CPUE standardization of blue marlin (*Makaira nigricans*) for the Taiwanese distant-water tuna longline fishery in the Pacific Ocean[*]

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Abstract

Catch and effort data of blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean were standardized using generalized linear models. Task II data (aggregated into 5°×5° grids) from 1967 to 2014 and those with hooks per basket (HPB) information for 2000-2014 were used for the standardization of CPUE (catch per unit effort) in this study. The CPUE standardization models were conducted based on three periods, 1967-1978, 1979-1999 and 2000-2014, due to the changes in the fishery such as targeting. Results show that the standardized CPUE of blue marlin were generally stable over 1979-1999, but have noticeably increased thereafter. The effect of HPB was statistically significant in the CPUE standardization. However, the CPUE trend with HPB information included in the model for 2000-2014 is similar to those without HPB included in the model. The standardized CPUE of blue marlin show a generally increasing trend in recent years (from 2008 until 2014). The standardized CPUE of blue marlin derived from this study could be used as basic input data for the assessment of this stock.

Keywords: Abundance Index, Generalized Linear Model, Hooks Per Basket

Introduction

Blue marlin (*Makaira nigricans*) is a highly migratory species distributed throughout tropical and temperate waters of the Pacific Ocean (Su et al., 2011). A single stock of blue marlin in the Pacific Ocean has been assumed based on genetic analyses (Graves and McDowell, 2003) and fishery-dependent catch-rate data (Kleiber et al., 2003). This assumption is also supported by the results of tagging experiments that have demonstrated that blue marlin migrate long distances (>8,000 km in some instances)

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and throughout the Pacific basin (Hinton, 2001).

Blue marlin are the largest of the billfishes, attaining up to 450 cm in length and over 900 kg in weight, and are the most popular gamefish because of their size and fighting ability (Molony, 2008). They exhibit, however, sexual dimorphism in size, with males reaching a maximum size of 200 cm in length while females can grow to much more than this (Wilson et al., 1991). The sizes-at-maturity of blue marlin also differ between males and females, with estimated size at about 130 and 180 cm EFL (eye fork length) respectively (Sun et al., 2009). Therefore, the assessment method for blue marlin in the Pacific Ocean need to take account of sex structure to improve the stock assessment, as suggested by previous studies (e.g., Su et al., 2012).

The objective of this study was to standardize the catch and effort data of the Taiwanese distant-water tuna longline fishery for blue marlin in the Pacific Ocean. The standardized abundance indices of blue marlin derived from this study could provide basic, necessary input data for stock assessments of this species.

Materials and methods

Fishery data

Task II data of the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for blue marlin, including catch (in number of fish) and fishing effort (in number of hooks) for 1967-2014 and those with hooks per basket (HPB) information from 1995 to 2014, were obtained from the Oversea Fisheries Development Council (OFDC, Taiwan). This data set contains information on time (year and month) and location (latitude and longitude), which were aggregated in 5° by 5 ° grid and month. 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, assuming that the expected value of a response variable is related to a linear combination of exploratory variables (Maunder and Punt, 2004). GLMs were thus used to standardize the catch and effort data of the Taiwanese distant-water tuna longline fishery for blue marlin in the Pacific Ocean. The full GLM model is expressed as follows:

BUM ~ Year + Quarter + Latitude + Longitude + Latitude:Longitude + HPB   (1)

where   BUM is the nominal CPUE of blue marlin with a small constant added;

Year is the factor for year;

Quarter is the season effect;

Latitude is the latitude effect;

Longitude is the longitude effect;

Latitude:Longitude is the interaction between latitude and longitude;

HPB is the hooks per basket information.

Diagnostic analysis

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

Results and discussion

There are in total 23,887 catch and effort records in 5° by 5° grids for the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for 1967-2014. However, the number of catch and effort observations with HPB information reduced substantially, because HPB information has become available since 1995. In general, high nominal CPUEs of blue marlin occur in tropical waters of the Pacific Ocean for the Taiwanese distant-water tuna longline fishery (Fig. 1).

The catches of blue marlin in Taiwan, from various fisheries, have increased gradually since the 1960s, most of which came from the offshore longline fishery (Sun et al., 2011). Annual catches of blue marlin from the Taiwanese distant-water tuna longline fishery were low before 2000, but have increased substantially to more than 1,000 mt afterward (Fig. 2).

The residual distributions from standardization models based on a lognormal error distribution appear normal in the GLM analysis (Fig. 3), which confirms the assumption of error models for lognormal distribution to standardize catch and effort data of the Taiwanese tuna longline fishery for blue marlin in the Pacific Ocean. According to the Q-Q plot, this assumption is also suitable to model the CPUE of Pacific blue marlin for this fleet, even when HPB information was included in the standardization (Fig. 3). Therefore, the CPUE standardization for blue marlin in this study was consequently based on the lognormal error distribution (Fig. 4).

The effects considered in the GLM models were all statistically significant based on the χ^2 test ($p < 0.001$) and the AIC values, including year, month, latitude,

longitude, and the interaction between latitude and longitude, as well as the HPB effect (Table 1). The deviance explained by the model for standardizing the blue marlin CPUE was 36.5% (1967-2014), while the deviance explained by the model that included the HPB information was reduced to 34.2% (based on different data sets for 2000-2014). The proportion of total deviance explained by the additional HPB factor was 3.3%, which increased the R^2 from 0.331 to 0.342 (Table 1b).

The standardized CPUEs of blue marlin for the Taiwanese distant-water longline fishery in the Pacific Ocean were generally stable, but slightly decreasing over 1980-2000, although nominal CPUEs of blue marlin varied largely for a few of the years (Fig. 5). Due to the change of targeting species from albacore tuna (*Thunnus alalunga*) to bigeye tuna (*Thunnus obesus*), the CPUE trend of blue marlin increased substantially in recent 15 years (since 2000) with a drop during 2005-2008.

However, the CPUE trend of blue marlin with HPB information included in the CPUE standardization was similar to that standardized without HPB information in the model (Fig. 5b). This may imply that the change in targeting cannot be quantified well in the CPUE standardization owing to a lack of more informative operational data, such as hooks-at-depth and bait types.

Given the targeting change in the fishery to bigeye tuna since 2000, as well as the fishing ground shifted in the early period, the CPUE standardization models of blue marlin in the Taiwanese distant-water tuna longline fishery were conducted based on three periods, 1967-1978, 1979-1999, and 2000-2014, to account for the temporal effect. The factors considered in the three CPUE standardizations were all statistically significant based on the χ^2 test (p < 0.001) and the AIC values (Table 1c-e).

In general, the standardized CPUE series were consistent with those based on the single time period, but it appears that the three separate standardized CPUE series fit the observed data (nominal CPUE) much better than the single time period CPUE series (Fig. 5b). The effect of HPB was statistically significant in the CPUE standardization of blue marlin. However, the CPUE trend with HPB information included in the model for 2000-2014 was almost identical to that without HPB included.

The standardized CPUE series with HPB included in the model were considered (by the working group) the best available scientific information from the fishery owing to additional deviance explained by HPB, compared with the one without HPB.

Therefore, we suggest using these abundance indices with HPB information included, as well as the CPUE series in the early two periods, in the coming stock assessment for Pacific blue marlin in 2016. The CPUE series (and standard deviation) of blue marlin for this fishery were summarized in Table 3.

References

Graves, J.E., McDowell, J.R. (2003). Stock structure of the world's istiophorid billfishes: a genetic perspective. Mar. Freshw. Res., 54: 287–298.

Hinton, M.G. (2001). Status of blue marlin in the Pacific Ocean. Inter-American Tropical Tuna Commission (IATTC), Stock Assessment Report 1, pp. 284–319.

Kleiber, P., Hinton, M.G., Uozumi, Y. (2003). Stock assessment of blue marlin (*Makaira nigricans*) in the Pacific using MUNTIFAN-CL. Mar. Freshw. Res., 54: 349–360.

Molony, B. (2008). Fisheries biology and ecology of highly migratory species that commonly interact with industrialised longline and purse-seine fisheries in the western and central Pacific Ocean. Working Paper EB-IP-6, 4th Meeting of the Scientific Committee of the Western and Central Pacific Fisheries Commission (WCPFC-SC4). Port Moresby, Papua New Guinea, 11-22 August 2008.

Maunder, M.N., Punt, A.E. (2004). Standardizing catch and effort data: a review of recent approaches. Fish. Res., 70: 141–159.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G. (2011). Modelling the impacts of environmental variation on the distribution of blue marlin, *Makaira nigricans*, in the Pacific Ocean. ICES J. Mar. Sci., 68: 1072–1080.

Su, N.J., Sun, C.L., Punt, A.E., Yeh, S.Z., DiNardo, G. (2012). Incorporating habitat preference into the stock assessment and management of blue marlin (*Makaira nigricans*) in the Pacific Ocean. Mar. Freshw. Res., 63: 565–575.

Sun, C.L., Su, N.J., Yeh, S.Z., Chang, Y.J. (2011). A review of Taiwan's billfish fisheries in the North Pacific Ocean, 1997-2009. The Intercessional Workshop of the Billfish Working Group of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). January 19-27, 2011. Honolulu, Hawaii, USA. ISC/11/BILLWG-1/01, 11 pp.

Sun, C.L., Chang, Y.J., Tszeng, C.C., Yeh, S.Z., Su, N.J. (2009). Reproductive biology of blue marlin (*Makaira nigricans*) in the western Pacific Ocean. Fish. Bull., 107: 420–432.

Wilson, C.A., Dean, J.M., Prince, E.D., Lee, D.W. (1991). An examination of sexual dimorphism in Atlantic and Pacific blue marlin using body weight, sagittae weight, and age estimates. J. Exp. Mar. Biol. Ecol., 151: 209–225.

Table 1. Deviance tables for the models selected to standardize the CPUE of blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean.

(a) 1967-2014

Predictors	Residual D.F.	Residual Dev	Dev	Pr(>Chi)	R^2	AIC
NULL	23617	26393				69653
+Year	23570	23223	3170	<0.001	0.120	66724
+Quarter	23567	22795	428	<0.001	0.136	66291
+Latitude	23550	18176	4619	<0.001	0.311	60977
+Longitude	23520	17755	421	<0.001	0.327	60483
+Latitude:Longitude	23172	16750	1005	<0.001	0.365	59803

(b) 2000-2014 (with HPB)

Predictors	Residual D.F.	Residual Dev	Dev	Pr(>Chi)	R^2	AIC
NULL	20095	24944				61377
+Year	20081	24383	561	<0.001	0.022	60948
+Quarter	20078	24138	245	<0.001	0.032	60751
+Latitude	20061	18775	5363	<0.001	0.247	55736
+Longitude	20031	17972	803	<0.001	0.280	54917
+Latitude:Longitude	19713	16687	1286	<0.001	0.331	54062
+HPB	19702	16405	282	<0.001	0.342	53741

Table 1. Continued.

(c) 1967-1978

Predictors	Residual D.F.	Residual Dev	Dev	Pr(>Chi)	R^2	AIC
NULL	4934	2739				11103
+Year	4923	2708	31	<0.001	0.011	11069
+Quarter	4920	2685	23	<0.001	0.020	11032
+Latitude	4905	2637	47	<0.001	0.037	10975
+Longitude	4881	2620	18	<0.001	0.044	10990
+Latitude:Longitude	4725	2489	131	<0.001	0.091	11049

(d) 1979-1999

Predictors	Residual D.F.	Residual Dev	Dev	Pr(>Chi)	R^2	AIC
NULL	6876	6838				19481
+Year	6856	6497	341	<0.001	0.050	19169
+Quarter	6853	5976	521	<0.001	0.126	18600
+Latitude	6836	4993	983	<0.001	0.270	17398
+Longitude	6806	4836	157	<0.001	0.293	17238
+Latitude:Longitude	6527	4464	372	<0.001	0.347	17246

(e) 2000-2014

| Predictors	Residual D.F.	Residual Dev	Dev	Pr(>Chi)	R^2	AIC
NULL	11805	14228				35711
+Year	11791	14018	210	<0.001	0.015	35563
+Quarter	11788	13922	96	<0.001	0.021	35488
+Latitude	11771	9627	4295	<0.001	0.323	31167
+Longitude	11741	9043	585	<0.001	0.364	30488
+Latitude:Longitude	11413	7970	1073	<0.001	0.440	29653

Table 2. Standardized CPUE and CV for blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean based on the models of specific periods (1967-1978, 1979-1999, and 2000-2014).

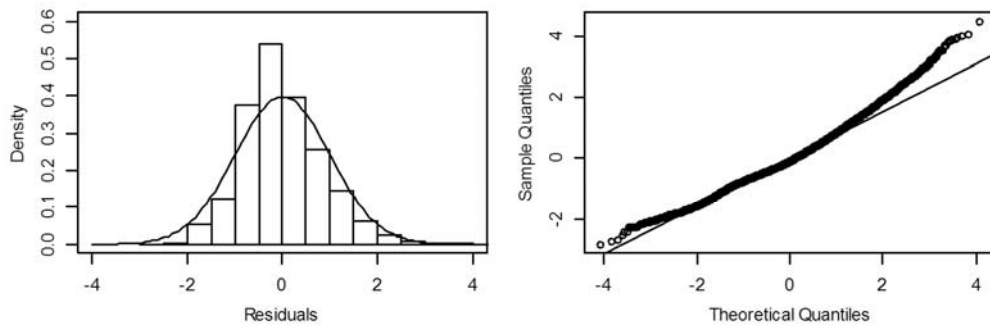| Year	CPUE	CV	Year	CPUE	CV	Year	CPUE	CV
1967	0.085	6.4	1979	0.153	6.5	2000	0.092	5.1
1968	0.088	6.5	1980	0.129	6.6	2001	0.099	4.2
1969	0.091	6.9	1981	0.136	6.4	2002	0.089	4.1
1970	0.080	6.6	1982	0.124	6.7	2003	0.108	4.0
1971	0.076	6.3	1983	0.118	7.3	2004	0.094	4.0
1972	0.080	6.4	1984	0.127	7.1	2005	0.127	4.0
1973	0.082	6.3	1985	0.138	7.7	2006	0.114	4.1
1974	0.079	5.9	1986	0.115	7.9	2007	0.111	4.4
1975	0.073	6.9	1987	0.103	7.1	2008	0.095	4.5
1976	0.081	6.8	1988	0.118	7.7	2009	0.095	4.5
1977	0.070	6.5	1989	0.113	7.7	2010	0.101	4.4
1978	0.074	7.0	1990	0.102	9.1	2011	0.094	4.4
			1991	0.123	8.2	2012	0.094	4.6
			1992	0.084	7.9	2013	0.111	5.0
			1993	0.103	6.9	2014	0.105	7.8
			1994	0.127	7.2			
			1995	0.106	8.5			
			1996	0.103	7.2			
			1997	0.081	7.5			
			1998	0.088	7.8			
			1999	0.102	6.8			
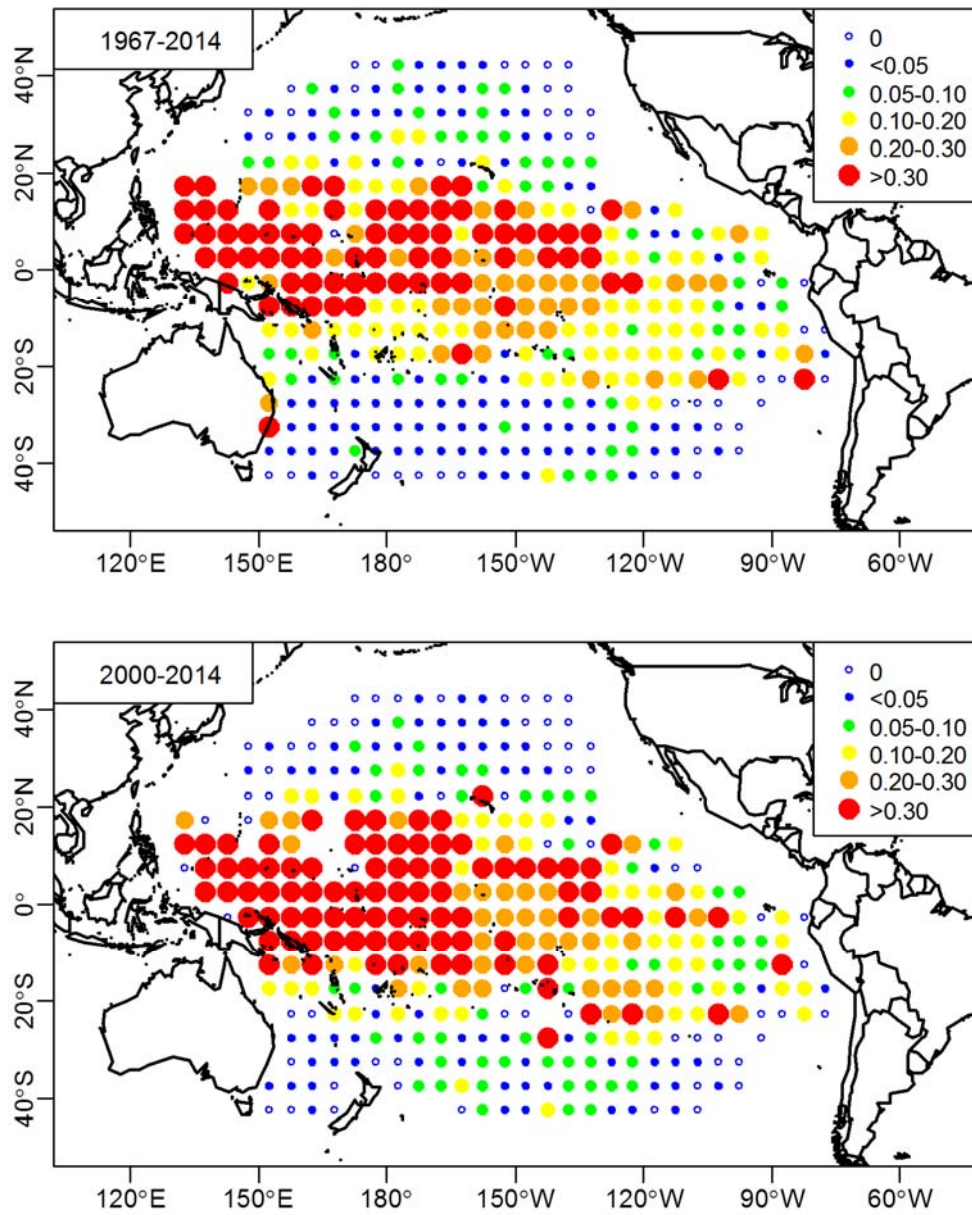
Fig. 1. Distributions of nominal CPUE (number of fish caught per 1000 hooks) for blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for 1967-2014 (upper panel) and 2000-2014 (lower panel).
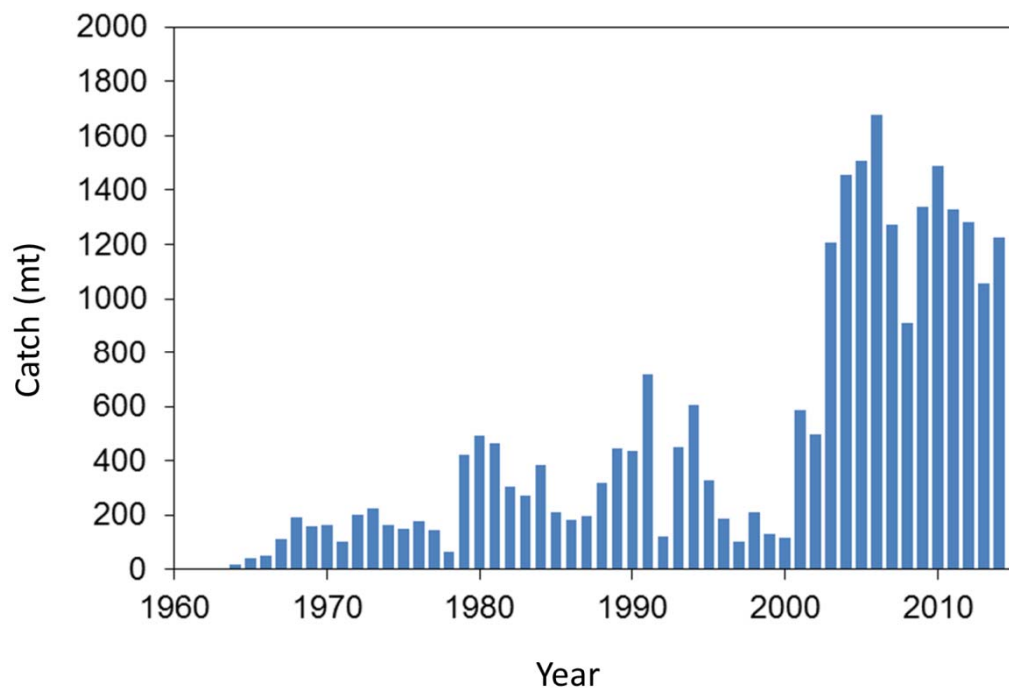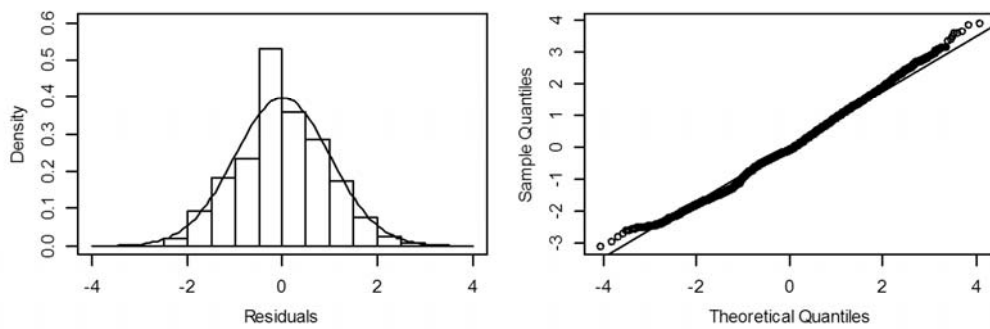
Fig. 2. Annual catches of blue marlin caught in the Taiwanese distant-water tuna
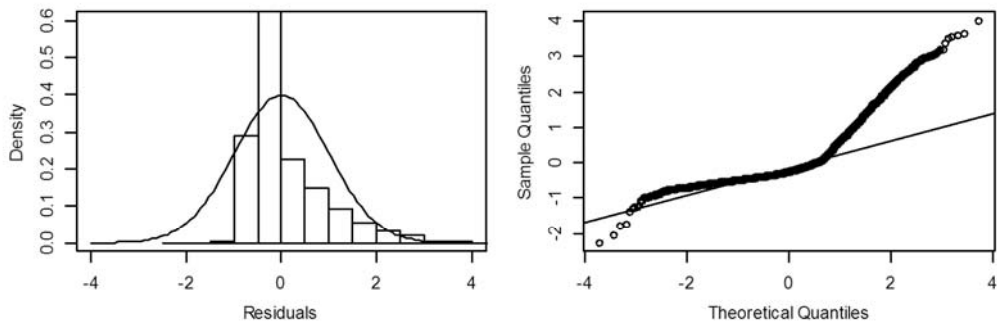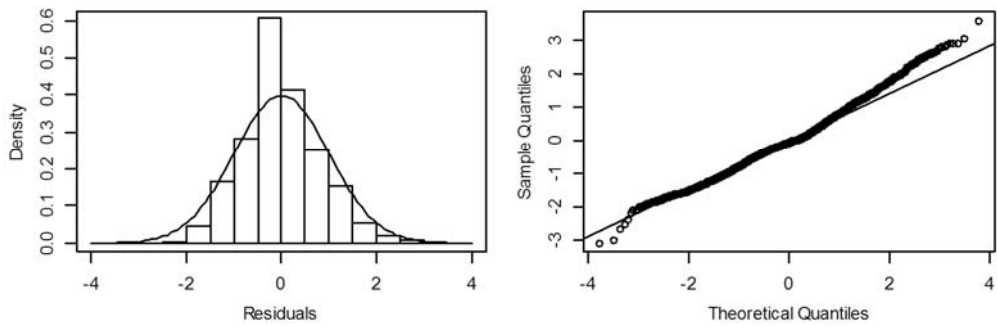longline fishery in the Pacific Ocean for 1964-2014.

Fig. 3. Residual distributions and diagnostic Q-Q plots for the models selected to standardize the CPUE of blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for (a) 1967-2014 (without HPB information) and (b) 2000-2014 (with HPB information).
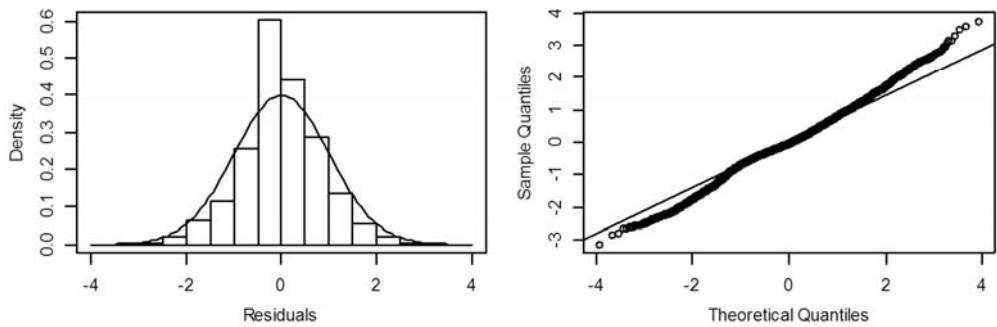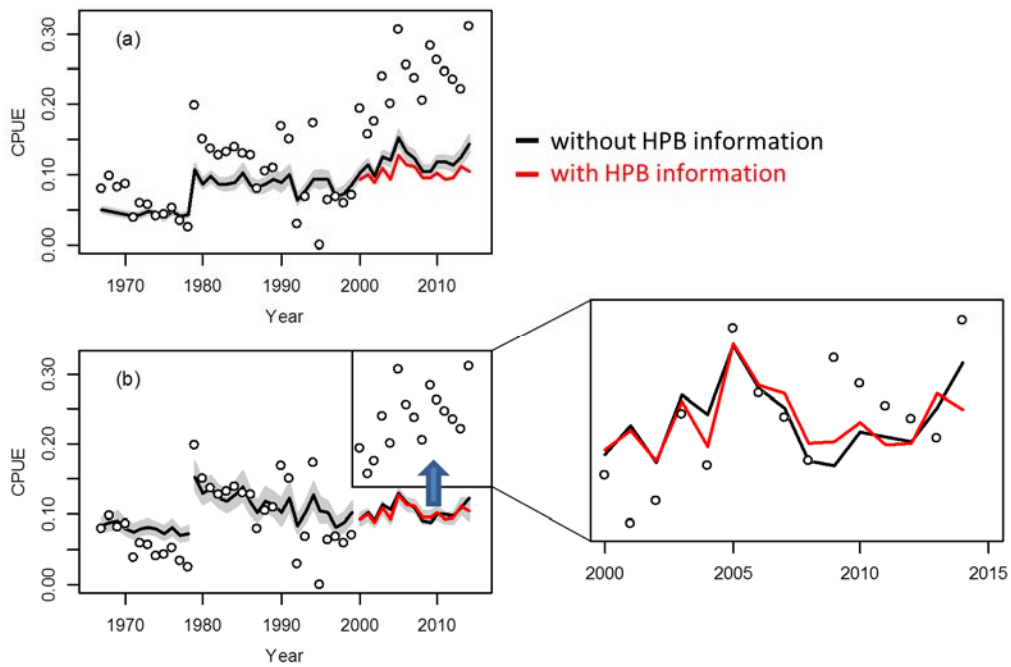
Fig. 4. Residual distributions and diagnostic Q-Q plots for the models selected to standardize the CPUE of blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for (a) 1967-1978 (without HPB information), (b) 1979-1999 (without HPB information) and (c) 2000-2014 (without HPB information).

Fig. 5. Nominal (open circles) and standardized CPUE (black lines: without HPB; red lines: with HPB) for blue marlin caught in the Taiwanese distant-water tuna longline fishery in the Pacific Ocean for models of various periods (a) 1967-2014 and 2000-2014 and (b) 1967-1978, 1979-1999 and 2000-2014. CPUE is expressed as the number of fish caught per 1000 hooks. The shadows indicate point-wise standard errors for the standardized CPUE of blue marlin.