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UPDATED STANDARDIZED CPUE OF SWORDFISH (*XIPHIAS GLADIUS*) FOR THE TAIWANESE LONGLINE FISHERY IN THE NORTH ATLANTIC OCEAN, 1968-2011

Chi-Lu Sun, Nan-Jay Su, and Su-Zan Yeh[1]

SUMMARY

*The catch and effort data for 1968-2011 from the Taiwanese distant-water longline fishery in the North Atlantic Ocean were standardized for swordfish (*Xiphias gladius*) in this study. Information on operation type (the number of hooks per basket) was included in the models from 1995 when available. Two alternative approaches (generalized linear models, GLMs, and generalized additive models, GAMs) were used to standardize the CPUE (catch per unit effort) of swordfish caught in this fishery. All of the main effects and the interaction terms are statistically significant for both GLM and GAM analyses. The abundance indices of swordfish derived from the two modeling approaches are very similar and fairly robust to the inclusion of gear configuration, but somewhat sensitive to the inclusion of target tuna species in the models as explanatory variables. The standardized CPUE of swordfish showed a continuous decreasing trend since 1968 through the late 1980s, but suddenly increased to a higher level during 1990-1997 and sharply dropped in the late 1990s, and then relatively stabilized from 1999 with two higher values in 2006 and 2011.*

RÉSUMÉ

*Les données de prise et d'effort pour la période 1968-2011 de la pêcherie palangrière du Taipei chinois opérant en eaux lointaines dans l'océan Atlantique Nord ont été standardisées pour l'espadon (*Xiphias gladius*) dans la présente étude. L'information sur le type d'opération (nombre d'hameçons par panier) a été incluse dans les modèles à partir de 1995, si disponible. Deux approches alternatives (modèles linéaires généralisés - GLM et modèles additifs généralisés - GAM) ont été utilisées pour standardiser la CPUE (capture par unité d'effort) de l'espadon capturé dans cette pêcherie. Tous les principaux effets et termes d'interaction sont importants d'un point de vue statistique à la fois pour les analyses du GLM et du GAM. Les indices d'abondance de l'espadon obtenus des deux approches de modélisation sont très similaires et assez robustes à l'inclusion de la configuration de l'engin, mais ils sont quelque peu sensibles à l'inclusion d'espèces thonières cibles dans les modèles comme variables explicatives. La CPUE standardisée de l'espadon a dégagé une tendance décroissante continue de 1968 à la fin des années 80, mais elle est soudainement passée à un niveau plus élevé entre 1990 et 1997 pour retomber brusquement vers la fin des années 90. Depuis 1999, elle s'est relativement stabilisée, connaissant des pics en 2006 et en 2011.*

RESUMEN

*Se estandarizaron los datos de captura y esfuerzo para 1968-2011 de la pesquería de palangre de aguas distantes de Taipei Chino en el Atlántico norte para el pez espada (*Xiphias gladius*). La información sobre el tipo de operación (número de anzuelos por cesta) fue incluida en los modelos, cuando estaba disponible, a partir de 1995. Se utilizaron dos enfoques alternativos (modelos lineales generalizados, GLM y modelos aditivos generalizados, GAM) para estandarizar la CPUE (captura por unidad de esfuerzo) del pez espada capturado en esta pesquería. Todos los efectos principales y los términos de interacción son estadísticamente significativos tanto para los análisis de GLM como para los de GAM. Los índices de abundancia de pez espada derivados de los dos enfoques de modelización son muy similares y bastante robustos ante la inclusión de la configuración del arte, pero algo sensibles a la inclusión de las especies objetivo de túnidos en los modelos como variables explicativas. La CPUE estandarizada del pez espada mostraba una tendencia descendente continua desde 1968 hasta finales de los ochenta, pero repentinamente aumentaba a un nivel mayor durante 1990-1997 y caía abruptamente a finales de los noventa, estabilizándose relativamente después, desde 1999, con dos picos en 2006 y 2011.*

KEYWORDS

CPUE standardization, Abundance index, GLM, GAM, Longline

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1. Introduction

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

The Taiwanese distant-water longline fleets started to operate in the Atlantic Ocean since the early 1960s, and have operated throughout the entire ocean from the 1990s, targeting albacore tuna (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*). 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 catch at ~110 tons during 2004 to 2011 (**Figure 1**) as a result of enhanced catch regulation for this species (ICCAT, 2010).

The CPUE (catch per unit effort) standardization of the Taiwanese distant-water longline fleets for swordfish was carried out by 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 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). Most of these studies, however, focused on the southern Atlantic stock of swordfish, except for Sun *et al*. (2010a). The abundance index of swordfish in the North Atlantic Ocean 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 and stabilized from 2000 (Sun *et al*. 2010a).

The objectives of this study were to use alternative analysis techniques to assess how robust the analytical framework (GLMs and GAMs) that might influence the swordfish CPUE caught in the Taiwanese distant-water longline fishery in the North Atlantic Ocean can be identified, and to examine how sensitive the factors of the target species and gear configuration are to the choice of analytical framework for standardizing catch and effort data for swordfish. The abundance index of swordfish developed in this study can be used in the assessment of this stock, and provide suggestions for 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, bigeye, albacore, and yellowfin tunas. This fishery also catches swordfish, billfishes and sharks, although these latter two species are not considered in the analyses of this paper. This data set contains information on time (year and month), fishing location (5° 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 (1968-2011 and 1995-2011 with HPB included) aggregated into monthly 5°×5° grids were used in the analyses. CPUE (catch per unit of effort) is expressed as the number of fish caught per 1000 hooks in this study.

2.2 Statistical model

Two alternative approaches, generalized linear models (GLMs; Nelder and Wedderburn 1972) and generalized additive models (GAMs; Hastie and Tibshirani 1990) were applied, assuming a lognormal error distribution, 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). GAMs are a semi-parametric extension of GLMs, with the underlying assumption that the response variable is related to smooth additive functions of the explanatory variables (Guisan *et al*. 2002). Time (year, season, and month), geographic area (latitude and longitude), gear configuration (HPB), and the catch-rates of target tuna species were included in the GLM and GAM analyses as main explanatory variables. The full GLM and GAM with interactions can be expressed as follows:

GLM1: SWO ~ Year + Season + Area + HPB + Interactions;

GLM2: SWO ~ Year + Season + Area + HPB + ALB + BET + YFT + Interactions;

GAM1: SWO ~ Year + Month + Latitude + Longitude + HPB + Interactions;

GAM2: SWO ~ Year + Month + Latitude + Longitude + HPB + ALB + BET + YFT + Interactions;

where 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, month, area, latitude, and longitude are temporal and spatial effects. ALB, BET, and YFT denote the effects of target tuna species CPUE for albacore, bigeye, and yellowfin tunas, respectively. A spline smoother function was used for covariates in GAM, except for year. Area stratification used in GLM analysis is shown in **Figure 2**. No interactions with year effect were considered in the GLM and GAM analyses (Maunder and Punt 2004). However, the effects of target tuna species (ALB, BET, and YFT) were included in the models because of their likely impacts on swordfish CPUE recognized in previous studies (Sun *et al*. 2010a; 2010b).

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 and GAM analyses. Standard methods, such as changes in residual deviance, the Akaike Information Criterion (AIC), and the Bayesian Information Criterion (BIC), were also implemented to compare alternative model structures for each modeling technique (GLMs and GAMs).

Although based on the same data set, the results in the GLM and GAM analyses cannot be compared directly using likelihood ratio tests because neither is nested within the other. Therefore, alternative model structures based on different modeling approaches to analyzing the fishery data were compared using the pseudo-coefficient of determination (pseudo R^2) and the adjusted R^2 (Swartzman *et al*. 1992):

Pseudo $R^2 = 1 - $ (residual deviance/null deviance);
Adjusted $R^2 = 1 - $ (residual deviance/degree of freedom)/(null deviance/degree of freedom).

3. Results and discussion

There were in total 7,321 catch and effort records (Task II) for 1968-2011, and 4,322 records with information on gear configuration (HPB) for 1995-2011 used in the analyses. High CPUE of swordfish for 1968-2011 occurred in tropical waters of the central Atlantic Ocean (Area 3 in **Figure 2a**), but shifted to the eastern North Atlantic Ocean during 1995-2011 (Area 2 in **Figure 2b**), suggesting that spatial covariates are likely to be an important factor in determining catchability of the Taiwanese longline fishery for swordfish. The area classification was thus used in the GLM analyses based on the nominal CPUE distributions of swordfish (**Figure 2**).

The deviance tables summarized the model selection process for the GLM and GAM analyses for 1968-2011 and 1995-2011 (**Tables 1 and 2**). All the explanatory variables and the interaction terms considered in the models were statistically significant ($P < 0.01$). The distributions of residuals appeared to be normal in a log-scale for both GLM and GAM analyses based on a lognormal error distribution (**Figure 4**). This assumption was further confirmed according to the Q-Q plots (**Figure 5**). However, the pseudo R^2 increased about 18~25% when the model takes the effects of target tuna species into account for both GLM and GAM analyses for 1968-2011 (**Table 1a**), while the pseudo R^2 only increased 6~10% when ALB, BET, and YFT were included in the models for the 1995-2011 analyses (**Table 1b**).

Effects of year, area in the GLM, and latitude in the GAM accounted for the largest proportions of the explained deviance of the models. However, it should be noted that 10~13% of deviance was explained by BET in both GLM and GAM analyses for 1968-2011. Additionally, the effect of gear configuration was also statistically significant in the GLM and GAM analyses, which might imply that the inclusion of this factor could capture some of the potential change in the development of deep longline operations that target bigeye tuna in tropical areas since the early 1990s.

The pseudo R^2, adjusted R^2, and AIC and BIC values shown in **Table 1** indicated that the models based on GAM approach provided better fits to the data than those based on GLM when the impacts of target tuna species were considered in the model (GAM2). This could be expected because the use of spline smooth functions in the GAM modeling could take account of non-linear relationships between the dependent variable and explanatory variables (Maunder and Punt 2004). We therefore suggest that the relative abundance index developed for swordfish in the North Atlantic Ocean should base on the GAM approach with target tuna species included as explanatory variables in the models.

The standardized CPUE of swordfish was robust to the choice of analytical framework (GLMs and GAMs), but somewhat sensitive to the inclusion of target tuna species in both GLM and GAM analyses with the 1968-2011 data set (**Figure 5a**). This can be expected because the fishing practices and target species for the Taiwanese distant-water longline fishery changed significantly during the past two decades. Similar conclusion can be obtained when information on gear configuration (HPB) was included in the models for the 1995-2011 analyses (**Figure 5b**). However, the trends in standardized CPUE of swordfish with HPB included (1995-2011) were fairly similar to those derived from the models without HPB (1968-2011) for both GLM and GAM analyses, except for the estimate for 1995 because of only a few data points with HPB available in 1995 (<2%) (**Figure 6**). Given that, we suggest the standardized CPUE of swordfish from GAM2 without HPB for the entire period (1968-2011) to be used as a relative abundance index in the assessment of this stock.

In general, the standardized CPUE of swordfish in the North Atlantic Ocean showed a decreasing trend in the early 1970s, but slightly increased from 1976 through 1989, and then suddenly increased to a higher level from 1990 to 1997, followed by a sharp decrease in the late 1990s. However, the trend of standardized swordfish CPUE was stabilized from 1999 until present, with two slightly higher estimates in 2006 and 2011 (**Figures 5 and 6**). 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; Sun *et al*. 2012).

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Table 1. Analysis table of significance level for the models selected to standardize the catch and effort data of the Taiwanese tuna longline fishery for swordfish in the North Atlantic Ocean for (a) 1968-2011 and (b) 1995-2011. The area stratification used in GLM is shown in **Figure 2**. ALB, BET, and YFT denote the effects of target species for albacore, bigeye, and yellowfin tunas respectively. HPB (the number of hooks per basket) represents the operation types. Information on HPB is available from 1995 for the Taiwanese distant-water longline fishery. "–" indicates the predictor variable not used in the model.

Predictor	(a) 1968-2011				(b) 1995-2011			
	GLM1	GLM2	GAM1	GAM2	GLM1	GLM2	GAM1	GAM2
+Year	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
+Month	-	-	<0.01	<0.01	-	-	<0.01	<0.01
+Season	<0.01	<0.01	-	-	<0.01	<0.01	-	-
+Area	<0.01	<0.01	-	-	<0.01	<0.01	-	-
+Season:Area	<0.01	<0.01	-	-	<0.01	<0.01	-	-
+Latitude	-	-	<0.01	<0.01	-	-	<0.01	<0.01
+Longitude	-	-	<0.01	<0.01	-	-	<0.01	<0.01
+Latitude:Longitude	-	-	<0.01	<0.01	-	-	<0.01	<0.01
+HPB	-	-	-	-	<0.01	<0.01	<0.01	<0.01
+ALB	-	<0.01	-	<0.01	-	<0.01	-	<0.01
+BET	-	<0.01	-	<0.01	-	<0.01	-	<0.01
+YFT	-	<0.01	-	<0.01	-	<0.01	-	<0.01
Pseudo R^2	0.302	0.379	0.338	**0.398**	0.275	0.302	0.294	**0.313**
Adjusted R^2	0.297	0.372	0.331	0.391	0.268	0.291	0.285	0.303
AIC	20253	19451	19903	19241	11406	11294	11315	11213
BIC	20639	20030	20412	19867	11693	11746	11675	11636

Table 2. Deviance tables for the models selected to standardize the catch and effort data of the Taiwanese distant-water tuna longline fishery for swordfish in the North Atlantic Ocean for (a) 1968-2011 and (b) 1995-2011. The area stratification used in GLM is shown in **Figure 2**. ALB, BET, and YFT denote the effects of target species for albacore, bigeye, and yellowfin tunas respectively. HPB denotes the number of hooks per basket, which is available since 1995 for the Taiwanese distant-water longline fishery in the North Atlantic Ocean.

Model	Predictor	(a) 1968-2011			(b) 1995-2011		
		Residual deviance	Deviance explained	% of total deviance explained	Residual deviance	Deviance explained	% of total deviance explained
	NULL	9633			4785		
	+Year	7891	1742	47.7	4083	702	48.6
	+Season	7829	63	1.7	3925	159	11.0
	+Area	6825	1003	27.5	3686	238	16.5
	+Season:Area	6724	102	2.8	3637	49	3.4
GLM1	+HPB	-	-	-	3470	167	11.6
	+ALB	6527	196	5.4	3432	37	2.6
	+BET	6059	468	12.8	3366	66	4.6
GLM2	+YFT	5980	80	2.2	3340	26	1.8
	NULL	9633			4785		
	+Year	7891	1742	45.4	4083	702	46.8
	+Month	7816	75	2.0	3898	186	12.4
	+Latitude	6732	1084	28.3	3622	275	18.4
	+Longitude	6495	236	6.2	3557	66	4.4
	+Latitude:Longitude	6379	117	3.0	3487	70	4.7
GAM1	+HPB	-	-	-	3379	108	7.2
	+ALB	6287	92	2.4	3359	20	1.3
	+BET	5891	395	10.3	3303	56	3.8
GAM2	+YFT	5800	92	2.4	3286	17	1.1

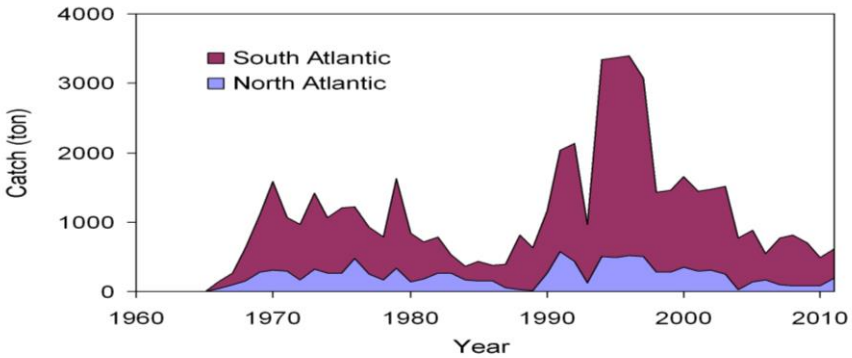


Figure 1. Annual catches of swordfish for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean.

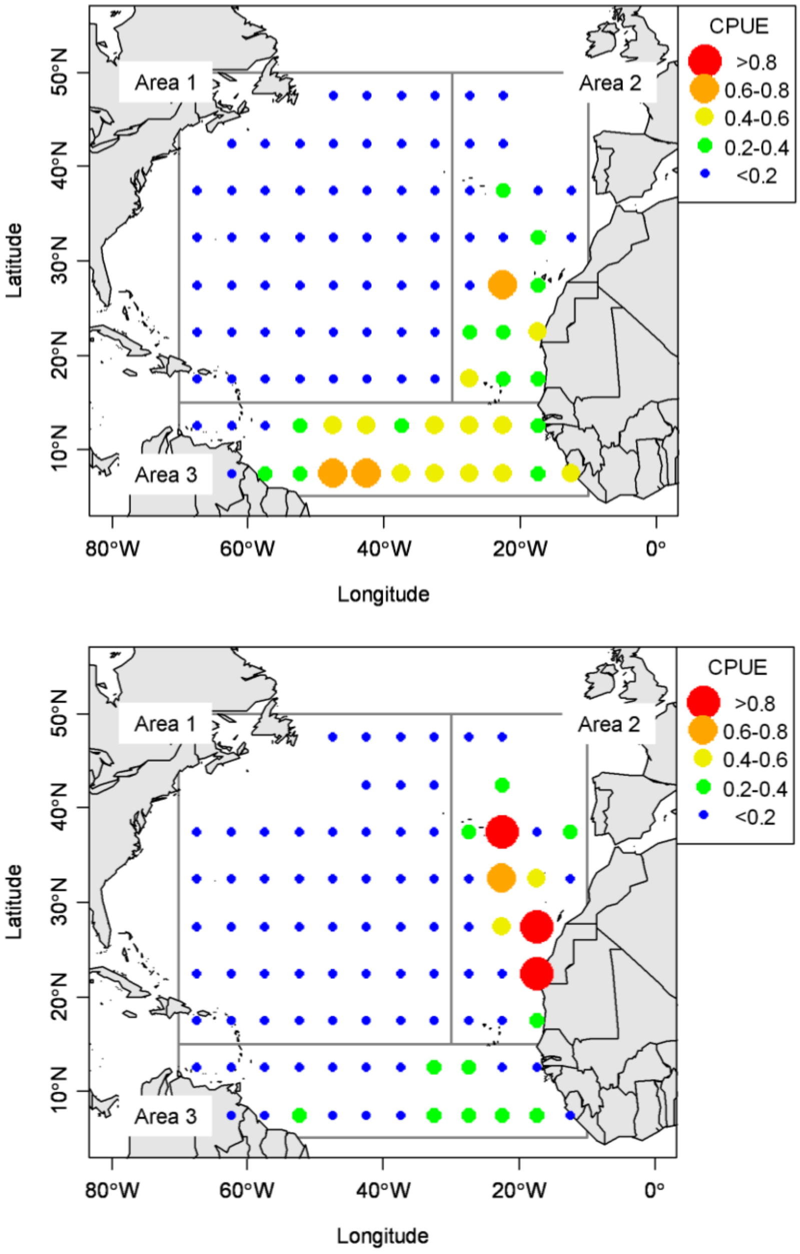
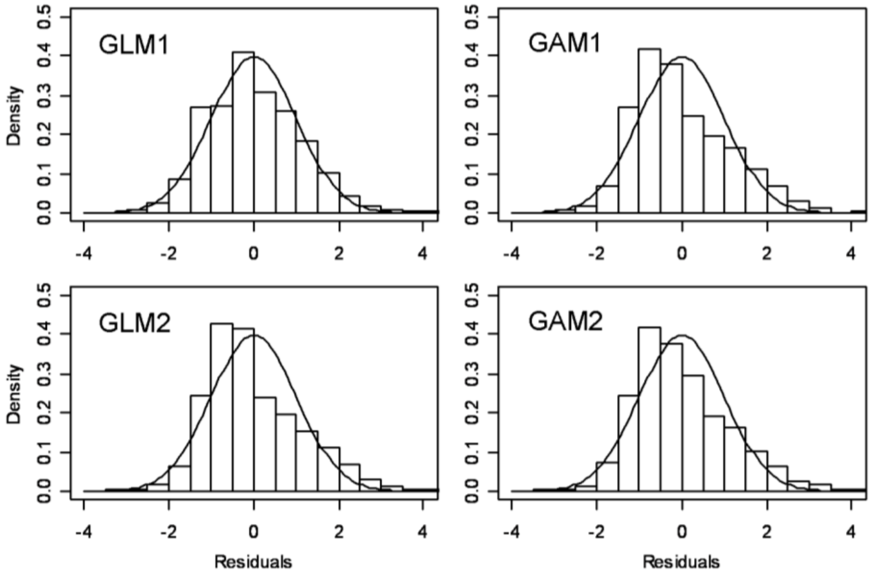


Figure 2. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for swordfish caught in the Taiwanese distant-water tuna longline fishery during (a) 1968–2011 and (b) 1995–2011. The area stratification of the North Atlantic Ocean was used in GLM analyses.

(a) 1968-2011



(b) 1995-2011

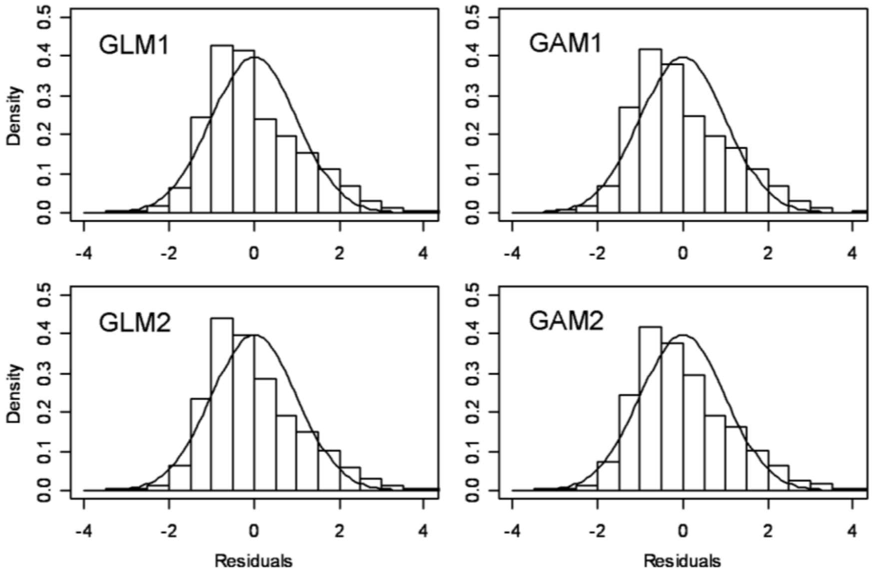
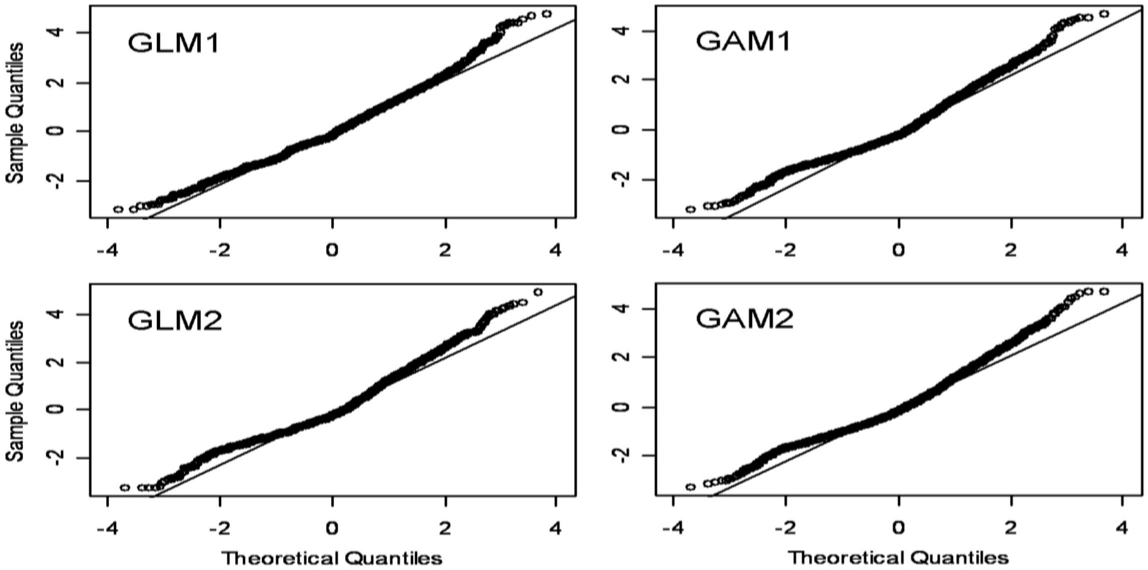


Figure 3. The diagnostic plots (residual distribution) of GLM (GLM1 and GLM2) and GAM (GAM1 and GAM2) analyses for standardizing the catch and effort data of swordfish caught by the Taiwanese distant-water tuna longline fleet in the North Atlantic Ocean for (a) 1968-2011 and (b) 1995-2011. The effects of target tuna species were included in GLM2 and GAM2 as predictor variables (see **Tables 1 and 2** for the model structure).

(a) 1968-2011



(b) 1995-2011

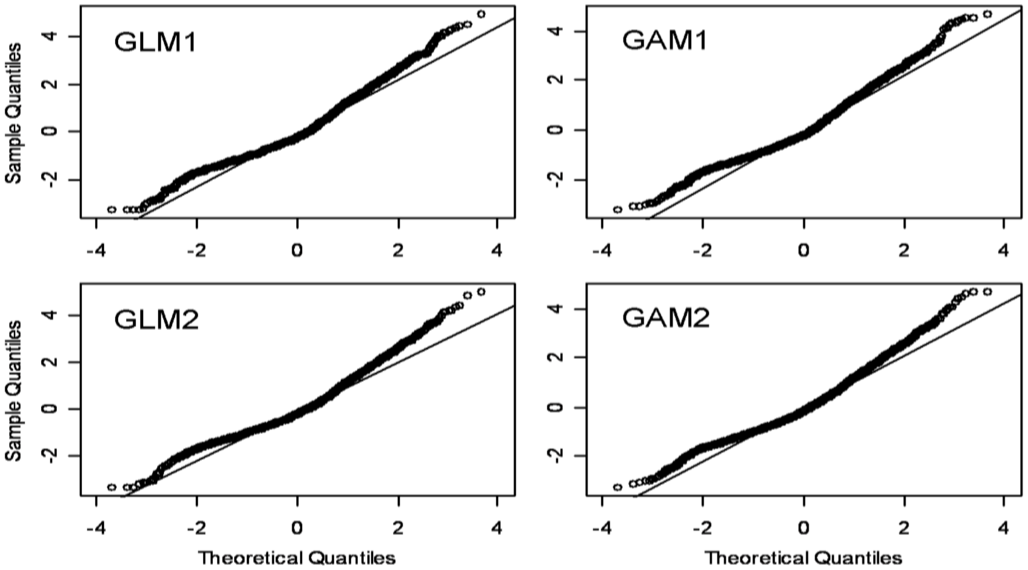
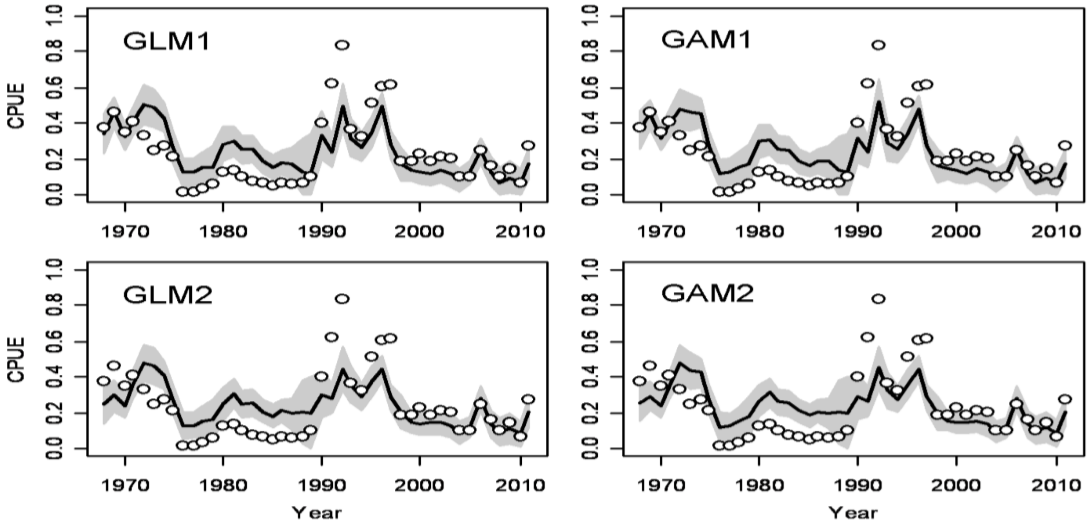


Figure 4. The diagnostic plots (Q-Q plot) of GLM (GLM1 and GLM2) and GAM (GAM1 and GAM2) analyses for standardizing the catch and effort data of swordfish caught by the Taiwanese distant-water tuna longline fleet in the North Atlantic Ocean for (a) 1968-2011 and (b) 1995-2011. The effects of target tuna species were included in GLM2 and GAM2 as predictor variables (see **Tables 1 and 2** for the model structure).

(a) 1968-2011



(b) 1995-2011

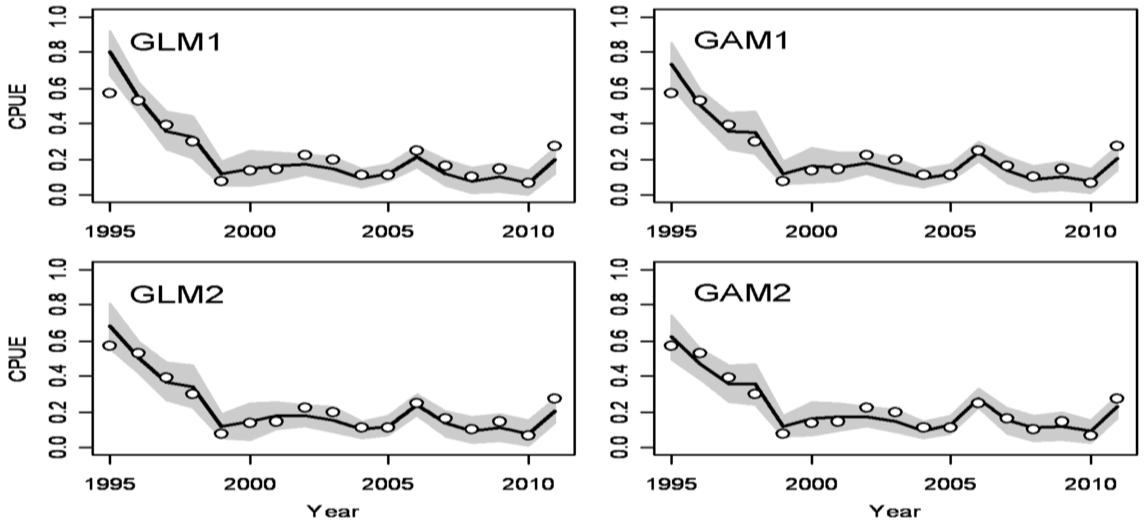


Figure 5. The nominal (open circles) and standardized (lines) CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean for (a) 1968-2011 and (b) 1995-2011. The shaded areas indicate the 95% confidence intervals for the standardized CPUE.

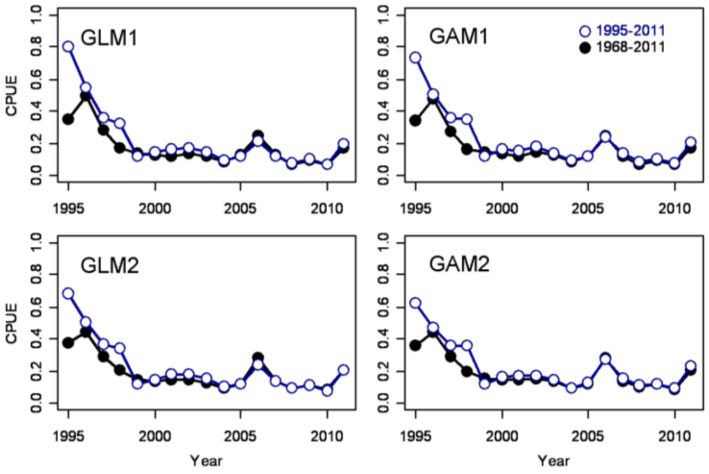


Figure 6. The standardized CPUE of swordfish for the Taiwanese distant-water tuna longline fishery in the North Atlantic Ocean derived from different data sets (1968-2011 and 1995-2011) given whether the information on gear configuration is available. See **Tables 1 and 2** for the model structure.