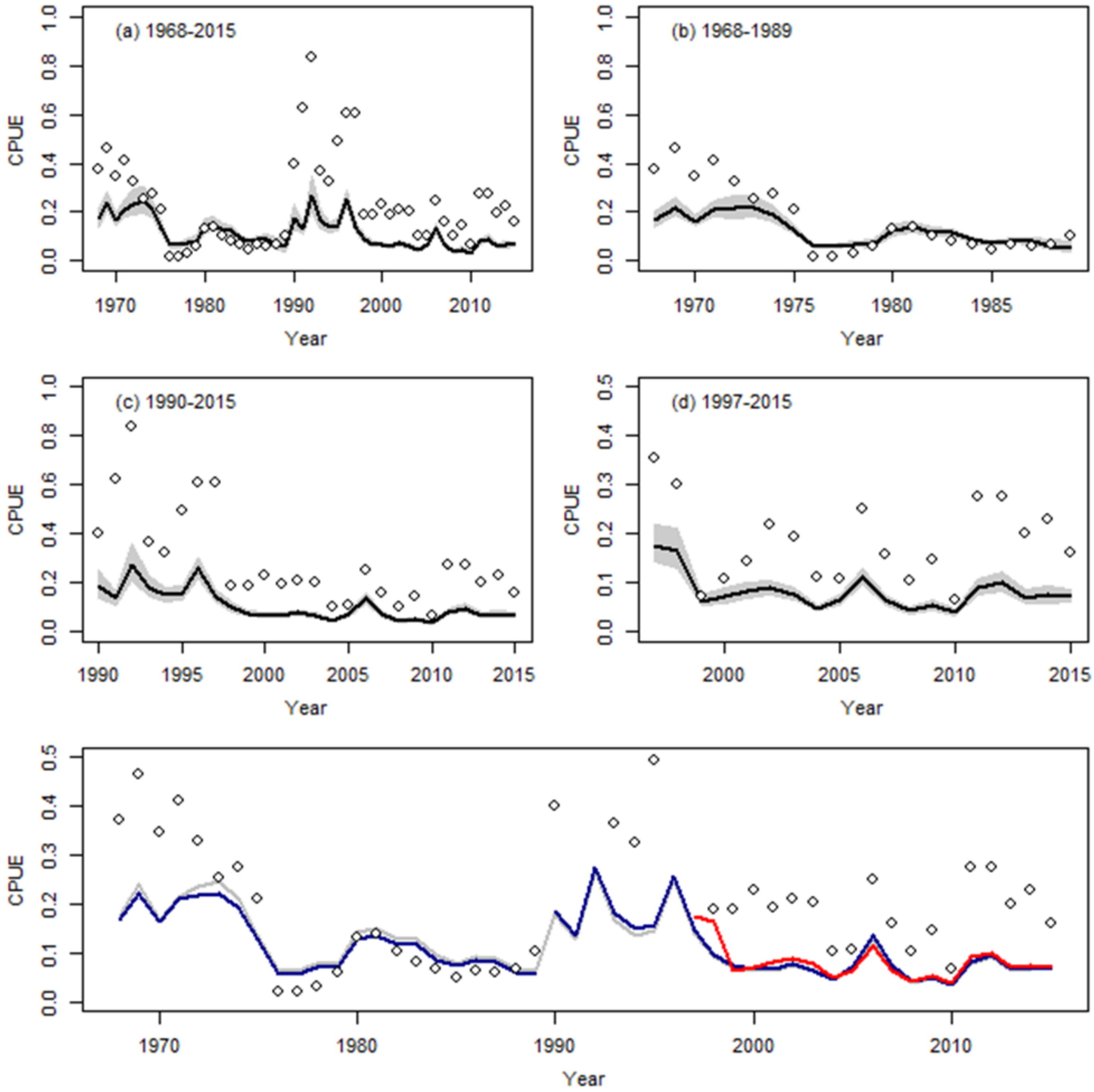

Figure 7. Nominal (open circles) and standardized (solid lines) CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean. Results are shown for various models and a comparison among models (lower panel). The shaded areas indicate 95% confidence intervals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