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Standardized Catch-Rates of Blue Marlin (*Makaira nigricans*) in the Pacific Ocean for Taiwanese Distant-water Longline Fishery, 1964-2010[1]

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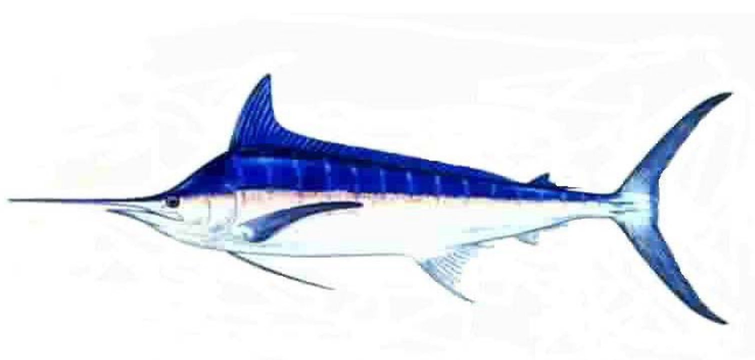

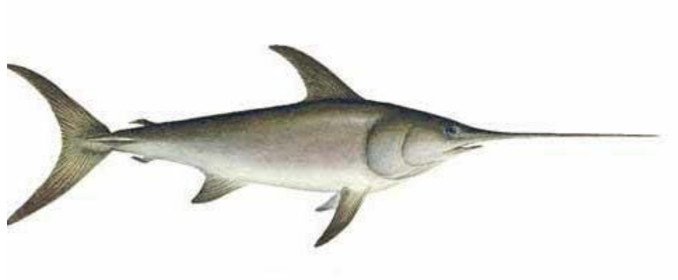

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Standardized catch-rates of blue marlin (*Makaira nigricans*) in the Pacific Ocean for Taiwanese distant-water longline fishery, 1964-2010*

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Abstract
Catch-rates (CPUE) of blue marlin in the Pacific Ocean caught by Taiwanese distant-water longline fleets were standardized using generalized additive models. Task II (logbook) data for 1964-2010 and those with hooks per basket (HPB) information for 1995-2009 were used separately in this study. Results show that the standardized catch-rates of blue marlin were generally stable over 1980-2000, but noticeably increased since 2000. A similar trend for the CPUE series is shown when HPB information was included in the standardization of catch-effort data.

Keywords: generalized additive model, hooks per basket

Introduction
Blue marlin (*Makaira nigricans*) is a highly migratory species distributed throughout tropical, sub-tropical, and temperate waters of the Pacific Oceans (Molony, 2008). A single stock of blue marlin in the Pacific Ocean has been assumed based on genetic analyses (Graves and McDowell, 2003) and fishery catch-rates (Kleiber et al., 2003). This assumption is also supported by the results of tagging experiments that have demonstrated that blue marlin migrate long distances 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).

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The objective of this study is to standardize the catch-effort data of Taiwanese distant-water longline fishery for blue marlin in the Pacific Ocean. The standardized catch-rates of blue marlin can provide basic, necessary input data for stock assessment of this species.

Materials and methods

Fishery data

Task II data of blue marlin catch (number of fish) and fishing effort (number of hooks) for 1964-2010 and those with hooks per basket (HPB) information from 1995 to 2009 were collected from Oversea Fisheries Development Council (OFDC, Taiwan) for the Taiwanese distant-water longline fishery in the Pacific Ocean. This data set contains information on time (year and month) and location (latitude and longitude), which were aggregated in 5 by 5 grids. Catch-rates (CPUE) are expressed as the number of fish caught per 1000 hooks in this study.

Statistical model

Generalized additive models (GAMs) are a standard and commonly used approach for standardizing catch and effort data (Maunder and Punt, 2004), assuming that the expected value of a transformed response variable is related to a linear combination of exploratory variables (Guisan et al., 2002). We used GAMs to standardize the catch and effort data of Taiwanese distant-water tuna longline fishery for blue marlin in the Pacific Ocean. The full GAM model is expressed as follows:

$$BUM \sim Year + s(Month) + s(Lat) + s(Lon) + s(HPB) \quad (1)$$

where BUM is the nominal catch-rates of blue marlin, added with a constant;
Year is the factor for year;
Month is the month effect;
Lat is the latitude effect;
Lon is the longitude effect;
HPB is the hooks per basket information; and
s(X) denotes a spline smoother function of the covariate X.

Diagnostic analysis

Diagnostic plots, i.e. the distribution of residuals and quantile-quantile (Q-Q) plots, were used to assess the error distribution (assuming lognormal distribution), as well as the model fitting for standardizing the catch-rates of blue marlin.

Results and discussion

There are in total 21,313 catch and effort records aggregated in 5 by 5 grids for the Taiwanese distant-water longline fishery during 1964-2010. However, observations of catch-effort data with HPB information are reduced, because HPB information is only available since 1995. The total catches of blue marlin in Taiwan, from various fisheries, have increased gradually since the 1960s, most of which comes 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. 1). In general, high (nominal) CPUEs of blue marlin occur in tropical waters of the Pacific Ocean for the Taiwanese distant-water longline fishery (Fig. 2).

The residual distribution based on the log-normal error distribution appears normal in the GAM analysis (Fig. 3). This result confirms the assumption of error models for log-normal distribution to standardize catch and effort data of Taiwanese longline fishery for blue marlin in the Pacific Ocean. According to the Q-Q plot, this assumption is also suitable to model the catch-rates of Pacific blue marlin, even when HPB information was included (Fig. 3). Therefore, analyses of standardizing blue marlin catch-rates in this study are consequently based on the log-normal error distribution.

The effects considered in the GAM models were all statistically significant ($p < 0.01$), even when the HPB effect was included (Table 1). The deviance explained by the model for standardizing catch-rates of blue marlin was 29.1%, while the deviance explained by the model that includes HPB information was 26.9% (based on different data sets). The proportion of total deviance explained by additional HPB factor was 7.4%, which increased the R^2 from 0.249 to 0.269 (Table 1).

The standardized catch-rates of blue marlin for Taiwanese distant-water longline fishery in the Pacific Ocean are generally stable over 1980-2000, although nominal catch-rates of blue marlin vary largely for few years (Fig. 4). However, the CPUE trend of blue marlin substantially increased in recent 10 years (2001-2010), probably due to the targeting change from albacore tuna (*Thunnus alalunga*) to bigeye tuna (*Thunnus obesus*). However, the CPUE trend of blue marlin is quite similar when HPB information was included in the standardization (Fig. 4). This may imply that the change in targeting cannot be quantified well owing to a lack of more informative operational data such as hooks-at-depth and bait types.

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Table 1. Analysis of deviance table for the models selected to standardize the catch-rates of blue marlin caught in the Taiwanese distant-water longline fishery in the Pacific Ocean.

(a) 1964-2010 (without HPB)

Predictor Variable	Residual Deviance	Deviance Explained	% of Deviance Explained	*P*(Chi)	R^2
NULL	23770.3				
+Year	20889.2	2881.1	41.7	< 0.01	0.121
+Month	20366.7	522.4	7.6	< 0.01	0.143
+Lat	17240.4	3126.4	45.3	< 0.01	0.275
+Longitude	16861.5	378.8	5.5	< 0.01	**0.291**

(b) 1995-2009 (with HPB)

Predictor Variable	Residual Deviance	Deviance Explained	% of Deviance Explained	*P*(Chi)	R^2
NULL	21120.8				
+Year	20088.3	1032.5	18.2	< 0.01	0.049
+Month	19772.4	316	5.6	< 0.01	0.064
+Latitude	16391.2	3381.2	59.6	< 0.01	0.224
+Longitude	15861.5	529.7	9.3	< 0.01	0.249
+HPB	15443.3	418.1	7.4	< 0.01	**0.269**

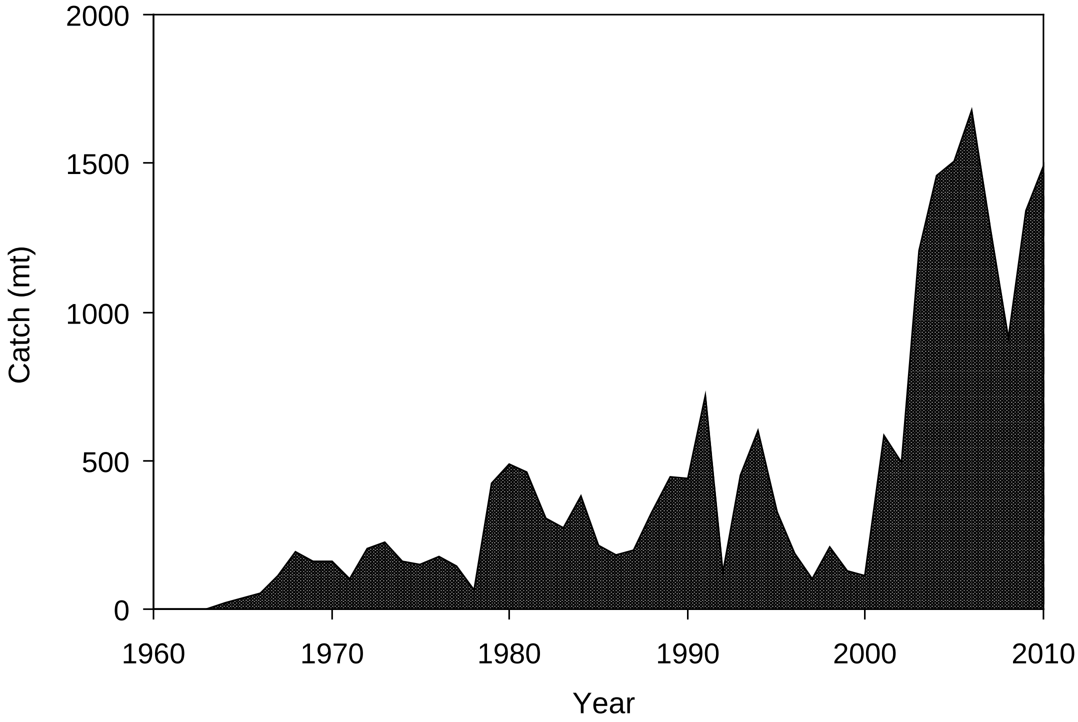

Fig. 1. Annual catches (1964-2010) of blue marlin caught by Taiwanese distant-water longline fleets in the Pacific Ocean.

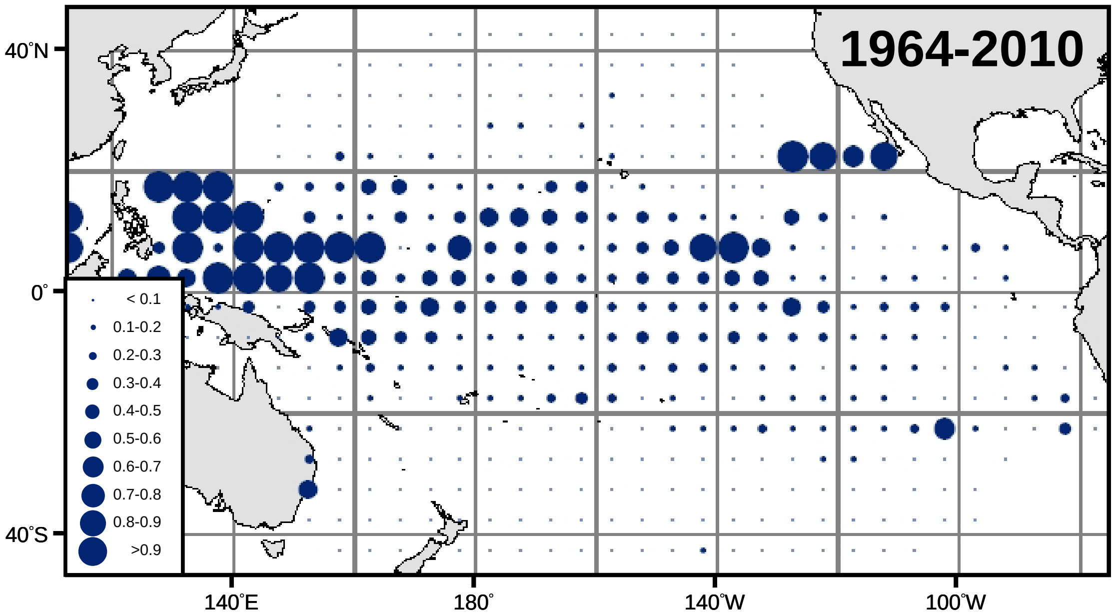

Fig. 2. Nominal catch-rates (number of fish caught per 1000 hooks) of blue marlin caught by Taiwanese distant-water longline fleets in the Pacific Ocean for 1964-2010.

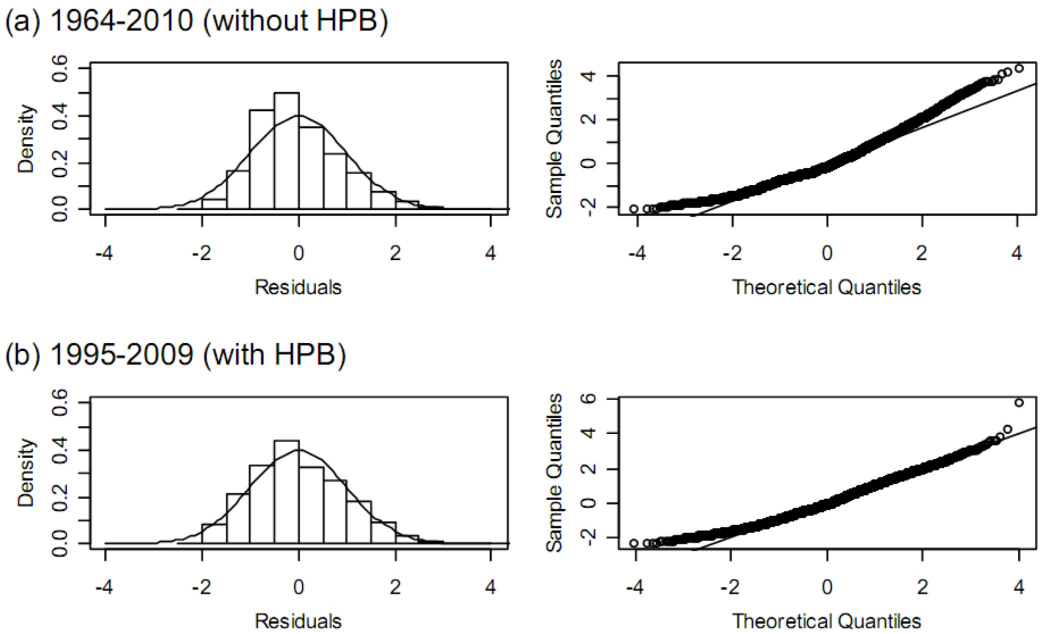

Fig. 3. Residual distributions and diagnostic Q-Q plots for the models selected to standardize the catch-rates of blue marlin caught by Taiwanese distant-water longline fleets in the Pacific Ocean for (a) 1964-2010 (without HPB information) and (b) 1995-2009 (with HPB information).

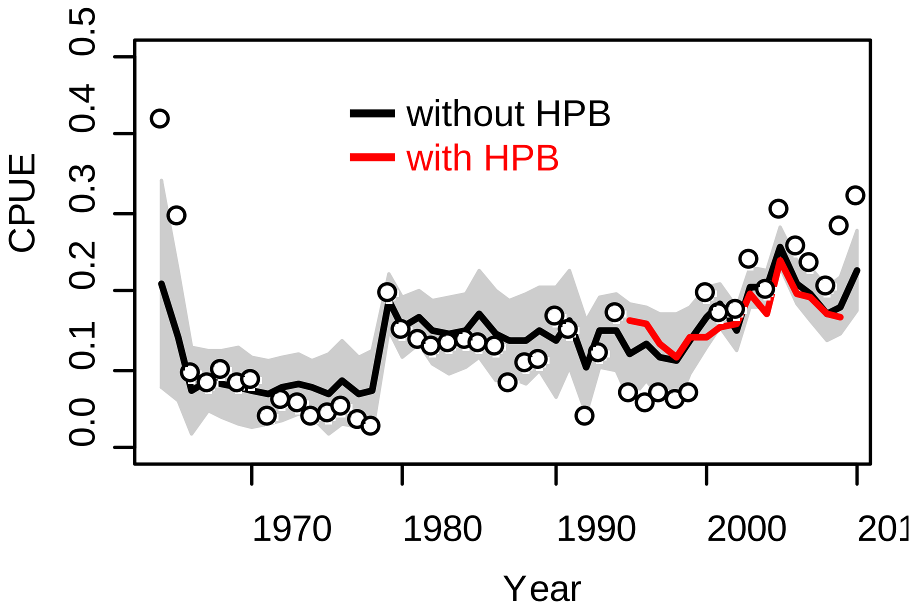

Fig. 4. The nominal (open dots) and standardized (black line: without HPB; red line: with HPB information) catch-rates of blue marlin caught by Taiwanese distant-water longline fleets in the Pacific Ocean. Catch-rates (CPUE) are expressed as the number of fish caught per 1000 hooks. The shadows indicate the point-wise standard errors for the standardized the catch-rate of blue marlin.