CPUE standardization of blue marlin (*Makaira nigricans*) for the Taiwanese distant-water tuna longline fishery in the Pacific Ocean during 1971 - 2019

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Abstract

Reliable indices of population abundance are an important type of data for stock assessment. This report provides annual changes in the standardized catch rate of blue marlin caught by the Taiwanese distant-water tuna longline fishery (DWLL) (1971 - 2019) in the Pacific Ocean. Catch rates were standardized using Vector-Autoregressive Spatio-Temporal Model (VAST), and the standardization models were conducted for three periods, 1971 - 1978, 1979 -1999, and 2000 - 2019, due to the heterogeneity of quality and quantity of the dataset and changes in the fishery such as targeting. The model with various catchability covariates, such as vessel, quarter, and HPB (only for 2000 - 2019) included in the VAST model were considered as the best model. Results indicated that the standardized index of the Pacific blue marlin decreased slightly over 1980 - 2000, thereafter increased gradually between 2001 and 2014. However, a decreasing trend of the standardized index was observed since 2015 except the recent increase in 2019.

1. Introduction

The nominal CPUE (catch-per-unit-effort) index, derived from yearly means of the raw CPUE data, can be severely biased due to the fishing vessels in specific locales using gear that increases catchability, low fishing effort in areas which give inaccurate average CPUE, oceanography conditions that increase catchability by, for instance, making fish more vulnerable to fishing gear, or simply chance (Maunder and Punt, 2004). The most commonly used standardization procedures entail the application of Generalized Linear Models (GLMs) or Generalized Additive Models (GAMs), which aim to isolate temporal abundance trends from the total variation in the CPUE data by adjusting for confounding effects on the estimated abundance trends (Guisan et al., 2002; Maunder and Punt, 2004).

CPUE observations that occur closer in space are more likely to be similar (spatial autocorrelation), which makes it harder to distinguish the real signal of a spatial effect by an explanatory variable. Recent years have seen the emergence of spatiotemporal modelling methods for standardizing CPUE data of the highly migratory species (e.g., Kai et al., 2017; Grüss et al., 2019; Xu et al., 2019) because the methods allow the spatial autocorrelation to be removed, which may yield more precise, biologically reasonable, and interpretable estimates of abundance than the common methods such as GLM (Shelton et al., 2014; Thorson et al. 2015).

Blue marlin (*Makaira nigricans*) is a highly migratory species distributed throughout tropical and temperate waters of the Pacific Ocean. A single stock of blue marlin in the Pacific Ocean has been supported by the genetic analyses (Graves and McDowell, 2003), fishery-dependent catch rate data (Kleiber et al., 2003), and the tagging experiments (Hinton, 2001). In this study, we applied a Vector-Autoregressive Spatio-Temporal Model (i.e., VAST, Thorson, 2019) to standardize the Pacific blue marlin CPUE data of the Taiwanese distant-water tuna longline fishery (DWLL). The standardized indices of blue marlin derived from this study could provide basic, necessary input data for stock assessments of this species.

2. Materials and methods

2.1 Fishery data

Operational logbook data of the Taiwanese DWLL during 1964 - 2019 in the Pacific Ocean were obtained from the Oversea Fisheries Development Council. This dataset contains information on time (year and month) and location (latitude and longitude), which were aggregated in 5° by 5 ° grid and month from 1964 - 2019 and those with hooks per basket (HPB) information for 2000 - 2019. CPUE is expressed as the number of fish caught per 1000 hooks in this study. This paper presents standardizations of the DWLL dataset from 1971 - 1978, 1979 - 1999, and 2000 - 2019, respectively, due to the heterogeneity of quality and quantity of the dataset and changes in the fishery such as targeting.

2.2 Spatio-temporal model

The approach we used here is adapted from the *R* package VAST (https://github.com/James-Thorson-NOAA/VAST) developed by Thorson et al. (2015). VAST uses the Gaussian random fields to model the spatial autocorrelation with anisotropy, and an interactive relationship between space and time (i.e., spatio-temporal autocorrelation). These Gaussian random fields are defined with a Matérn covariance function (see Thorson, 2019). VAST requires the previous definition of knots *s* which are points where the correlation of spatial and spatio-temporal effects are estimated. Each observation in the dataset then gets assigned to the knot which is the closest to them using the *k*-means. In this study, we explore and found the most appropriate number of knots by trial and errors to improve the precision of the predicted abundance indices at each knot and then specify 100, 200, and 200 spatial knots for three periods to approximate the spatial and spatio-temporal autocorrelated variations. We have confirmed that more knots would result in similar abundance indices. VAST is a delta-generalized linear mixed modelling framework (delta-GLMM), where the probability distribution for catch data is decomposed into two components representing the probability of encounter (binominal component) and the expected catch rate (positive catch rate component), given that is encountered (Thorson, 2019). The delta-GLMM structure was implemented in *R* by using the VAST package (Thorson, 2019) and is defined below:

<u>Binominal component:</u>

$$\text{logit}(p_{1,i}) = \beta_1(t_i) + \omega_1(s_i) + \varepsilon_1(s_i,t_i) + \delta_1(v_i) + \sum_{k_1=1}^{n_{k_1}} \lambda_1(k_1)Q(i,k_1)$$

<u>Positive catch rate component:</u>

$$\log(p_{2,i}) = \beta_2(t_i) + \omega_2(s_i) + \varepsilon_2(s_i,t_i) + \delta_2(v_i) + \sum_{k_2=1}^{n_{k_2}} \lambda_2(k_2)Q(i,k_2)$$

where $\beta(t_i)$ is the intercept for each year as a fixed effect, $\omega(s_i)$ is a time-invariant spatial autocorrelated variation for knot *s*, and $\varepsilon(s_i,t_i)$ is a time-varying spatial-temporal autocorrelated variation for knot *s* and in year *t* (i.e., the interaction of spatial variation and time), $\delta(v_i)$ is the random variation in catchability for the *v* th vessel (the variation in density for the vessel). *Q*(*i*,*k*) are the fixed effects for catchability (e.g., seasonal effect and HPB, $n_{k1} = n_{k_2} = 2$). The seasonal effect on CPUE was categorized into four quarters: January - March (1st quarter), April - June (2nd quarter), July - September (3rd quarter) and October - December (4th quarter).

2.3 Abundance indices

Estimated values of fixed and random effects are used to predict the density ($d(s,t)$) for knot s and year t except for the catchability variables (Thorson et al., 2019). The yearly index of abundance of blue marlin, $B(t)$, is calculated as the sum of the density of each knot by using an area-weighted approach:

$$d(s,t) = \text{logit}^{-1}\left(\beta_1(t_i) + \omega_1(s_i) + \varepsilon_1(s_i,t_i)\right) \times \exp\left(\beta_2(t_i) + \omega_2(s_i) + \varepsilon_2(s_i,t_i)\right)$$

$$B(t) = \sum_{s=1}^{n_s}\left(a(s) \times d(s,t)\right)$$

where $B(t)$ is the area re-weighted density in year t throughout the population domain, $a(s)$ is the area of knot s.

2.4 Model selection and diagnostics

We used the Akaike Information Criterion (AIC; Akaike, 1973) to identify which model had greater support given available data. The final model was checked for convergence, and diagnostics were run to evaluate the model fit. We check whether observed encounter frequencies for either low or high probability samples are within the 95% predictive interval for predicted encounter probability and visualize fit to residuals of catch-rates given encounters by using quantile-quantile probability plots (Q-Q plots).

3. Results and discussion

The spatial distributions of the nominal CPUE of blue marlin for the Taiwanese DWLL in the Pacific Ocean during 1971 - 2019 were shown in **Figures 1 - 3**. The convergence in optimization was confirmed for each model if the Hessian matrix was positive, and the maximum gradient of each component was smaller than 0.0001. According to the AIC value, we used the most parameterized model of VAST to predict the annual changes in CPUE of blue marlin during the studied period except for 1971 - 1978 (**Tables 1 - 3**). Model diagnostics suggested the best models for three periods had good fits to the observed CPUE data between binominal (**Figure 4**) and positive catch rate models (**Figure 5**). The results indicated that the standardized index of the Pacific blue marlin decreased slightly over 1980 - 2000, thereafter increased gradually between 2001 and 2014 (**Figure 6**). However, a decreasing trend of the standardized index was observed since 2015, except for the recent increase in 2019. The standardized indices (and coefficient of variations) of the Pacific blue marlin were summarized in **Table 4**.

The spatio-temporal modeling approach was chosen for the CPUE standardization because of its ability to account for correlated spatial processes, predict densities in unfished areas via imputation, and implement an appropriate area-weighting scheme (Grüss et al., 2019; Kai et al., 2019; Xu et al., 2019). We recommend that using these indices in the coming stock assessment for Pacific blue marlin in 2021.

References

Akaike, H. (1974). A new look at the statistical model identification. IEEE transactions on automatic control, 19(6), 716-723.

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

Grüss, A., Walter III, J. F., Babcock, E. A., Forrestal, F. C., Thorson, J. T., Lauretta, M. V., and Schirripa, M. J. (2019). Evaluation of the impacts of different treatments of spatio-temporal variation in catch-per-unit-effort standardization models. Fish Res., 213, 75-93.

Guisan, A., Edwards Jr, T. C., and Hastie, T. (2002). Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecological modelling, 157(2-3), 89-100.

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.

Kai, M., Thorson, J. T., Piner, K. R., and Maunder, M. N. (2017). Spatiotemporal variation in size-structured populations using fishery data: an application to shortfin mako (*Isurus oxyrinchus*) in the Pacific Ocean. Can. J. Fish Aquat. Sci., 74(11), 1765-1780.

Kai, M. (2019). Spatio-temporal changes in catch rates of pelagic sharks caught by Japanese research and training vessels in the western and central North Pacific. *Fish. Res.*, 216, 177-195.

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.

Maunder, M. N., and Punt, A. E. (2004). Standardizing catch and effort data: a review of recent approaches. Fish Res., 70(2-3):141–159.

R Development Core Team (2018). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0. Retrieved from http://www.R-project.org

Shelton, A. O., Thorson, J. T., Ward, E. J., and Feist, B.E. (2014).Spatial semiparametric models improve estimates of species abundance and distribution. *Can. J. Fish Aquat. Sci.* 71(11): 1655–1666.

Thorson, J. T., Shelton, A. O., Ward, E. J., and Skaug, H. (2015). Geostatistical delta-generalized linear mixed models improve precision for estimated abundance indices for West Coast groundfishes. *ICES J. Mar. Sci*., 72, 1297–1310.

Thorson, J. T., and Kristensen, K. (2016). Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. *Fish Res*., 175, 66-74.

Thorson, J. T. (2019). Guidance for decisions using the Vector Autoregressive Spatio-Temporal (VAST) package in stock, ecosystem, habitat and climate assessments. *Fish Res.*, 210:143–161.

Xu, H., Lennert-Cody, C. E., Maunder, M. N., Minte-Vera, C. V. (2019). Spatiotemporal dynamics of the dolphin-associated purse-seine fishery for yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean. *Fish. Res*., 213, 121-131.

Table 1. Summary of the model selection information for the VAST model of blue marlin caught in the Taiwanese distant-water tuna longline (DWLL) fishery in the Pacific Ocean during 1971 - 1978.

ID	**Model structure**	**Deviance**	**AIC**	**ΔAIC**	**Maximum gradient**
M1	Year	7024.55	7035	1077	<0.0001
M2	Year + Knot	6877.488	6923	966	<0.0001
M3	Year + Knot + Year-Knot	6822.88	6873	916	<0.0001
M4	Year + Knot + Year-Knot + vessel	5903.066	5957	0	<0.0001
M5	Year + Knot + Year-Knot + vessel + quarter	5941.778	6008	51	<0.0001

Table 2. Summary of the model selection information for the VAST model of blue marlin caught in the Taiwanese distant-water tuna longline (DWLL) fishery in the Pacific Ocean during 1979 - 1999.

ID	Model structure	Deviance	AIC	ΔAIC	Maximum gradient
M1	Year	23537	23547	6763	<0.0001
M2	Year + Knot	19399	19497	2713	<0.0001
M3	Year + Knot + Year-Knot	18943	19045	2261	<0.0001
M4	Year + Knot + Year-Knot + vessel	17101	17207	424	<0.0001
M5	Year + Knot + Year-Knot + vessel + quarter	16666	16784	0	<0.0001

Table 3. Summary of the model selection information for the VAST model of blue marlin caught in the Taiwanese distant-water tuna longline (DWLL) fishery in the Pacific Ocean during 2000 - 2019.

ID	Model structure	Deviance	AIC	ΔAIC	Maximum gradient
M1	Year	71324	71334	26763	<0.0001
M2	Year + Knot	52572	52666	8095	<0.0001
M3	Year + Knot + Year-Knot	49022	49120	4549	<0.0001
M4	Year + Knot + Year-Knot + vessel	48081	48183	3612	<0.0001
M5	Year + Knot + Year-Knot + vessel + quarter	47485	46313	1742	<0.0001
M6	Year + Knot + Year-Knot + vessel + quarter + HPB	44453	44571	0	<0.0001

Table 4. Standardized CPUE and coefficient of variation (CV) for blue marlin caught in the Taiwanese distant-water tuna longline (DWLL) fishery in the Pacific Ocean based on the models of specific periods (1971 - 1978, 1979 - 1999, and 2000 - 2019).

Year	CPUE	CV	Year	CPUE	CV	Year	CPUE	CV
1971	0.689	0.23	1979	1.926	0.12	2000	0.382	0.16
1972	1.145	0.21	1980	1.600	0.11	2001	0.745	0.12
1973	0.912	0.20	1981	1.255	0.10	2002	0.715	0.14
1974	0.721	0.20	1982	1.127	0.14	2003	1.008	0.10
1975	0.965	0.22	1983	1.019	0.18	2004	0.827	0.11
1976	1.377	0.25	1984	1.287	0.17	2005	1.210	0.08
1977	0.581	0.23	1985	1.313	0.19	2006	1.017	0.09
1978	0.696	0.27	1986	1.131	0.21	2007	0.948	0.10
			1987	0.674	0.19	2008	0.940	0.11
			1988	0.857	0.22	2009	0.937	0.09
			1989	1.090	0.20	2010	0.952	0.09
			1990	0.826	0.21	2011	0.920	0.09
			1991	0.846	0.20	2012	0.987	0.10
			1992	0.432	0.35	2013	1.196	0.10
			1993	1.058	0.24	2014	1.434	0.10
			1994	1.721	0.17	2015	1.364	0.09
			1995	0.911	0.21	2016	1.377	0.09
			1996	0.768	0.21	2017	1.127	0.09
			1997	0.300	0.23	2018	0.798	0.11
			1998	0.342	0.29	2019	1.117	0.11
			1999	0.517	0.26			

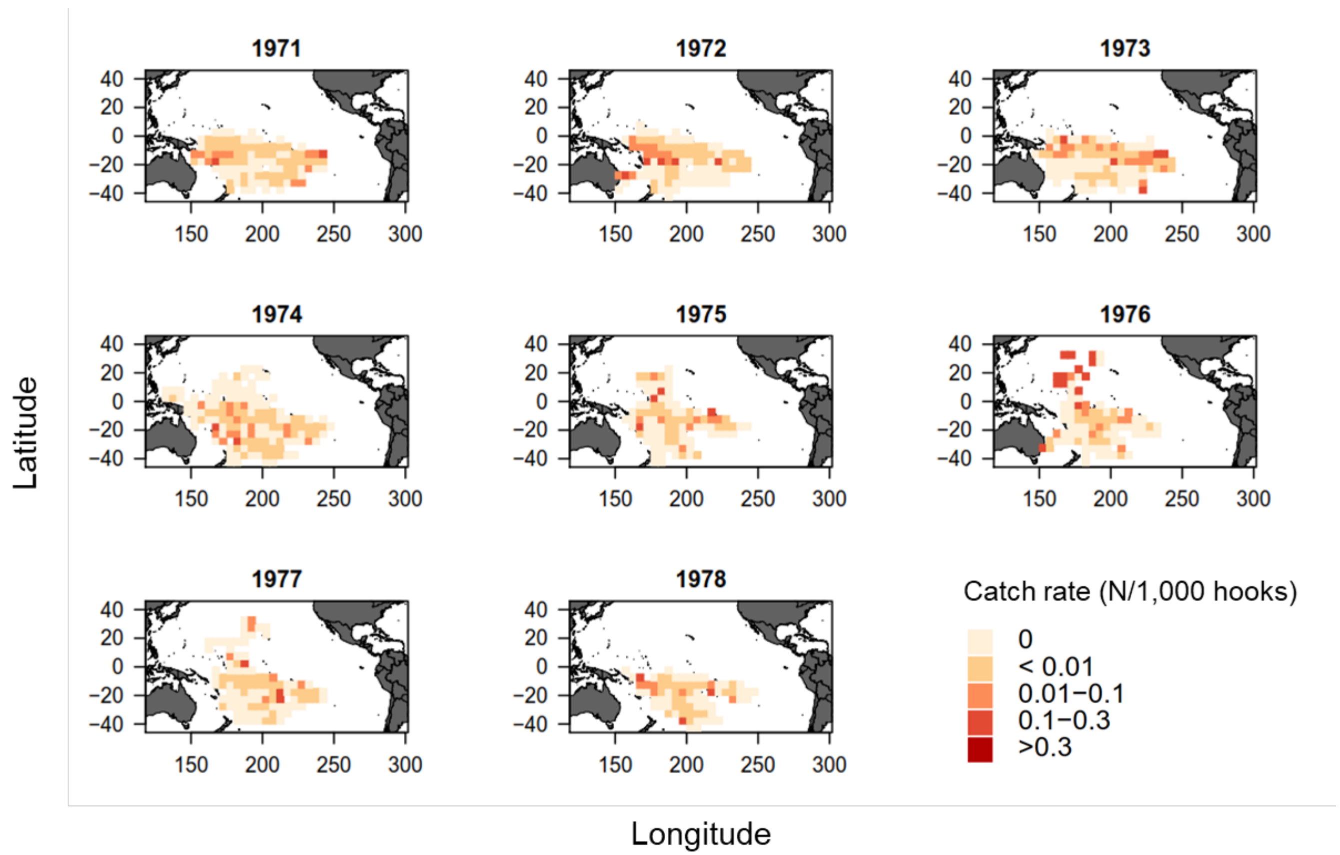

Figure 1. Distributions of nominal CPUE (number of fish caught per 1000 hooks) of blue marlin by the Taiwanese distant-water tuna longliners (DWLL) in the Pacific Ocean during 1971 - 1978.

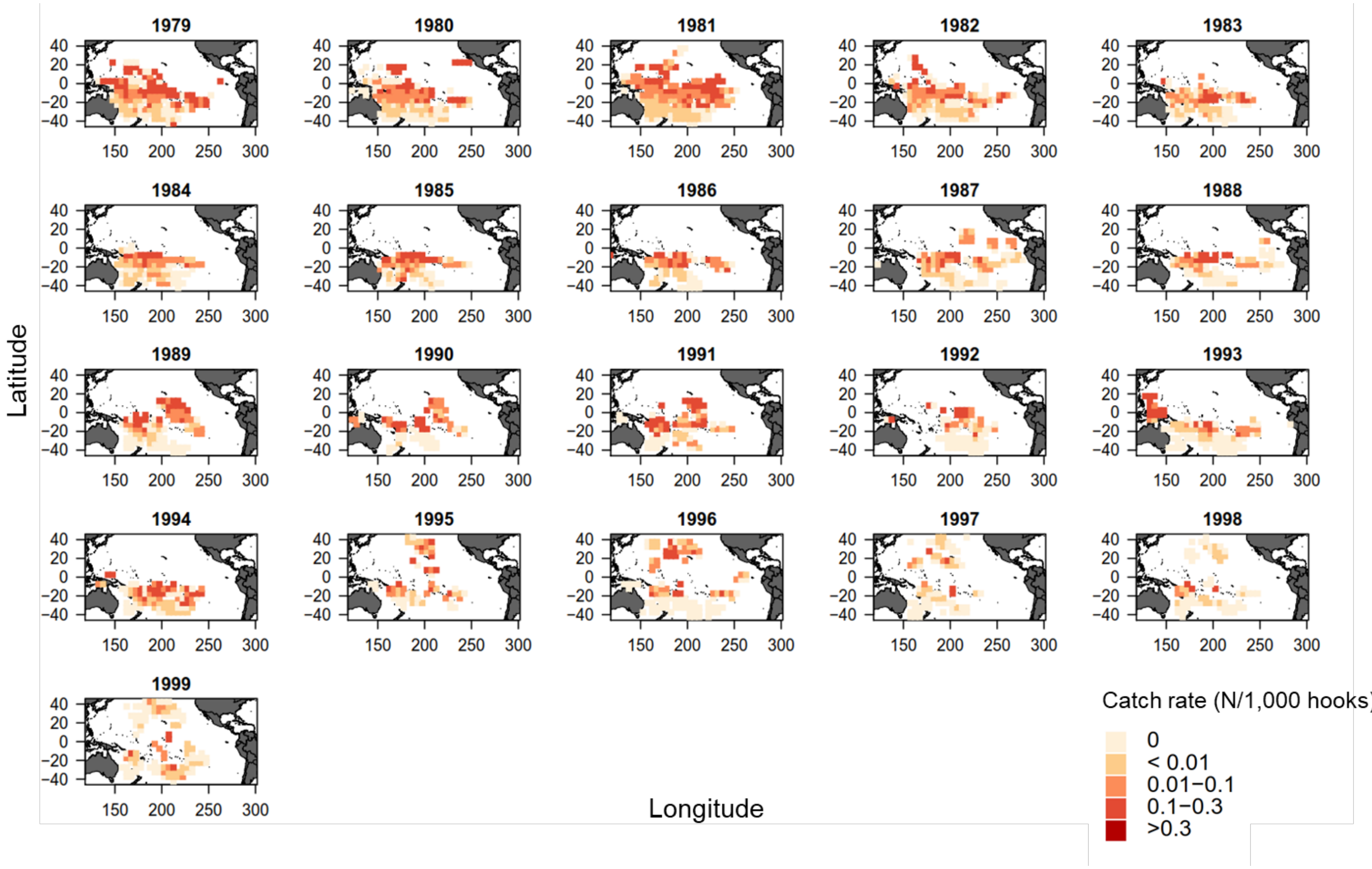

Figure 2. Distributions of nominal CPUE (number of fish caught per 1000 hooks) of blue marlin by the Taiwanese distant-water tuna longliners (DWLL) in the Pacific Ocean during 1979 - 1999.

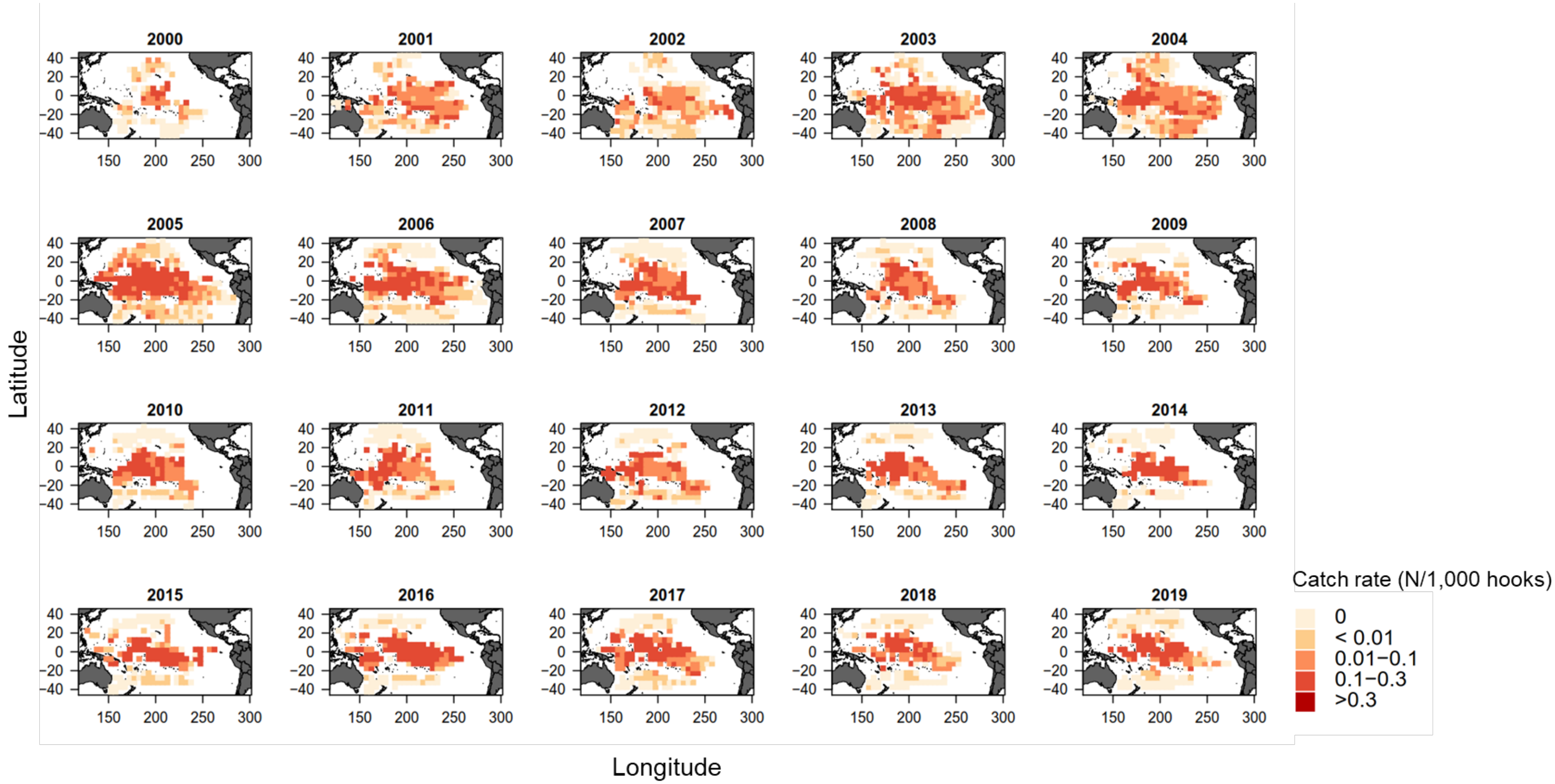

Figure 3. Distributions of nominal CPUE (number of fish caught per 1000 hooks) of blue marlin by the Taiwanese distant-water tuna longliners (DWLL) in the Pacific Ocean during 2000 - 2019.

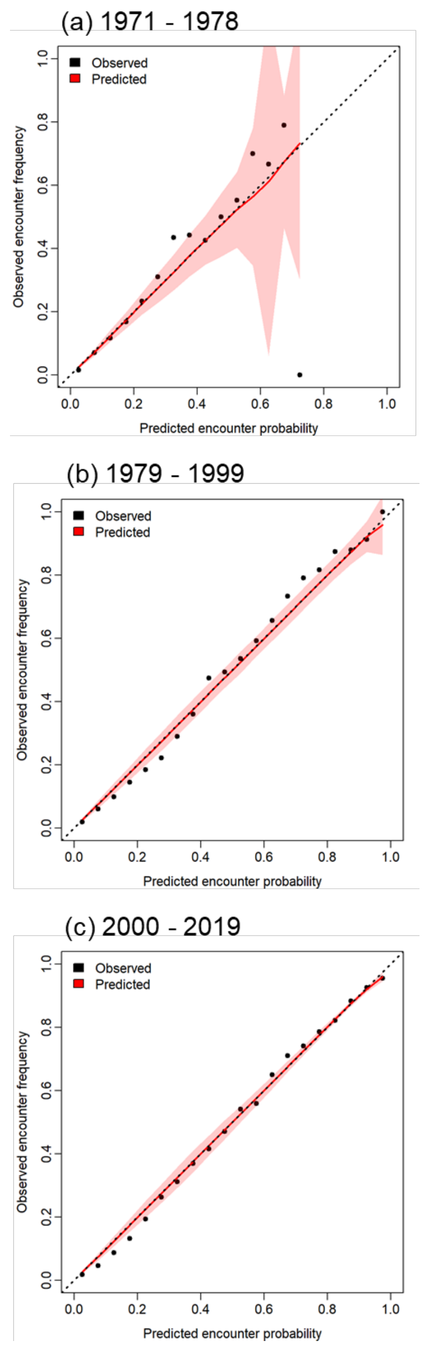

Figure 4. Observed (black points) vs. predicted (red shading) encounter probability of the Pacific blue marlin during (a) 1971 - 1978, (b) 1979 - 1999, and (c) 2000 - 2019.

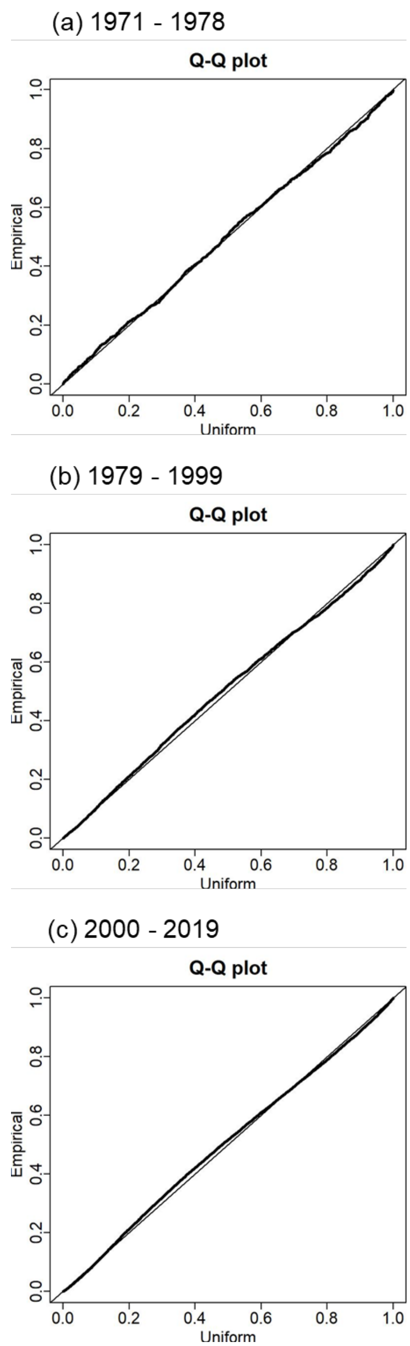

Figure 5. Normal Q-Q plot for positive catches component of blue marlin during (a) 1971 - 1978, (b) 1979 - 1999, and (c) 2000 - 2019.

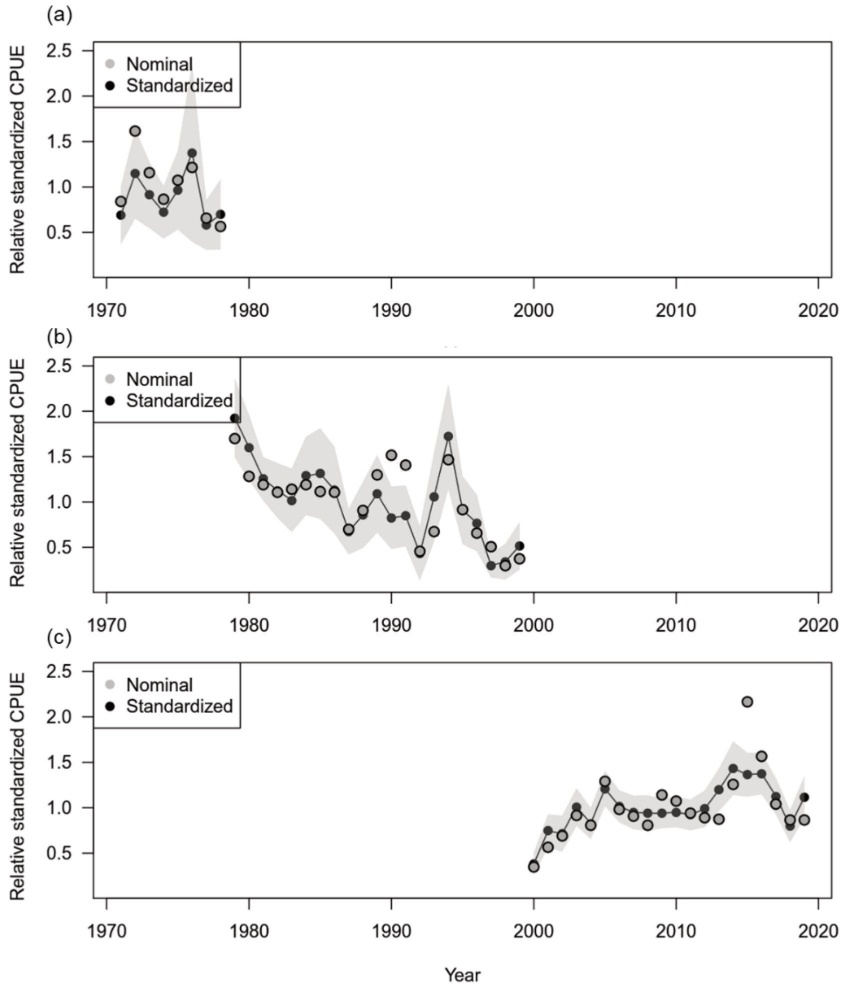

Figure 6. Nominal (total numbers of fish caught/total number of hooks) and relative standardized indices (centered to mean) for the Pacific blue marlin caught by the Taiwanese distant-water tuna longliners (DWLL) during (a) 1971 - 1978; (b) 1979 - 1999, and (c) 2000 - 2019. Shaded area indicates the 95% confidence intervals.