Standardized CPUE of swordfish (*Xiphias gladius*) for the Taiwanese distant-water tuna longline fishery, based on a two-stock scenario in the North Pacific Ocean*

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Abstract

CPUE (catch per unit effort) of swordfish caught in the Taiwanese distant-water tuna longline fishery was standardized using generalized linear models (GLMs), based on a two-stock scenario in the North Pacific Ocean (i.e., a WCNPO and an EPO stock), as suggested by Ichinokawa and Brodziak (2008). Year, quarter, fishing area, and the two-way interactions between quarter and fishing area were used as predictors in the standardization models for an entire period (1968-2012) and two separate periods of 1968-1999 and 2000-2012 due to changes in targeting species and fishing ground of this fishery. Information on hooks per basket (HPB, available since 1995) was statistically significant in the CPUE standardization models, and therefore was included in the models for 2000-2012. Results showed that, for both stocks, standardized CPUE of swordfish was generally stable during the early period 1968-1999, but increased dramatically after 2000. However, the standardized CPUE of swordfish for the WCNPO stock has stabilized since 2005, while those for the EPO stock showed an increasing trend from 2005 until present.

Keywords: abundance index, generalized linear model, hooks per basket, longline.

Introduction

The Taiwanese distant-water tuna longline fishery has operated in the Pacific Ocean since 1963 (Sun et al., 2009). Albacore tuna are the primary target species in this fishery, but substantial numbers of yellowfin and bigeye tunas were landed. Swordfish, and other billfishes, are incidental catches of this fishery (Sun and Yeh, 1999). CPUE (catch per unit effort) of swordfish caught by Taiwan's distant-water tuna longline

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vessels in the North Pacific Ocean during the period of 1995 to 2006 was standardized by Yeh and Sun (2008), whereas Sun et al. (2009) developed the swordfish abundance trends using generalized linear models (GLMs) based on a two-stock scenario in the North Pacific Ocean (Fig. 1), as suggested by Ichinokawa and Brodziak (2008). The objective of this study was to update standardized CPUE of swordfish for the Taiwanese distant-water tuna longline fishery based on a two-stock scenario in the North Pacific Ocean. The standardized abundance indices of swordfish derived from this study could provide basic, necessary input data for stock assessments.

Materials and methods

Fishery data

Task II data of the Taiwanese distant-water tuna longline fishery in the Pacific Ocean, including swordfish catch (in number of fish caught) and fishing effort (in number of hooks employed) for 1968-2012 and those with hooks per basket (HPB) information from 1995 to 2012, were obtained from the Oversea Fisheries Development Council (OFDC) of Taiwan. This data set contains information on time (year and month) and location (latitude and longitude), but was aggregated by month and by 5º by 5º grid cell. CPUE is expressed as the number of fish caught per 1000 hooks in this study.

Statistical model

Generalized linear models (GLMs) are a standard and commonly used approach for standardizing catch and effort data. We thus applied GLMs to standardize catch and effort data of the Taiwanese distant-water longline fishery for both stocks of swordfish in the North Pacific Ocean. Three standardization models were developed respectively for an entire period (1968-2012) and two separate periods of 1968-1999 and 2000-2012 in this study, due to changes in targeting species (Fig. 1A). The full GLM can be expressed as follows:

$$\text{SWO} \sim \text{Year} + \text{Quarter} + \text{Area} + \text{Quarter:Area} + \text{HPB} \qquad (1)$$

where SWO is the nominal CPUE of swordfish, with a constant added;
Year is the factor for year;
Quarter is the factor for quarter;
Area is the factor for fishing area (see area definition below);
Quarter:Area is the interaction between quarter and fishing area;
HPB is the hooks per basket information, for the 2000-2012 models only.

Diagnostic analysis

Diagnostic plots (i.e., distribution of residuals and quantile-quantile (Q-Q) plot) were used to assess the assumed log-normal error distribution. The deviance analysis, the χ^2 test, and AIC (Akaike Information Criterion) values between models were also used to examine the model fit.

Results and discussion

Annual catches of swordfish for both stocks (Fig. 1) from the Taiwanese distant-water tuna longline fishery were low before 2000, but the catch of swordfish from the EPO stock increased substantially to near 3,000 mt in 2002 and then decreased to less than 1,000 mt in 2005 and thereafter until present (Fig. 2).

For the Taiwanese distant-water tuna longline fishery, high nominal CPUE of swordfish for the WCNPO stock generally occurred in sub-tropical waters of the central North Pacific Ocean around 20ºN, while swordfish CPUE of the EPO stock from this fishery was high in waters close to the coast of Central America (Fig. 3). Based on Sun et al. (2009) and Fig. 3, the WCNPO and EPO were separated into six and four fishing areas respectively, which were then used as the area factor in GLM analysis.

The residual distributions for all the models of the WCNPO and EPO stocks based on a lognormal error distribution appear normal in the GLM analysis, which confirms the assumption of error models for lognormal distribution to standardize catch and effort data of the Taiwanese tuna longline fishery for swordfish, except for the WCNPO models of early period (1968-1999) that were less than ideal due to small and limited data points (Fig. 4).

According to the Q-Q plot, this assumption of lognormality is also suitable to model the swordfish CPUE for the WCNPO and EPO stocks in the North Pacific Ocean for the Taiwanese distant-water tuna longline fishery, even when information on HPB was included in the CPUE standardization model for the 2000-2012 (Fig. 5). Therefore, the CPUE standardization for swordfish in this study was consequently based on the lognormal error distribution.

Except for the 1968-1999 WCNPO model, the effects considered in the GLM models, including year, quarter, area, and the two-way interaction between quarter and area, were all statistically significant based on the χ^2 test ($p < 0.05$) and the lower AIC values, as well as the factor of HPB included in the 2000-2012 models for both stocks (Tables 1 and 2). The deviance explained by the models that were used to standardize the swordfish CPUE of the Taiwanese tuna longline fleets varied from 12.5 to 47.0%. However, it should be noted that a large proportion of deviance was explained by HPB for both WCNPO and EPO stocks of swordfish (Tables 1 and 2).

Standardized CPUE of swordfish for both WCNPO and EPO stocks in the North Pacific Ocean were generally stable during 1968-1999, but increased dramatically after 2000 and decreased in the early 2000s. However, the standardized swordfish CPUE of the WCNPO stock has stabilized since 2005, while those for the EPO stock showed an increasing trend from 2005 until present (Fig. 6).

The effect of HPB was statistically significant in the CPUE standardization for swordfish, but the CPUE trends with HPB information included in the 2000-2012 models were similar with that without HPB included (except for the EPO stock in the last year 2012 due to limited data points). Owing to additional deviance explained by HPB, we suggest using the abundance indices from the model of 2000-2012 with HPB included, as well as those from the 1968-1999 models without HPB, as part of the basic input data for updating the assessments of both swordfish stocks in the North Pacific Ocean (Table 3).

References

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Table 1. Deviance tables for the models selected to standardize swordfish CPUE of the WCNPO stock for the Taiwanese distant-water tuna longline fishery.

(a) 1968-2012 (without HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	3088	3444.7			9107
+Year	3050	2687.7	757.0	<0.01	8416
+Quarter	3047	2643.0	44.7	<0.01	8371
+Area	3042	2601.3	41.7	<0.01	8331
+Quarter:Area	3028	2574.8	26.6	<0.01	8328
R^2		**0.253**			

(b) 1968-1999 (without HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	832	615.4			2116
+Year	807	415.0	200.4	<0.01	1838
+Quarter	804	414.6	0.4	0.84	1843
+Area	799	409.0	5.6	0.05	1841
+Quarter:Area	787	401.8	7.3	0.29	1851
R^2		**0.347**			

(c) 2000-2012 (with HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	3821	3756.4			10784
+Year	3809	3646.2	110.3	<0.01	10694
+Quarter	3806	3533.7	112.5	<0.01	10581
+Area	3801	3436.3	97.4	<0.01	10484
+Quarter:Area	3788	3388.8	47.5	<0.01	10457
+HPB	3770	3145.9	242.9	<0.01	10208
R^2		**0.163**			

Table 2. Deviance tables for the models selected to standardize swordfish CPUE of the EPO stock for the Taiwanese distant-water tuna longline fishery.

(a) 1968-2012 (without HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	4938	9751.6			17380
+Year	4894	5335.0	4416.5	<0.01	14489
+Quarter	4891	5319.5	15.5	<0.01	14481
+Area	4888	5237.2	82.3	<0.01	14410
+Quarter:Area	4879	5169.5	67.7	<0.01	14364
$\mathbf{R^2}$		**0.470**			

(b) 1968-1999 (without HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	1530	1229.7			4013
+Year	1499	1091.4	138.2	<0.01	3893
+Quarter	1496	1089.2	2.2	0.37	3896
+Area	1493	1073.1	16.2	<0.01	3879
+Quarter:Area	1484	1051.4	21.6	<0.01	3865
$\mathbf{R^2}$		**0.145**			

(c) 2000-2012 (with HPB)

Predictor	Residual D.F.	Residual Deviance	Deviance Explained	*p*-value	AIC
NULL	7642	7843.8			21892
+Year	7630	7660.0	183.8	<0.01	21735
+Quarter	7627	7612.1	48.0	<0.01	21693
+Area	7624	7418.5	193.6	<0.01	21502
+Quarter:Area	7615	7332.4	86.1	<0.01	21431
+HPB	7595	6863.4	469.1	<0.01	20966
$\mathbf{R^2}$		**0.125**			

Table 3. Standardized CPUE and CV of swordfish for the WCNPO and EPO stocks for the Taiwanese distant-water tuna longline fishery". "-" indicates no data available for that year.

	WCNPO		EPO			WCNPO		EPO	
Year	**CPUE**	**CV**	**CPUE**	**CV**	**Year**	**CPUE**	**CV**	**CPUE**	**CV**
1968	-	-	0.053	12.1	2000	0.138	12.1	0.440	10.9
1969	0.056	39.6	0.054	13.8	2001	0.170	11.5	0.571	7.0
1970	0.051	59.6	0.062	12.6	2002	0.240	11.8	0.531	7.0
1971	0.054	26.2	0.057	12.6	2003	0.188	11.1	0.500	7.1
1972	0.052	27.8	0.058	12.8	2004	0.268	10.0	0.509	7.2
1973	0.043	100.3	0.047	12.6	2005	0.171	10.0	0.425	7.3
1974	0.054	13.1	0.058	13.9	2006	0.171	10.1	0.447	7.3
1975	0.060	16.3	0.045	19.1	2007	0.162	10.3	0.478	8.0
1976	0.144	18.2	0.087	22.1	2008	0.156	10.3	0.492	8.8
1977	0.056	16.3	0.049	14.2	2009	0.158	10.6	0.571	9.0
1978	-	-	0.049	16.8	2010	0.175	10.7	0.502	8.0
1979	0.078	13.8	0.104	14.3	2011	0.160	10.4	0.510	8.6
1980	0.064	14.5	0.079	21.4	2012	0.172	11.0	0.571	11.5
1981	0.056	12.6	0.077	11.6					
1982	0.059	19.9	0.065	13.8					
1983	0.053	40.5	0.051	15.5					
1984	0.055	97.9	0.054	17.4					
1985	-	-	0.058	17.8					
1986	-	-	0.059	17.3					
1987	0.065	29.3	0.054	12.5					
1988	-	-	0.060	14.4					
1989	0.105	17.9	0.081	12.8					
1990	0.159	30.2	0.058	16.1					
1991	0.137	21.4	0.052	14.5					
1992	0.107	47.0	0.055	14.2					
1993	-	-	0.064	21.0					
1994	-	-	0.065	18.1					
1995	0.156	12.1	0.065	32.3					
1996	0.075	10.6	0.108	22.6					
1997	0.070	10.8	0.072	17.8					
1998	0.057	12.6	0.098	18.6					
1999	0.076	11.0	0.158	14.1					

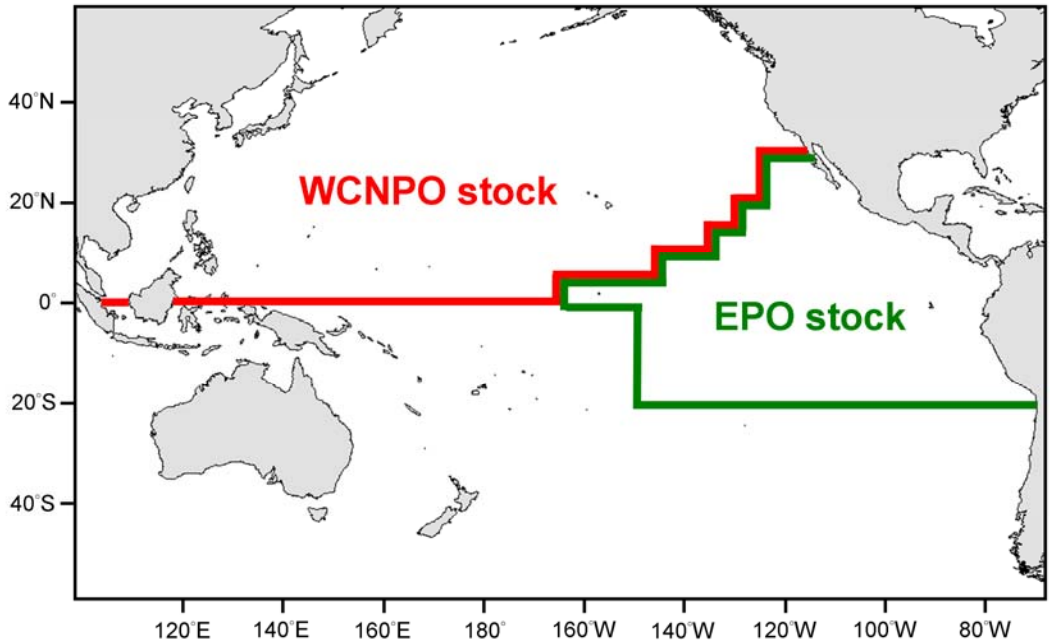

Fig. 1. Map showing the WCNPO and EPO stocks of swordfish in the North Pacific Ocean, as suggested by Ichinokawa and Brodziak (2008).

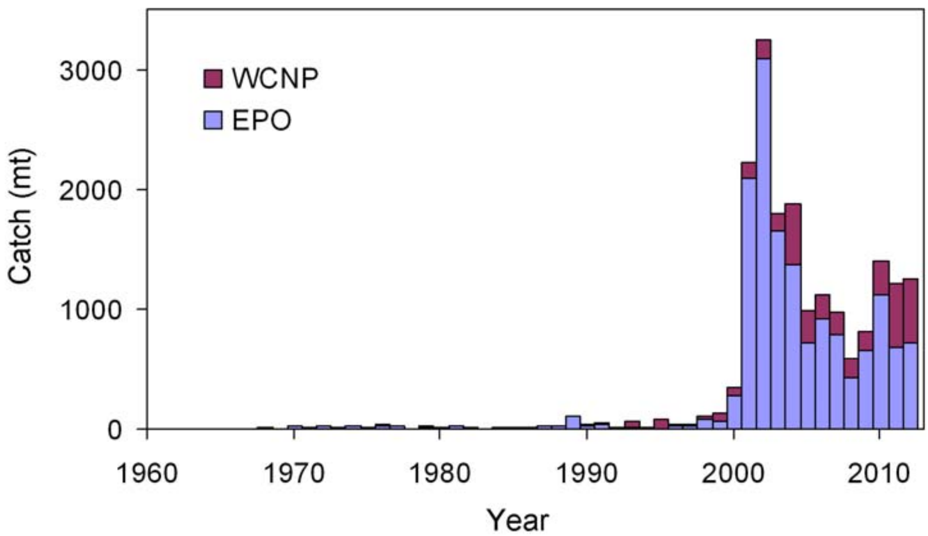

Fig. 2. Annual catches of swordfish by the WCNPO and EPO stocks caught in the Taiwanese distant-water tuna longline fishery for 1968-2012.

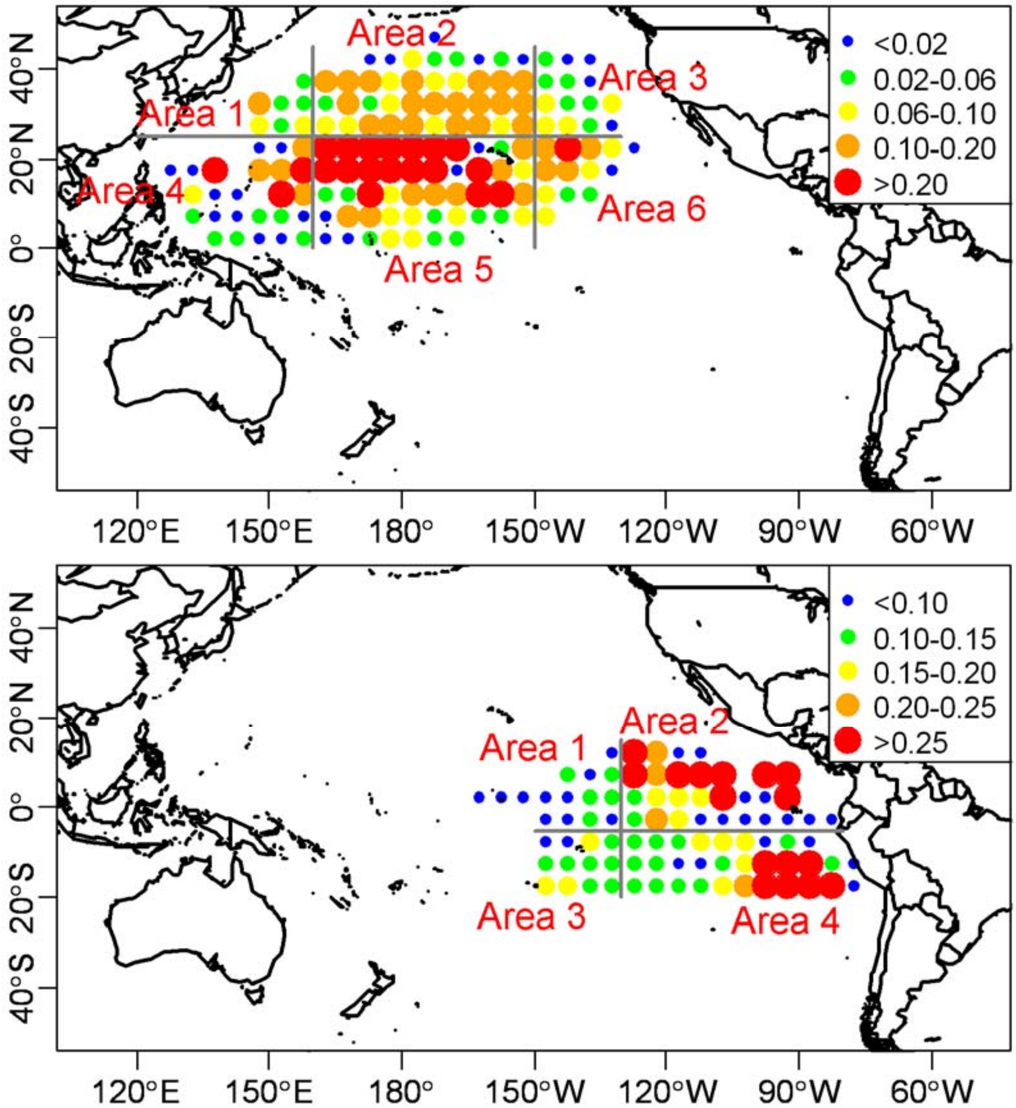

Fig. 3. Distributions of nominal CPUE (number of fish caught per 1000 hooks) of swordfish for the WCNPO stock (upper panel) and EPO stock (lower panel) for the Taiwanese distant-water tuna longline fishery for 1968-2012. Note that the six areas in the WCNPO and four areas in the EPO were used in the CPUE standardization models as the area factor.

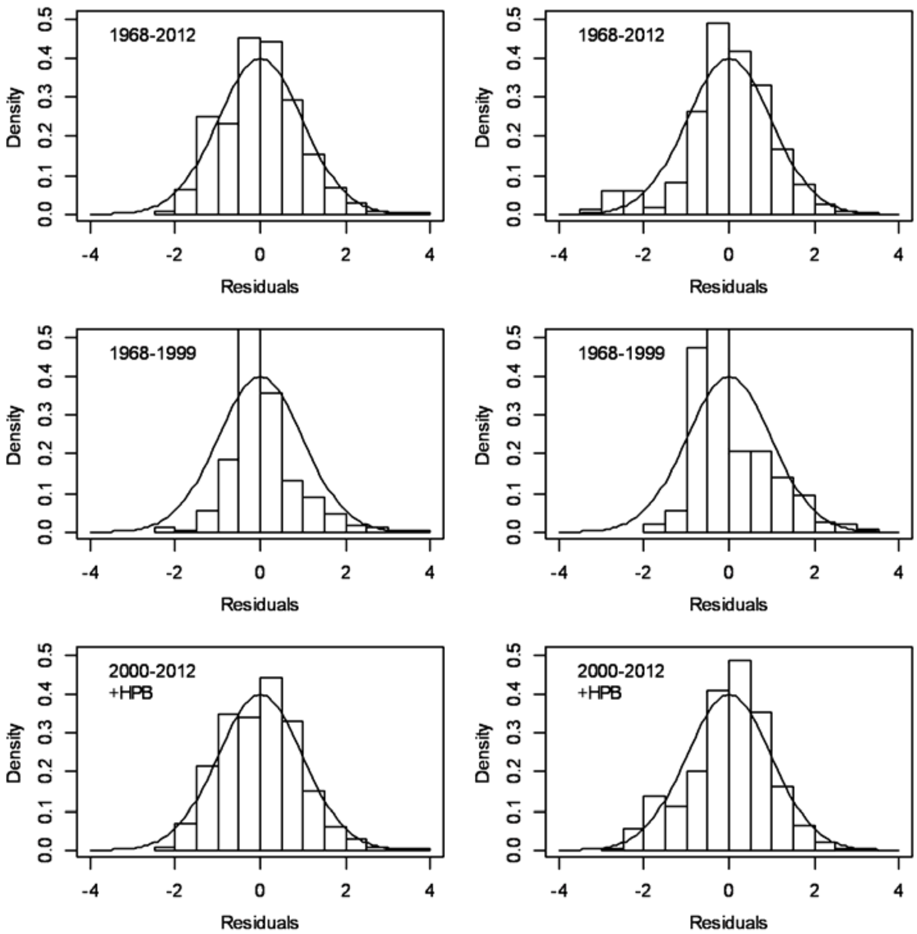

Fig. 4. Residual distributions for the models selected to standardize the CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery for the WCNPO stock (left panels) and the EPO stock (right panels).

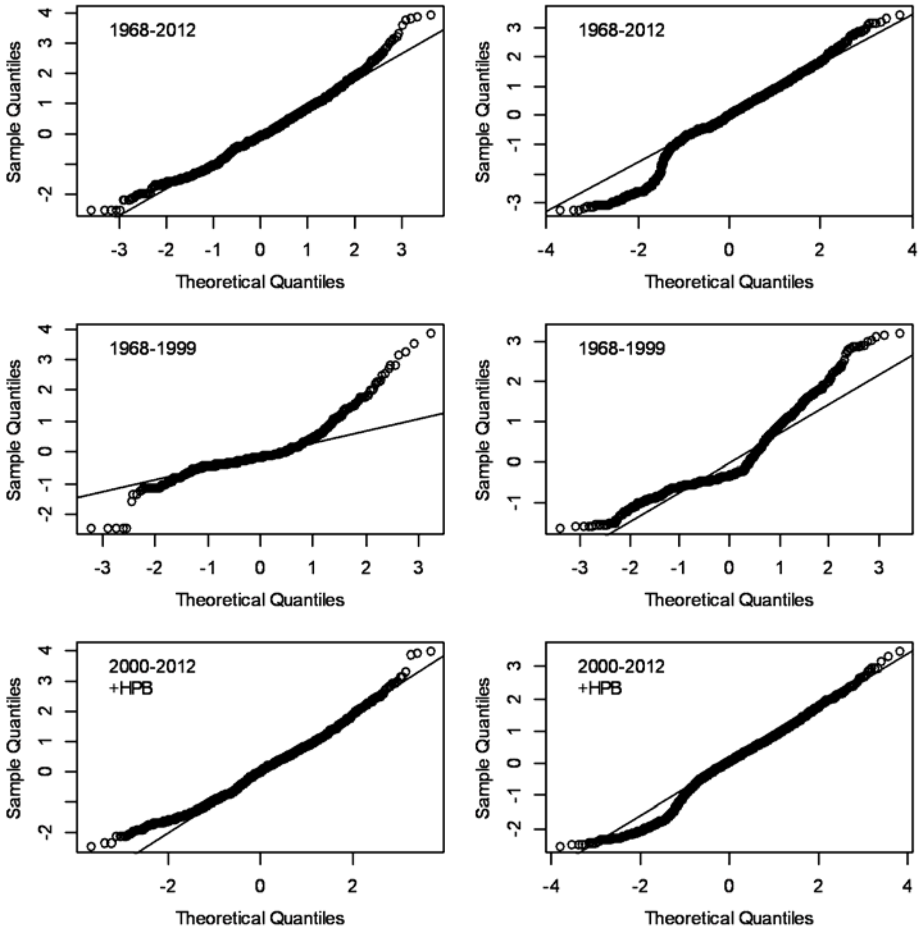

Fig. 5. Diagnostic Q-Q plots for the models selected to standardize the CPUE of swordfish caught in the Taiwanese distant-water tuna longline fishery for the WCNPO (left panels) and the EPO stock (right panels).

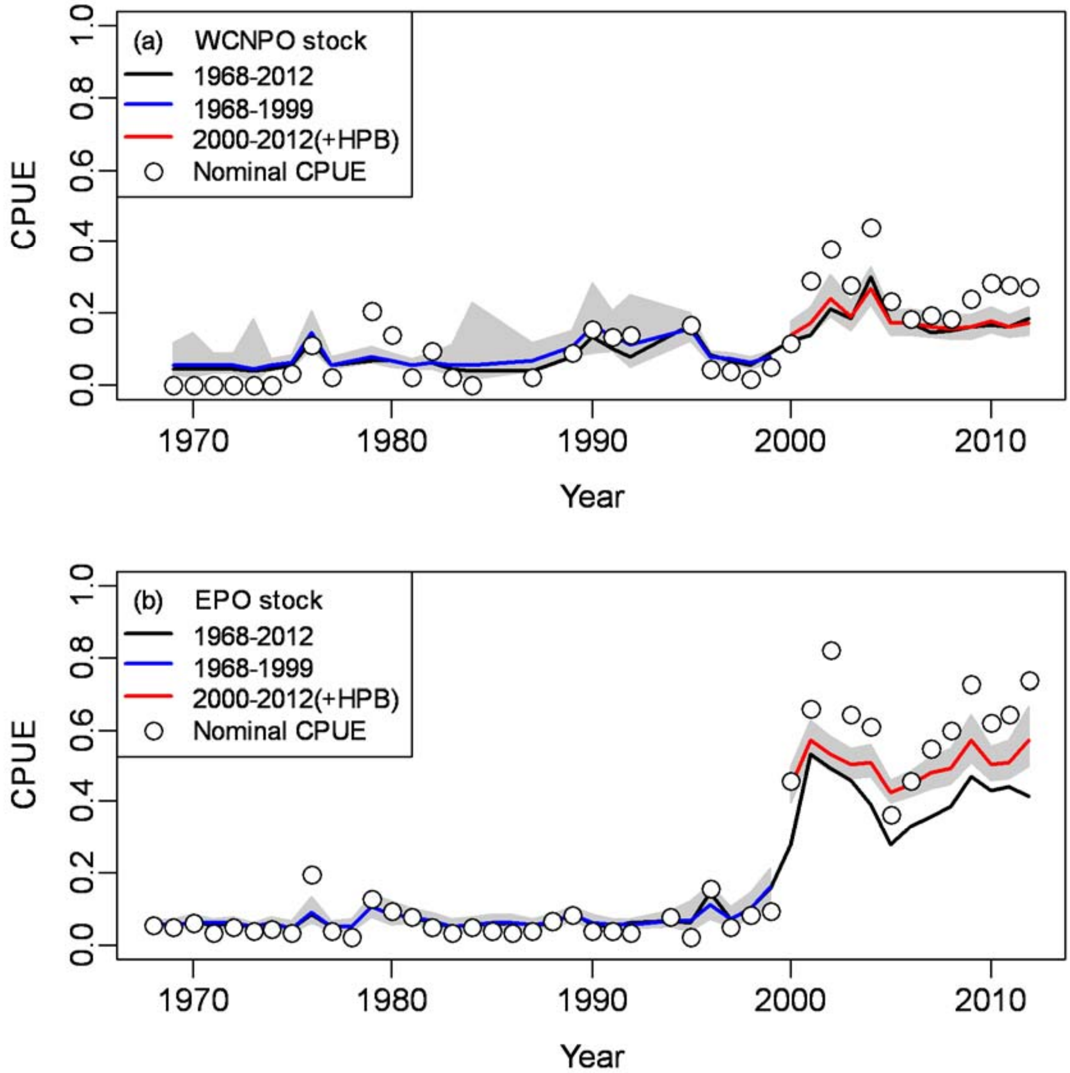

Fig. 6. Nominal (open circles) and standardized (solid lines) swordfish CPUE of the (a) WCNPO stock and (b) EPO stock for the Taiwanese distant-water tuna longline fishery. CPUE is expressed as the number of fish caught per 1000 hooks. The shadows indicate point-wise standard errors for the standardized CPUE of swordfish.

Appendix

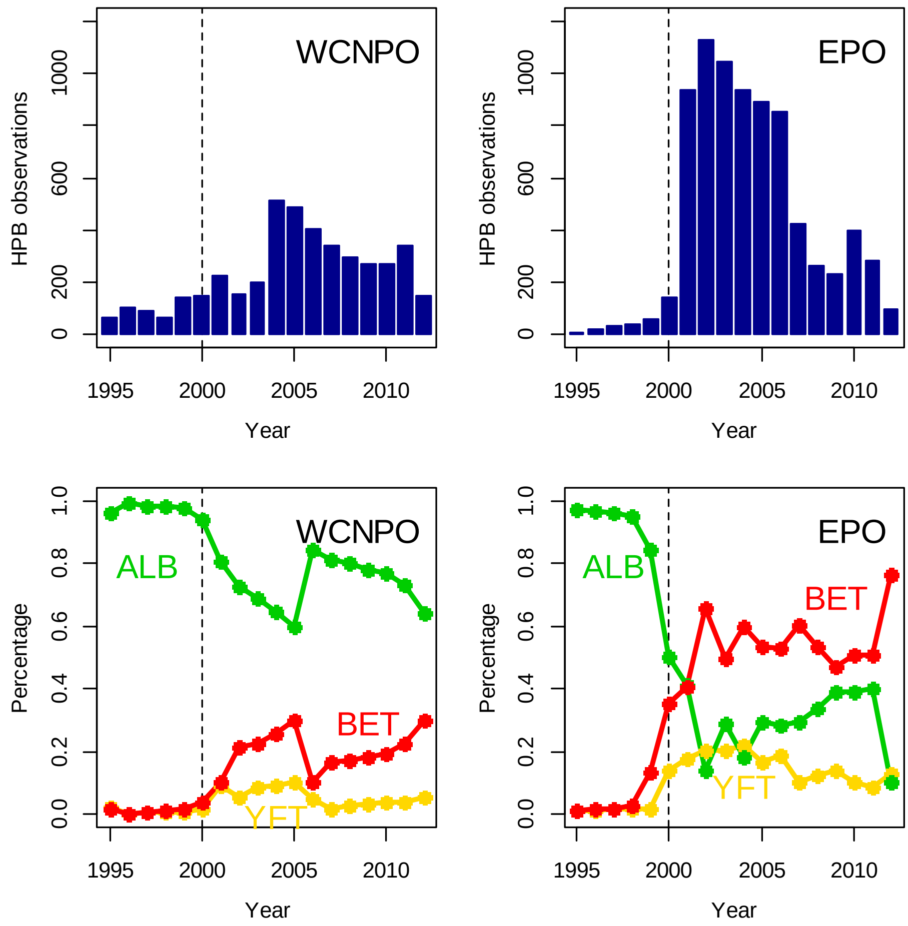

Fig. 1A. Sample sizes of hooks per basket (HPB) data (upper panels) and the catch composition (lower panels) of the Taiwanese distant-water tuna longline fishery in the WCNPO and EPO.