Standardized catch-rates of swordfish (*Xiphias gladius*) for the Taiwanese distant-water tuna longline fishery in the North Pacific Ocean for 1964-2016

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Abstract

CPUE (catch per unit effort) of swordfish caught in the Taiwanese distant-water tuna longline fishery was standardized using delta lognormal generalized linear models (GLMs) for the areas of western central North Pacific Ocean (WCNPO) and eastern tropical Pacific Ocean (EPO). Year, quarter, fishing region, and the two-way interactions between quarter and fishing region were used as predictors in the standardization models for an entire period (1964-2016) and two separate periods of 1964-1999, and 2000-2016 (with and without hooks-per-basket) due to changes in targeting species and fishing ground of this fishery. Results showed that, for both areas, standardized CPUE of swordfish was generally stable during the early period 1964-1999, 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.

Introduction

Swordfish (*Xiphias gladius*), a.k.a. broadbill swordfish, inhabit a wide region of the Pacific between the latitudes of 50˚N and 50˚S (Ward et al., 2000). Swordfish is a highly migratory species with high economic value in both commercial and recreational fisheries. In the North Pacific, the majority of catch has been taken by longline fishing vessels from Japan, Taiwan and the United States, which accounted for 95% of the total harvest in the North Pacific in 2010s, with the remaining catch taken by China, Korea, Mexico, and Spain.

Several stock structures have been proposed for Pacific swordfish (Alvarado Bremer et al., 2006; Ichinokawa and Brodziak, 2008). Recent genetic model in Lu et al. (2016) shows complex genetic population structure in the Pacific. To account for some stock structure uncertainty, we presented here the updated standardized catch-rates of swordfish for the Taiwanese distant-water tuna longline fishery in the area of western central North Pacific Ocean (WCNPO) and eastern tropical Pacific Ocean (EPO), respectively.

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; Sun et al., 2014). The objective of this study was to update standardized CPUE of swordfish for the Taiwanese distant-water tuna longline fishery by Sun et al. (2014). In preparation for the next swordfish stock assessment in 2018, 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 1964-2016 and those with hooks per basket (HPB) information from 1995 to 2016, were obtained from the Oversea Fisheries Development Council (OFDC) of Taiwan. This dataset contains information on time (year and month) and location (latitude and longitude), but was aggregated by month and by 5° by 5° grid cell. CPUE is expressed as the number of fish caught per 1000 hooks in this study.

Statistical model

Standardizations were performed for swordfish catch and effort data using GLM. The number of zero swordfish catches was relatively high (**Table 1**). As these zeros can cause mathematical problems for fitting the models, we used the delta-lognormal (DLN) for the catch-rates standardization. The DLN analyzes separately the positive observations (positive process) and the probability that a null or positive observation occurs (zero process), and consists of two GLM which respectively use a lognormal and a binomial distribution. The logarithm of the CPUE is the response variable in the lognormal model and the identity is the link function. The proportion of positive captures is the response variable in the binomial model and the link function is the logit.

The candidate factor variables followed the previous work from Sun et al. (2014), and included the years, calendar quarters, fishing regions. The candidate continuous variables included sea-surface temperature (SST; ℃) and HPB. An interaction between fishing regions and quarter was also added. To account the changes in targeting species of the Taiwanese distant-water tuna longline fishery in the Pacific Ocean, we separated the entire time-series into two periods of 1964-1999 and 2000-2016 (**Fig. 1**). Four standardization models for the positive process and the zero process were developed, respectively: an entire period (1964-2016), 1964-1999, 2000-2016, and 2000-2016 with the HPB covariate.

The models were fitted by forward selection stepwise based on Akaike Information Criterion (AIC). At each step in the model selection procedure, the factor that resulted in the greatest reduction in AIC from the model in the previous step was added to the model.

Model diagnostics

Pearson and randomized quantile residuals (Dunn and Smyth, 1996) were plotted against fitted values and against each explanatory variable in lognormal and a binomial model, respectively. Histograms of residuals were used to assess normality for all models, in addition the quantile-quantile normal probability plots (Q-Q plot) for both of the lognormal and binomial models.

Given that spatial autocorrelation is commonly a problem in modeling species abundance, semivariograms were used to test for the presence of autocorrelation in the response data (Nishida and Chen, 2004). Empirical semivariograms were also calculated for the residuals of the final models in order to compare how each of the models handled spatially structured variance.

Year effect and its precision

Indices of relative abundance were calculated for each distribution. The standardized CPUE index and its variance were calculated as the mean and variance, respectively, of the predicted values on the scale of the response in each year using the "predict" function in R. The variance of the delta-lognormal distribution was calculated as the Taylor series expansion of the variance of the product of two independent random variables (see Brodziak and Walsh, 2013; Eq. 7). Bias-correction was applied when back-transforming the positive process of the DLN model from ln(CPUE) to CPUE. All statistical analyses for this paper were carried out with the R Project for Statistical Computing version 3.1.0 (R Core Team, 2014).

Results and discussion

The spatial distributions of the nominal CPUE of swordfish in the Pacific Ocean were shown in **Fig. 2**. Based on Sun et al. (2014) and **Fig. 2**, the WCNPO and EPO were separated into six and four fishing regions respectively, which were then used as the region factor in GLM analysis.

Deviance tables for the models selected to standardize swordfish CPUE of the WCNPO area and the EPO area stock were shown in **tables 2-5** and **tables 6-9**, respectively. It should be noted that environmental variable (SST) were not statistically significant based on the χ^2 test ($p < 0.05$) of the models for the WCNPO area. For the EPO area, SST was statistically significant for the 2000-2016 lognormal model and 2000-2016 HPB lognormal mode, but not in the binomial model. Furthermore, HPB was not statistically significant in the 2000-2016 lognormal model for the WCNPO area. Comparing the 2000-2016 models with HPB effect and without HPB effect, the models with the HPB effect all indicated lower AIC values (**Table 10**).

The residual distributions for all the models of the WCNPO and EPO area based on the lognormal distributions appear normal in the GLM analysis (**Fig. 3**), which confirms the assumption of error distribution is appropriate to standardize catch and effort data of the Taiwanese tuna longline fishery for swordfish. According to the Q-Q plot (**Fig. 4**), this assumption of lognormality is also suitable to model the swordfish CPUE for the WCNPO and EPO area in the North Pacific Ocean for the Taiwanese distant-water tuna longline fishery. Furthermore, the Q-Q plots of the randomized quantile residuals of the binomial model also showed normality in the distribution of the residuals (**Fig. 5**).

Semivariogram plots were used to test this assumption (**Fig. 6**). From the plot, there is evidence of some degree of spatial dependence in first 20 lags (degree) of data. Empirical semivariogram plots of model residuals visually confirm that the ability of the models in reducing variance relative to the native variance (i.e., nominal CPUE variance). Although none of the regression models used here are structurally equipped to deal with autocovariance, as are spatial regression techniques (Thorson et al., 2015), the level of autocorrelation in the model residuals does appear to decrease to some extent relative to native levels.

The time-series trends of the standardized swordfish CPUEs among four models are generally similar for both the WCPNO area and EPO area. List of values for the time-series of standardized CPUEs and its precisions were shown in **tables 11-12**. Standardized CPUEs of swordfish for the WCNPO area were stable before 1990, but increased dramatically in 1995, then decreased in the late 1990s. The standardized CPUEs increased in early 2000s and stayed stable since then. However, the standardized swordfish CPUEs for the EPO area showed an increasing trend from 2005 until present (**Fig. 7**).

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Table 1. Time-series of the numbers of total observations, observations with hooks-per-basket (HPB), and observations with positive catch of swordfish (SWO) for the logbook data of the Taiwanese distant-water tuna longline fishery in the Pacific Ocean.

Year	Total	HPB	Positive SWO	
			western central North Pacific Ocean	eastern tropical Pacific Ocean
1964	592	-	-	4
1965	1,784	-	-	1
1966	7,192	-	-	-
1967	11,229	-	-	118
1968	10,298	-	-	56
1969	7,738	-	-	39
1970	11,001	-	-	123
1971	10,233	-	-	55
1972	10,022	-	-	59
1973	11,877	-	-	44
1974	10,849	-	-	66
1975	5,654	-	8	17
1976	4,551	-	12	32
1977	6,865	-	5	38
1978	5,617	-	-	15
1979	15,172	-	18	122
1980	18,717	-	23	42
1981	18,428	-	16	161
1982	13,847	-	7	101
1983	7,938	-	1	28
1984	8,060	-	-	40
1985	5,746	-	-	40
1986	5,125	-	-	62
1987	6,751	-	6	118
1988	4,993	-	-	68
1989	2,851	-	44	188
1990	1,617	-	32	50
1991	2,482	-	21	56
1992	3,047	-	13	40
1993	6,285	-	136	51
1994	5,406	-	16	32
1995	4,130	2,657	287	6
1996	6,307	4,058	107	41
1997	5,053	3,216	81	47
1998	3,319	2,062	24	73
1999	6,439	3,506	176	169

2000	6,378	2,727	285	857
2001	15,869	10,629	462	4,801
2002	17,910	17,227	527	6,848
2003	17,446	17,370	696	5,256
2004	31,831	31,001	2,201	7,116
2005	27,786	27,722	1,620	6,189
2006	24,792	24,792	1,803	5,956
2007	19,241	19,241	1,580	3,974
2008	15,512	15,512	1,317	2,043
2009	16,245	16,245	1,016	2,584
2010	18,507	18,282	1,432	4,136
2011	17,132	17,132	2,109	2,913
2012	17,164	17,164	1,909	3,498
2013	14,553	14,553	1,568	3,703
2014	12,370	12,370	771	3,960
2015	13,393	13,393	1,155	4,722
2016	18,200	18,200	2,179	5,547

Table 2. Deviance tables for the models selected to standardize swordfish CPUE of the WCNPO area for the Taiwanese distant-water tuna longline fishery during 1964-1999.

Predictor	Df	Deviance	Resid. Df	Resid. Dev	Pr（>Chi）
Positive process					
NULL			295	523.30	
Year	18	252.151	277	271.15	< 0.01 ***
Quarter	3	1.727	274	269.42	0.6123
Region	4	7.125	270	262.30	0.1128
Quarter:Region	11	15.461	259	246.84	0.1331
Zero process					
NULL			864	1111.49	
Year	27	194.448	837	917.05	< 0.01 ***
Quarter	3	1.645	834	915.40	0.65
Region	5	11.859	839	903.54	0.04 *
Quarter:Region	12	30.905	817	872.64	< 0.01 **

Table 3. Deviance tables for the models selected to standardize swordfish CPUE of the WCNPO area for the Taiwanese distant-water tuna longline fishery during 2000-2016.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			2308	2450.5	
Year	16	200.773	2292	2249.7	< 0.01 ***
Quarter	3	194.084	2289	2055.6	< 0.01 ***
Region	5	186.883	2284	1868.8	< 0.01 ***
SST	1	0.071	2283	1868.7	0.7675
Quarter:Region	13	36.890	2270	1831.8	< 0.01 ***
Zero process					
NULL			3018	3293.5	
Year	16	73.824	3002	3219.6	< 0.01 ***
Quarter	3	15.179	2999	3204.5	< 0.01 **
Region	5	96.116	2994	3108.3	< 0.01 ***
SST	1	0.001	2993	3108.3	0.97
Quarter:Region	14	33.796	2979	3074.6	< 0.01 **

Table 4. Deviance tables for the models (with hooks-per-basket) selected to standardize swordfish CPUE of the WCNPO area for the Taiwanese distant-water tuna longline fishery during 2000-2016.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			2098	2025.4	
Year	16	137.837	2082	1887.6	< 0.01 ***
Quarter	3	150.944	2079	1736.7	< 0.01 **
Region	5	186.178	2074	1550.5	< 0.01 ***
SST	1	0.215	2073	1550.3	0.59
HPB	1	0.010	2072	1550.2	0.90
Quarter:Region	13	41.240	2059	1509	< 0.01 ***
Zero process					
NULL			2673	2783.9	
Year	16	45.35	2657	2738.6	< 0.01 ***
Quarter	3	15.13	2654	2723.4	< 0.01 **
Region	5	84.87	2649	2638.6	< 0.01 ***
SST	1	0.37	2648	2638.2	0.54
HPB	1	690.29	2647	1947.9	< 0.01 ***
Quarter:Region	14	23.58	2633	1924.3	0.05

Table 5. Deviance tables for the models selected to standardize swordfish CPUE of the WCNPO area for the Taiwanese distant-water tuna longline fishery during 1964-2016.

Predictor	Df	Deviance	Resid. Df	Resid. Dev	Pr（>Chi）
Positive process					
NULL			2604	3066.1	
Year	35	545.26	2569	2520.9	< 0.01 ***
Quarter	3	171.47	2566	2349.4	< 0.01 ***
Region	5	185.37	2561	2164	< 0.01 ***
Quarter:Region	13	33.85	2548	2130.2	< 0.01 ***
Zero process					
NULL			3883	4922.4	
Year	44	785.75	3839	4136.7	< 0.01 ***
Quarter	3	9.88	3836	4126.8	0.02 *
Region	5	82.75	3831	4044.1	< 0.01 ***
Quarter:Region	14	42.71	3817	4001.3	< 0.01 ***

Table 6. Deviance tables for the models selected to standardize swordfish CPUE of the EPO area for the Taiwanese distant-water tuna longline fishery during 1964-1999.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			681	847.28	
Year	34	102.136	647	745.14	< 0.01 ***
Quarter	3	22.234	644	722.91	< 0.01 ***
Region	3	35.124	641	687.78	< 0.01 ***
Quarter:Region	9	16.639	632	671.14	0.07
Zero process					
NULL			1630	2217.1	
Year	35	163.506	1595	2053.6	< 0.01 ***
Quarter	3	31.85	1592	2021.8	< 0.01 ***
Region	3	22.896	1589	1998.9	< 0.01 ***
Quarter:Region	9	15.722	1580	1983.2	0.07

Table 7. Deviance tables for the models selected to standardize swordfish CPUE of the EPO area for the Taiwanese distant-water tuna longline fishery during 2000-2016.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			3829	3254.7	
Year	16	270.866	3813	2983.8	< 0.01 ***
Quarter	3	22.818	3810	2961	< 0.01 ***
Region	3	158.053	3807	2802.9	< 0.01 ***
SST	1	44.188	3806	2758.7	< 0.01 ***
Quarter:Region	9	106.449	3797	2652.3	< 0.01 ***
Zero process					
NULL			4182	2420.8	
Year	16	61.233	4166	2359.6	< 0.01 ***
Quarter	3	3.387	4163	2356.2	0.34
Region	3	42.383	4160	2313.8	< 0.01 ***
SST	1	0.596	4159	2313.2	0.44
Quarter:Region	9	58.501	4150	2254.7	< 0.01 ***

Table 8. Deviance tables for the models (with hooks-per-basket) selected to standardize swordfish CPUE of the EPO area for the Taiwanese distant-water tuna longline fishery during 2000-2016.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			3517	2969.1	
Year	16	280.207	3501	2688.9	< 0.01 ***
Quarter	3	23.511	3498	2665.4	< 0.01 ***
Region	3	118.09	3495	2547.3	< 0.01 ***
SST	1	34.694	3494	2512.6	< 0.01 ***
HPB	1	32.608	3493	2480	< 0.01 ***
Quarter:Region	9	96.84	3484	2383.2	< 0.01 ***
Zero process					
NULL			3842	2227.3	
Year	16	65.52	3826	2161.8	< 0.01 ***
Quarter	3	4.15	3823	2157.7	0.25
Region	3	40.83	3820	2116.8	< 0.01 ***
SST	1	0.11	3819	2116.7	0.74
HPB	1	602.62	3818	1514.1	< 0.01 ***
Quarter:Region	9	31.92	3809	1482.2	< 0.01 ***

Table 9. Deviance tables for the models selected to standardize swordfish CPUE of the EPO area for the Taiwanese distant-water tuna longline fishery during 1964-2016.

Predictor	**Df**	**Deviance**	**Resid. Df**	**Resid. Dev**	**Pr（>Chi）**
Positive process					
NULL			4511	5909.7	
Year	51	2180.73	4460	3728.9	< 0.01 ***
Quarter	3	19.97	4457	3709	< 0.01 ***
Region	3	173.03	4454	3535.9	< 0.01 ***
Quarter:Region	9	139.89	4445	3396	< 0.01 ***
Zero process					
NULL			5813	6184.4	
Year	52	1771.19	5761	4413.2	< 0.01 ***
Quarter	3	19.82	5758	4393.4	< 0.01 ***
Region	3	37.19	5755	4356.2	< 0.01 ***
Quarter:Region	9	62.73	5746	4293.5	< 0.01 ***

Table 10. Residual deviances and AICs for the models selected to standardize swordfish CPUE of the areas of WCNPO and EPO for the Taiwanese distant-water tuna longline fishery.

Model	Area	Year	Res. deviance	pseudo R^2	AIC
Positive process	WCNPO	1964-1999	246.8	0.53	862.25
		2000-2016	1832	0.21	6098.08
		2000-2016 (+HPB)	1509	0.25	5346.02
		1964-2016	2130	0.01	6984.48
	EPO	1964-1999	671.1	0.25	2026.49
		2000-2016	2652	0.31	9529.75
		2000-2016 (+HPB)	2383	0.31	8683.55
		1964-2016	3396	0.19	11658.5
Zero process	WCNPO	1964-1999	872.6	0.21	968.6364
		2000-2016	3075	0.11	3154.552
		2000-2016 (+HPB)	1924	0.19	2006.307
		1964-2016	4001	0.07	4135.347
	EPO	1964-1999	1983	0.20	2085.167
		2000-2016	2255	0.33	2320.69
		2000-2016 (+HPB)	1482	0.43	1550.17
		1964-2016	4293	0.31	4429.452

Table 10. Time-series of nominal, standardized CPUEs (number-per 1000 hooks) and its precisions of four standardization models of swordfish in the WCNPO area by the Taiwanese distant-water tuna longline fishery.

Year	Nominal	Model 1964-1999		Model 2000-2016		Model 2000-2016 (+HPB)		Model 1964-2016	
		Std. CPUE	SE	Std. CPUE	SE	Std. CPUE	SE	Std. CPUE	SE
1975	0.08	0.02	0.04					0.02	0.02
1976	0.26	0.36	0.04					0.34	0.13
1977	0.11	0.02	0.03					0.02	0.05
1979	0.53	0.10	0.09					0.09	0.05
1980	0.27	0.05	0.14					0.05	0.11
1981	0.08	0.03	0.15					0.03	0.18
1982	0.63								
1983	0.02								
1987	0.05	0.02	0.70					0.02	0.19
1989	0.10	0.11	0.22					0.10	0.15
1990	0.17	0.20	0.27					0.18	0.15
1991	0.17	0.18	0.09					0.17	0.06
1992	0.69	0.44	0.38					0.41	0.12
1993	1.32	0.70	0.14					0.66	0.20
1995	0.22	0.23	0.26					0.22	0.23
1996	0.08	0.05	0.36					0.05	0.26
1997	0.06	0.04	0.20					0.03	0.25
1998	0.02	0.01	0.24					0.01	0.15
1999	0.06	0.05	0.27					0.05	0.19
2000	0.14			0.13	0.31	0.19	0.35	0.14	0.28
2001	0.36			0.22	0.29	0.36	0.30	0.22	0.27
2002	0.40			0.33	0.35	0.39	0.34	0.33	0.32
2003	0.37			0.37	0.33	0.36	0.36	0.38	0.31
2004	0.37			0.48	0.38	0.34	0.37	0.49	0.35
2005	0.21			0.24	0.35	0.23	0.42	0.24	0.32

2006	0.19	0.21	0.35	0.20	0.44	0.22	0.33
2007	0.20	0.18	0.31	0.18	0.46	0.19	0.30
2008	0.18	0.17	0.35	0.16	0.52	0.17	0.33
2009	0.24	0.19	0.36	0.19	0.48	0.20	0.33
2010	0.28	0.21	0.35	0.20	0.49	0.21	0.32
2011	0.28	0.22	0.32	0.21	0.45	0.22	0.29
2012	0.26	0.27	0.40	0.26	0.46	0.27	0.36
2013	0.21	0.25	0.34	0.25	0.40	0.25	0.32
2014	0.21	0.22	0.36	0.23	0.45	0.22	0.33
2015	0.34	0.27	0.36	0.27	0.45	0.27	0.33
2016	0.42	0.34	0.36	0.33	0.45	0.35	0.33

Table 11. Time-series of nominal, standardized CPUEs (number-per 1000 hooks) and its precisions of four standardization models of swordfish in the EPO area by the Taiwanese distant-water tuna longline fishery.

Year	**Nominal**	**Model 1964-1999**		**Model 2000-2016**		**Model 2000-2016 (+HPB)**		**Model 1964-2016**	
		Std. CPUE	**SE**	**Std. CPUE**	**SE**	**Std. CPUE**	**SE**	**Std. CPUE**	**SE**
1964	0.20								
1965	0.07								
1967	0.11	0.07	0.20					0.06	0.15
1968	0.10	0.05	0.13					0.04	0.10
1969	0.09	0.05	0.12					0.05	0.09
1970	0.09	0.06	0.21					0.05	0.16
1971	0.05	0.04	0.24					0.04	0.18
1972	0.09	0.05	0.18					0.05	0.13
1973	0.06	0.03	0.20					0.02	0.13
1974	0.05	0.04	0.16					0.04	0.07
1975	0.05	0.02	0.12					0.02	0.08
1976	0.28	0.20	0.03					0.17	0.02
1977	0.06	0.03	0.17					0.02	0.12
1978	0.04	0.02	0.20					0.02	0.12
1979	0.13	0.13	0.26					0.11	0.16
1980	0.11	0.08	0.21					0.07	0.26
1981	0.09	0.09	0.31					0.08	0.22
1982	0.05	0.05	0.27					0.04	0.20
1983	0.04	0.03	0.20					0.03	0.11
1984	0.06	0.04	0.16					0.03	0.07
1985	0.05	0.04	0.17					0.04	0.07
1986	0.04	0.04	0.21					0.03	0.09
1987	0.05	0.05	0.30					0.04	0.21
1988	0.09	0.05	0.29					0.04	0.19
1989	0.10	0.12	0.30					0.10	0.19

1990	0.09	0.06	0.20					0.06	0.16
1991	0.05	0.04	0.32					0.04	0.23
1992	0.07	0.07	0.21					0.06	0.13
1993	0.05	0.05	0.17					0.04	0.06
1994	0.10	0.06	0.25					0.05	0.16
1995	0.03	0.06	0.21					0.05	0.13
1996	0.21	0.29	0.78					0.25	0.48
1997	0.09	0.08	0.20					0.07	0.13
1998	0.09	0.10	0.40					0.09	0.24
1999	0.10	0.21	0.33					0.18	0.20
2000	0.52			0.45	0.22	0.45	0.20	0.47	0.20
2001	0.66			0.79	0.36	1.00	0.38	0.82	0.36
2002	0.84			0.80	0.28	0.78	0.27	0.83	0.27
2003	0.65			0.69	0.28	0.69	0.27	0.72	0.27
2004	0.62			0.66	0.28	0.66	0.29	0.69	0.27
2005	0.37			0.41	0.25	0.41	0.28	0.42	0.23
2006	0.46			0.48	0.27	0.48	0.28	0.50	0.26
2007	0.55			0.54	0.26	0.53	0.31	0.55	0.24
2008	0.60			0.52	0.26	0.52	0.27	0.54	0.22
2009	0.73			0.69	0.22	0.69	0.25	0.71	0.22
2010	0.62			0.59	0.24	0.59	0.26	0.61	0.23
2011	0.63			0.63	0.24	0.64	0.25	0.65	0.24
2012	0.84			0.58	0.25	0.59	0.28	0.60	0.22
2013	0.77			0.62	0.23	0.62	0.25	0.64	0.21
2014	0.95			0.77	0.24	0.79	0.26	0.80	0.23
2015	1.17			1.23	0.30	1.22	0.32	1.27	0.32
2016	1.33			1.10	0.23	1.09	0.22	1.13	0.23

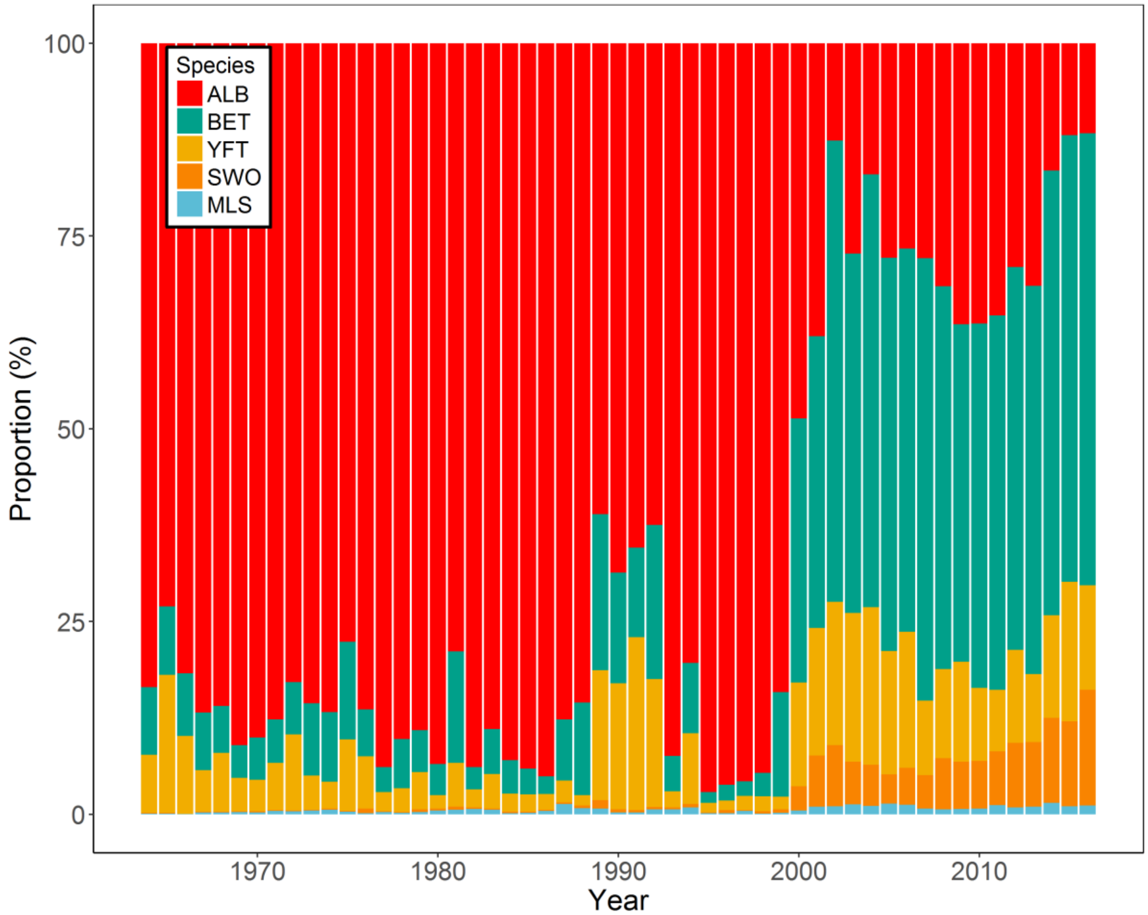

Figure 1. Annual catch proportions of albacore tuna, bigeye tuna, yellowfin tuna, swordfish, and striped marlin by the Taiwanese distant-water tuna longline fishery in the Pacific Ocean during 1964-2016.

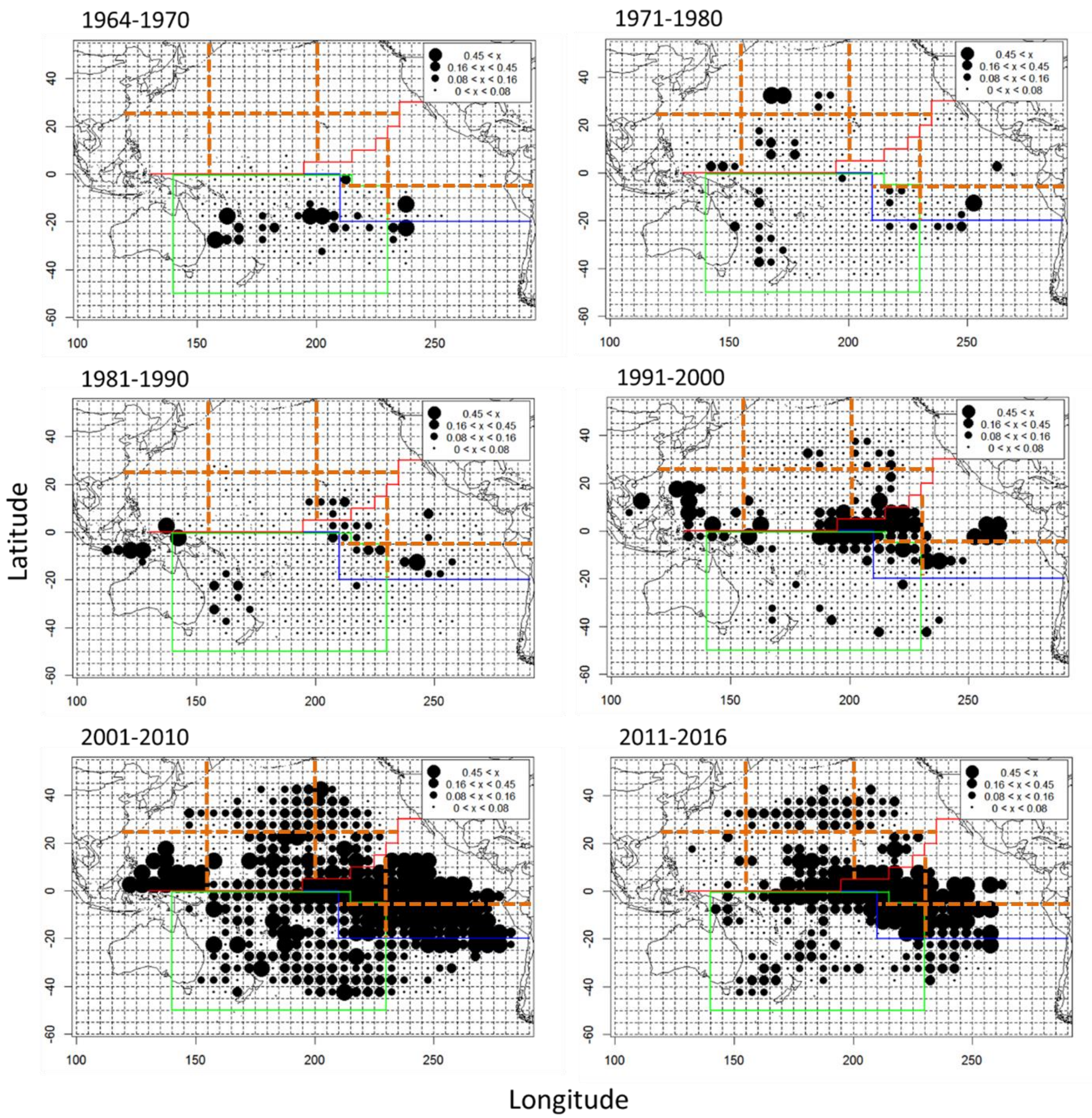

Figure 2. Distributions of nominal CPUE (number of fish caught per 1000 hooks) of swordfish in the areas of WCNPO and EPO for the Taiwanese distant-water tuna longline fishery. Note that the six regions in the WCNPO and four regions in the EPO were used in the CPUE standardization models as the area factor. Red line = boundary of the WCPNP and EPO, blue line = southern boundary the North stock, orange line = boundaries of GLM regions, green line = stock of the southern west Pacific swordfish.

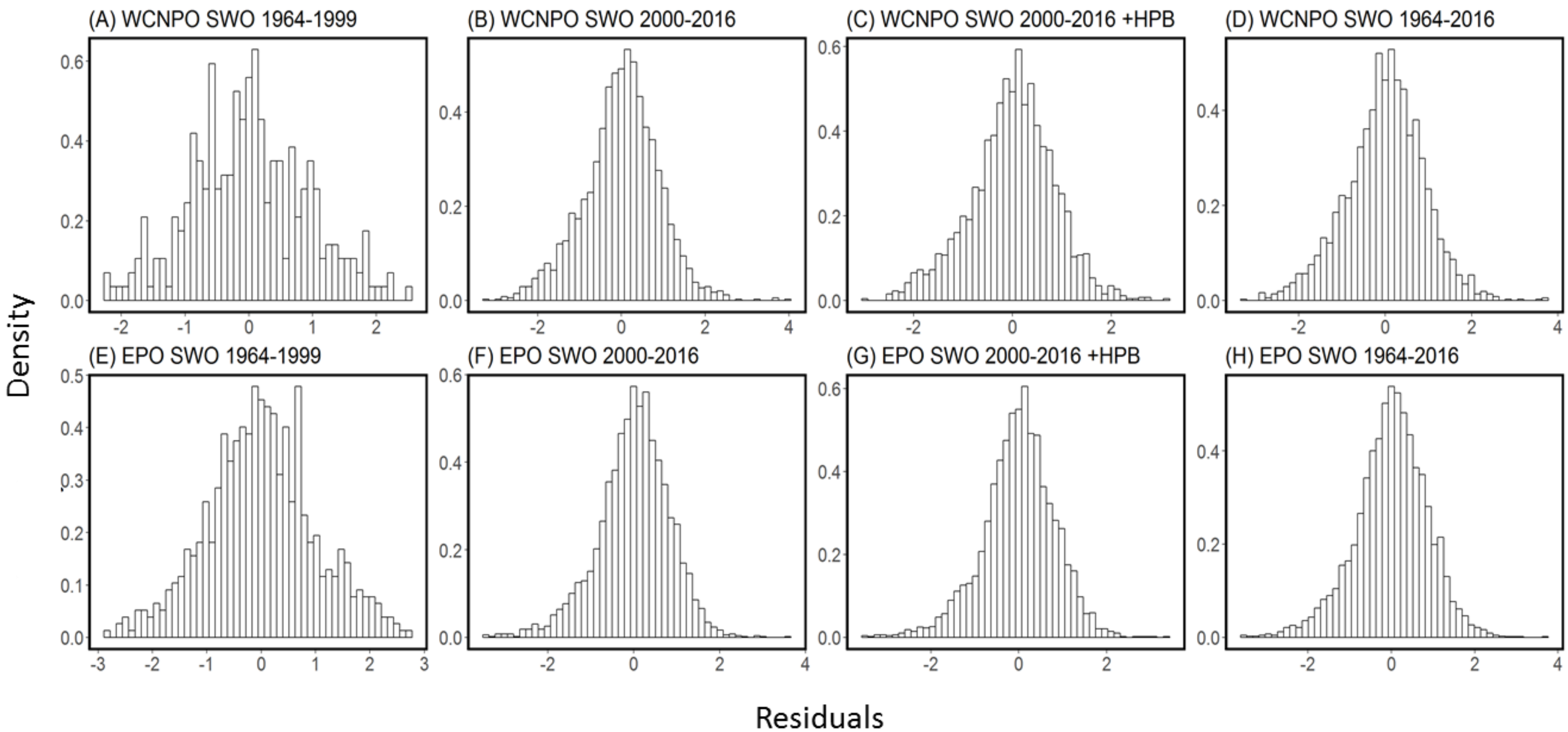

Figure 3. Residual distributions for the models selected to standardize the CPUE of swordfish in the areas of WCNPO (panels A-D) and EPO (panels E-H) by the Taiwanese distant-water tuna longline fishery.

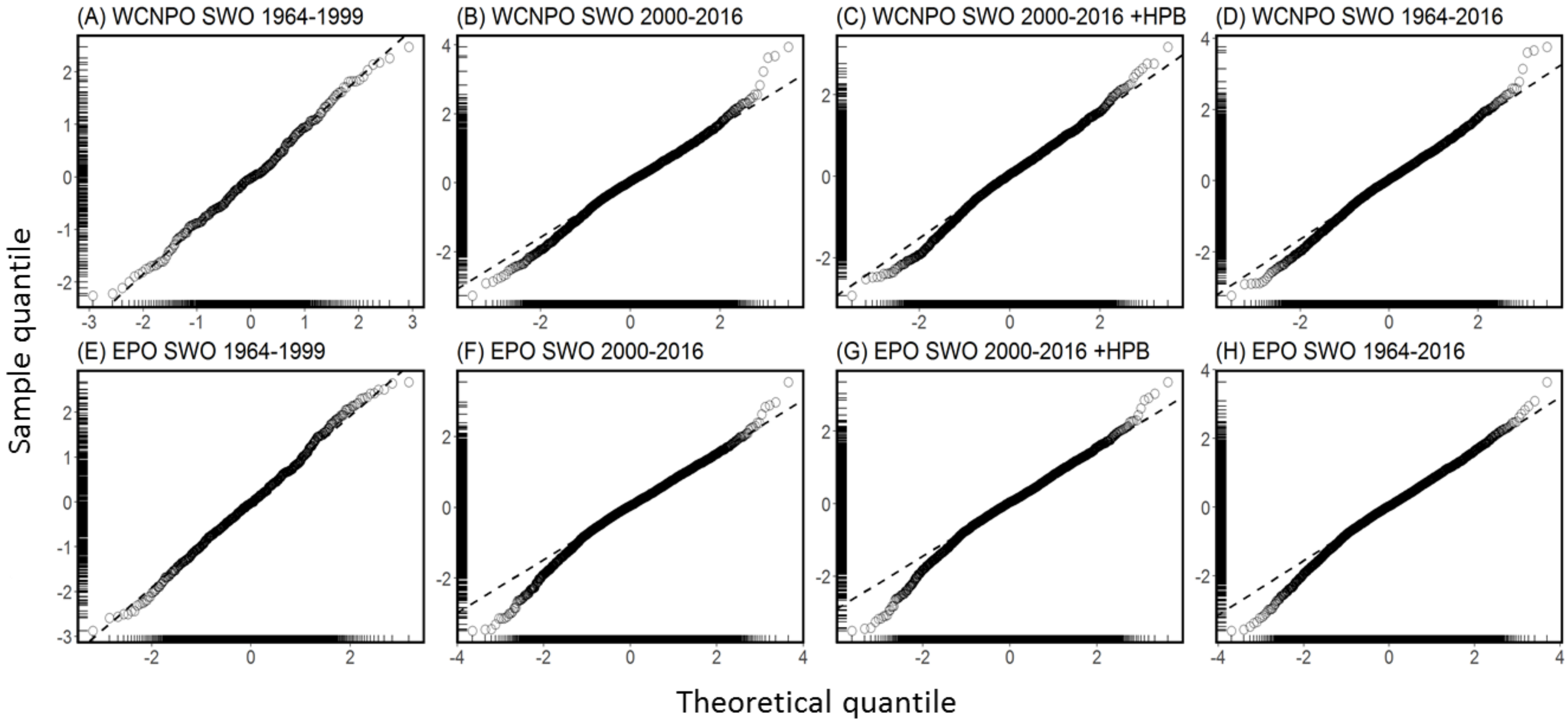

Figure 4. Diagnostic Q-Q plots of Pearson residuals for the positive process for the models selected to standardize the CPUE of swordfish in the areas of WCNPO (panels A-D) and EPO (panels E-H) by the Taiwanese distant-water tuna longline fishery.

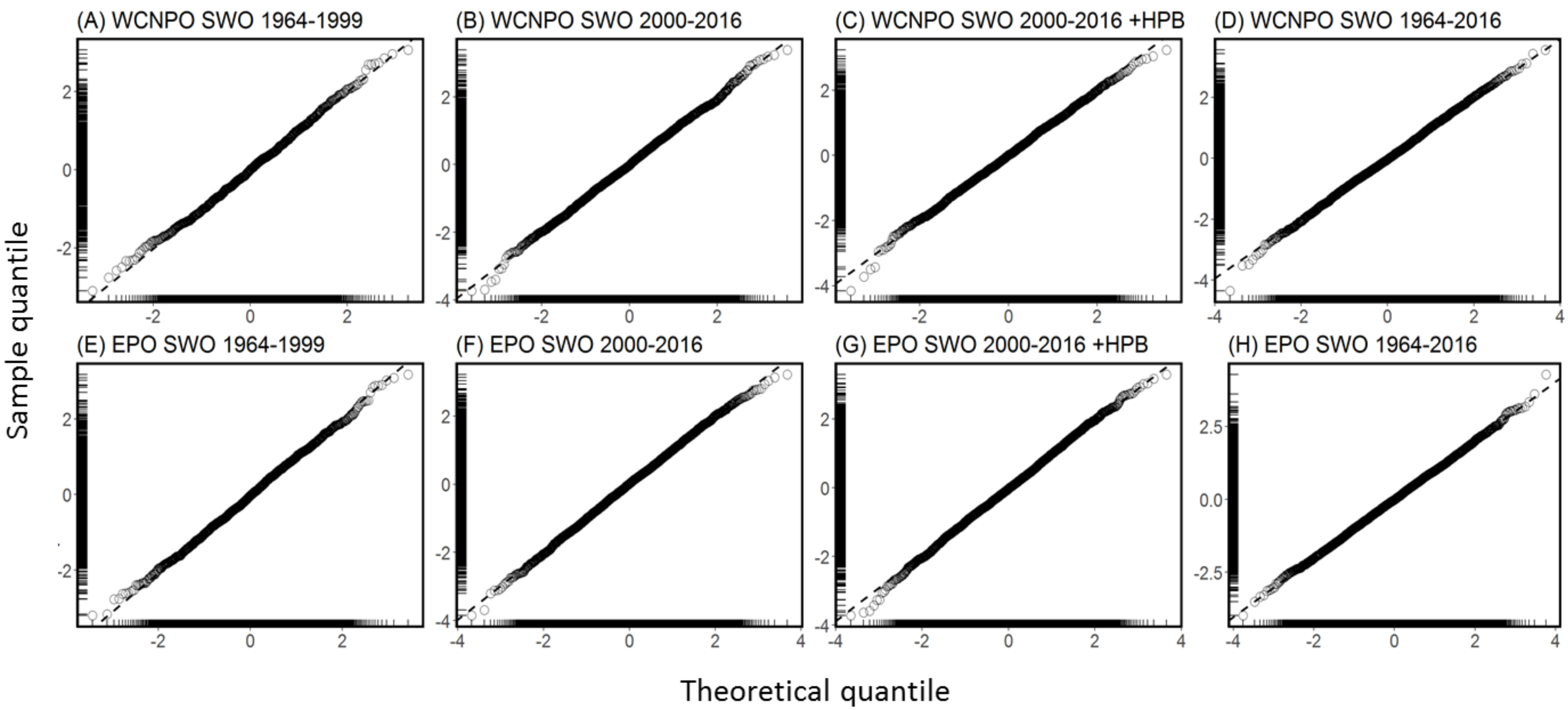

Figure 5. Diagnostic Q-Q plots of randomized quantile residuals for the zero process for the models selected to standardize the CPUE of swordfish in the areas of WCNPO (panels A-D) and EPO (panels E-H) by the Taiwanese distant-water tuna longline fishery.

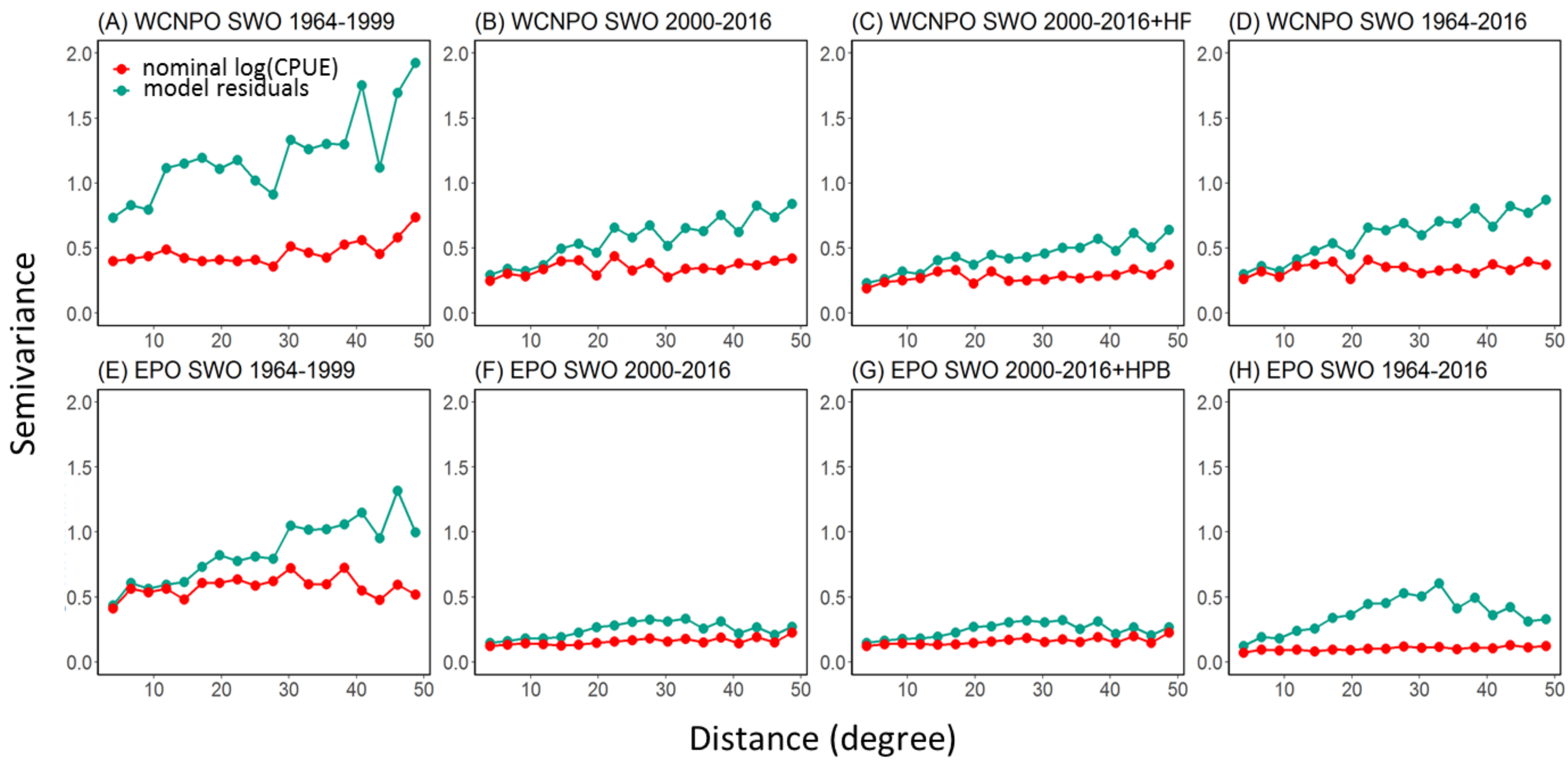

Figure 6. Semivariograms of model residuals and empirical semivariogram of the nominal log(CPUE) for the four standardization models.

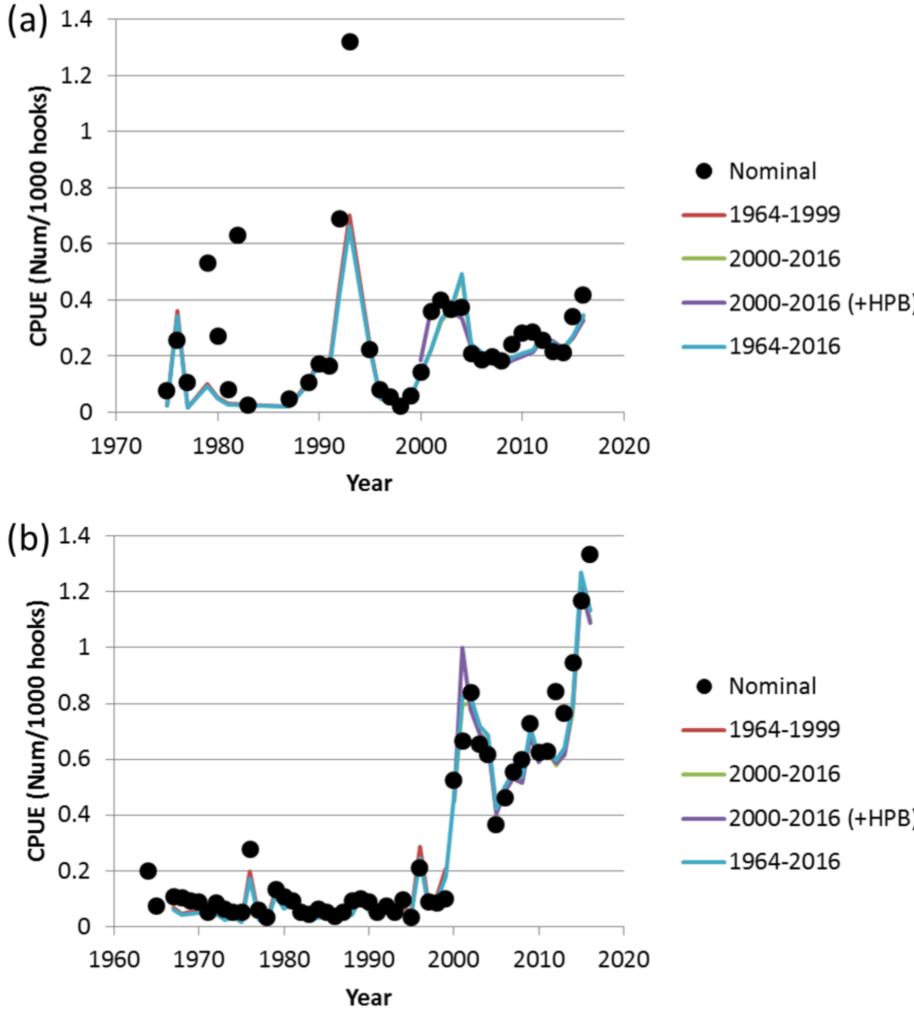

Figure 7. Nominal (closed circles) and standardized (solid lines) swordfish CPUEs in the areas of WCNPO (a) and EPO (b) by the Taiwanese distant-water tuna longline fishery. CPUE is expressed as the number of fish caught per 1000 hooks.