ISC/25/BILLWG-01/07

Preliminary Joint CPUE standardization of Pacific stripe marlin in the Western and Central North Ocean by using the spatio-temporal modelling approach

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Abstract

A joint CPUE standardization was conducted for striped marlin in the Western and Central North Pacific Ocean using longline data from Japanese and U.S. fleets (sourced from the WCPCF Public Domain Aggregated Catch/Effort Data) and Taiwanese fleets (derived from aggregated logbook data) for the period 1995–2022. Using a spatio-temporal delta-generalized linear mixed model (sdmTMB), which explained 63% of the variation, the analysis revealed distinct spatial patterns between encounter probability and positive catch rates. The standardized abundance indices showed high values during 1995-1997, followed by a declining trend before stabilizing at lower levels from 2008 onwards, with higher seasonal abundance in the first quarter. This preliminary analysis of joint standardization demonstrates the potential for developing comprehensive abundance indices with wider spatial coverage and consistent methodology across multiple fleets.

1. Introduction

Catch per unit effort (CPUE) standardization plays a crucial role in stock assessments by providing relative abundance indices that inform our understanding of population dynamics. However, the current approach of analyzing striped marlin CPUE data in the Western and Central North Pacific Ocean (WCNPO) separately by fleet presents several challenges, as discussed in peer-reviewed stock assessments of striped marlin (ISC, 2024). Different fleets may show conflicting trends, spatial coverage can contract over time, and varying standardization methods across nations can lead to inconsistencies. These issues can introduce uncertainty into stock assessments and complicate the interpretation of population trends. Joint CPUE standardization across multiple fleets and nations offers a promising solution by creating unified indices that cover broader spatial ranges, maintaining consistent methodology, and fostering collaboration among researchers. This approach is particularly important for highly migratory species where no single fleet can effectively monitor the entire population.

The objective of this study is to develop standardized abundance indices for striped marlin in the Western and Central North Pacific Ocean by jointly analyzing CPUE data from multiple fishing fleets. By combining data from Japanese and U.S. fleets available on the WCPFC public website (https://www.wcpfc.int/public-domain) , along with Taiwanese logbook data, this study aims to produce abundance indices that may better represent population trends across the species' range while maintaining consistent standardization methodology.

2. Methods

2.1 Joint CPUE dataset

This study developed a joint CPUE dataset by combining monthly data from Japanese, U.S., and Taiwanese longline fleets during 1995 - 2022, as standardized indices from these three main members were included in the stock assessment for striped marlin in the WCNPO. The Japanese and U.S. longline CPUE data were obtained from the aggregated dataset of the WCPFC Public Domain, which is organized into 5° by 5° latitude/longitude grids and categorized by attributes such as FLAG, YEAR, and MONTH, while Taiwanese data were sourced from distant-water longline logbook records. Specifically, Japanese CPUE data were derived from two fleets operating in Area 1 during the first quarter (JP_Q1A1) and third quarter (JP_Q3A1), in accordance with the definitions used in the latest stock assessment (ISC, 2024). The spatial distribution of CPUE data for each fleet during 1995-2022 is shown in **Figure 1**.

2.2 Model structure and abundance index prediction

The spatio-temporal modeling approach used in this study is implemented through the R package "*sdmTMB*" (https://github.com/pbs-assess/sdmTMB), developed by Anderson et al. (2022). The package uses Gaussian random fields to model spatial and spatiotemporal components, utilizing a Matérn covariance function. By estimating the correlation structure of the data, this model can interpolate abundance in unobserved strata while accounting for spatial and temporal dependencies. In this study, the spatial mesh comprised 100 knots with uniform distribution (**Figure 2**) to approximate spatial random effects and capture underlying spatial and spatiotemporal autocorrelation patterns in the CPUE data. This study gives a brief description of how the sdmTMB is applied to the striped marlin joint CPUE dataset below and refer the readers to the original reference for more technical details (see Anderson et al., 2022). sdmTMB implements a delta-generalized linear mixed model which models the encounter rate (p) and positive catch (q) components separately. The same model structure was applied to both components:

$$\text{logit}(p) = \beta_1(t) + \omega_1(s) + \varepsilon_1(s,t) + \eta_1(v) \quad (1)$$

$$\log(q) = \beta_2(t) + \omega_2(s) + \varepsilon_2(s,t) + \eta_2(v) \quad (2)$$

where $\beta(t)$ is the fixed effect intercept of year-season t; $\omega(s)$ is the time-invariant spatial auto-correlated variation for knot s (100 knots); $\varepsilon(s,t)$ is the time-varying spatial-temporal auto-correlated variation for knot s in year t; $\eta(v)$ is the random variation in catchability for fleets v (JP_Q1A1, JP_Q3A1, TW, and US). Standardized CPUEs of WCNPO striped marlin are computed CPUE estimates for each year-season t by using area-weighting as follows (Campbell, 2015):

$$C\hat{P}UE(t) = \sum_{s=1}^{n_s} A(s) \times \text{logit}^{-1}(p(s,t)) \times \exp(q(s,t))$$

Residual analysis was performed using probability-integrated-transform (PIT) residuals (Warton et al., 2017), evaluated using the "*DHARMa*" R package (Hartig and Lohse, 2017).

3. Results and discussion

The current model explained 63% of the variation (R^2) in the data. **Figure 3a** shows the spatial pattern of aggregated PIT residuals across all years and seasons, displaying a relatively random distribution across the WCNPO, with most values close to 0.5, indicating model fit well. Higher residuals appear near the coast of Japan (around 35°N) and in some areas around 10°N, while lower values are observed around 180°. Additionally, **Figure 3b** shows the spatial distribution of residuals by fleet. Overall, the residual patterns appear random across most areas for each fleet; however, for JP_Q3A1, higher and lower PIT residuals were observed in certain areas. Furthermore, the annual PIT residuals from 1995 to 2022 fluctuated around 0.5 across the years (**Figure 4**).

Figure 5 shows the spatial random effects for encounter probability and positive catch rate components. For encounter probability, higher values were observed in the central and eastern regions (20°N - 40°N), particularly around 160°W, while lower probabilities occurred in southern regions below 20°N. The positive catch rate component displayed a different pattern, with high values concentrated in a band around 20°N - 25°N from 140°E to 160°W, and off the coast of Japan. These contrasting spatial patterns suggest that areas with higher striped marlin encounters or occurrences do not necessarily correspond to areas with higher catch rates.

The seasonal relative abundance indices and nominal CPUE from 1995 to 2022 are shown in **Figure 6**. In general, higher abundance values were observed in the early period (1995-1997), particularly in the first two quarters. A general declining trend is evident after 1997, with relative abundance stabilizing at lower levels from 2008 onwards. Higher relative abundances were found in the first quarter compared to the other quarters. This preliminary analysis of joint standardization demonstrates the potential for developing comprehensive abundance indices with wider spatial coverage and consistent methodology across multiple fleets.

References

Anderson, S. C., Ward, E. J., English, P. A., and Barnett, L. A. K. (2022). sdmTMB: an R package for fast, flexible, and user-friendly generalized linear mixed effects models with spatial and spatiotemporal random fields. preprint, Ecology.

Hartig, F. and Lohse, L. (2017). Residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.1, 5:1 - 21

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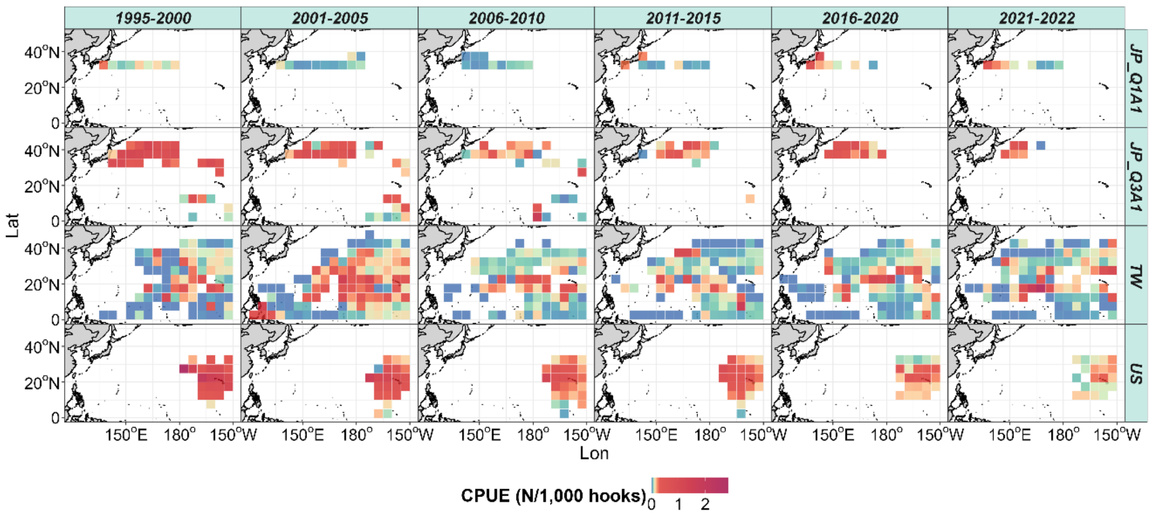

Figure 1. Spatio-temporal distribution of catch-per-unit-effort (CPUE) data of striped marlin by each fleet during 1995 – 2022 in the Western and Central North Pacific Ocean.

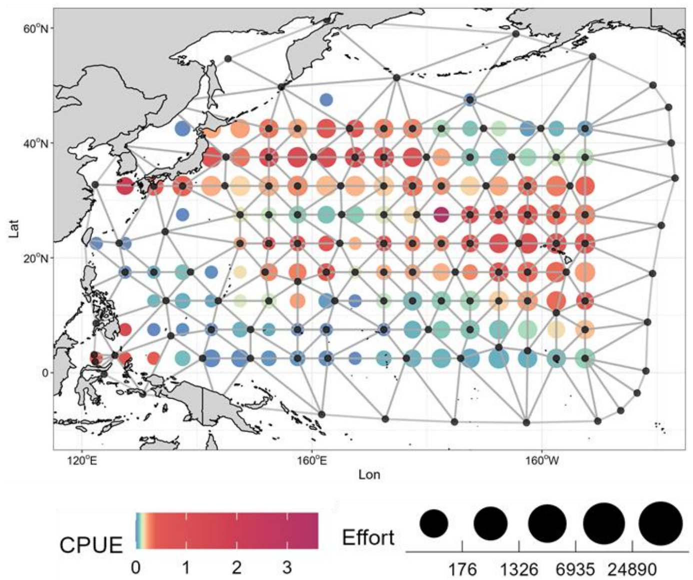

Figure 2. Mesh used for fitting the sdmTMB model. Black points represent the 100 spatial knots where effects are estimated. Colored circles indicate aggregated striped marlin CPUE data within 5° × 5° grids from 1995 to 2022 in the Western and Central North Pacific Ocean. The size of the colored circles represents the level of fishing effort.

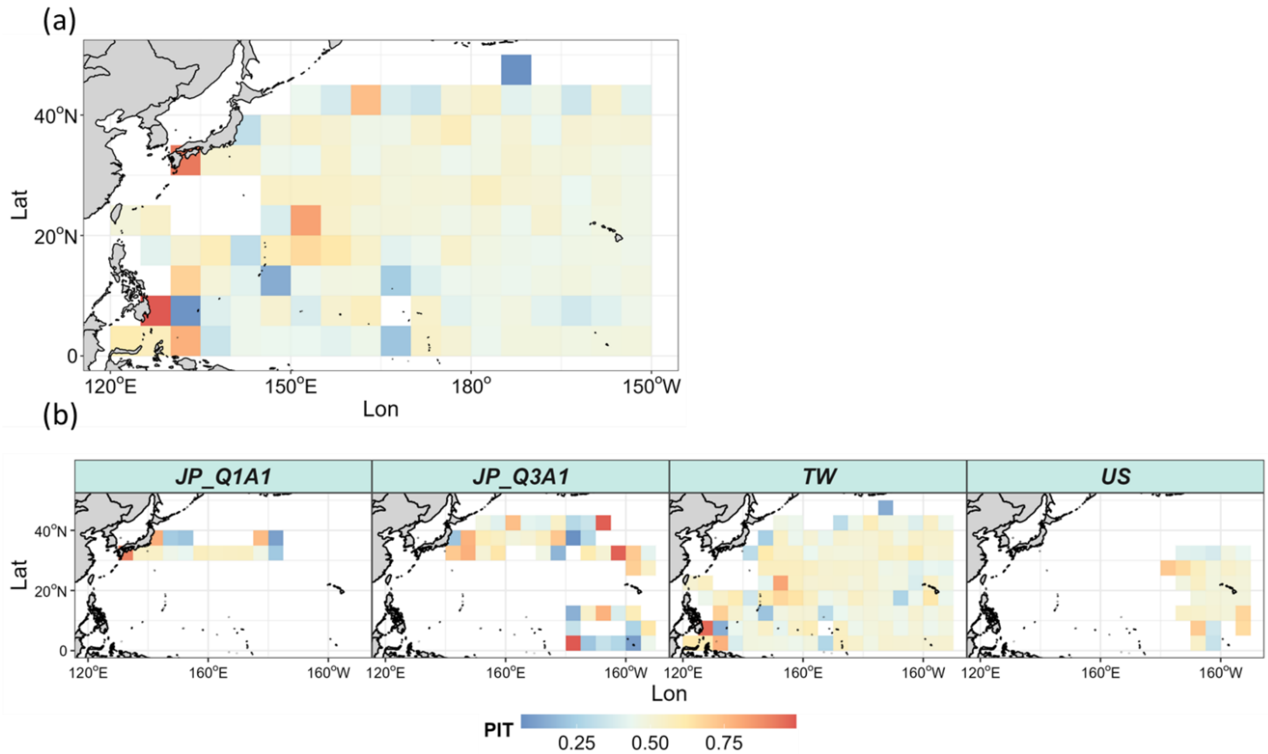

Figure 3. Spatial distribution of probability integral transform (PIT) residuals (a) aggregated across the time series and (b) by fleet for striped marlin at a 5° × 5° spatial resolution in the Western and Central North Pacific Ocean.

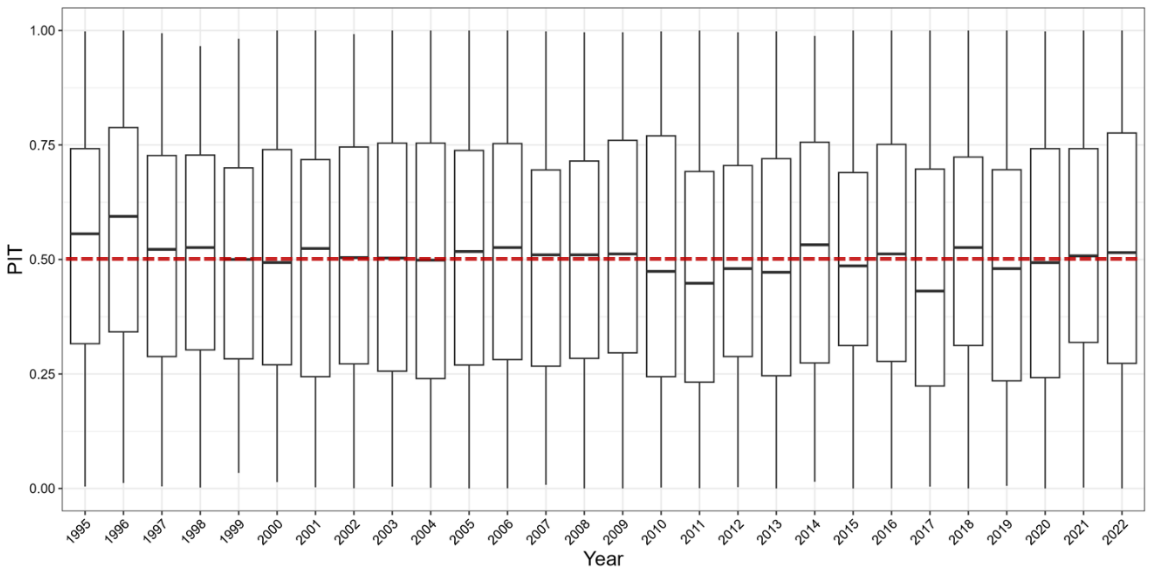

Figure 4. Time-series of probability integral transform (PIT) residuals for striped marlin CPUE standardization during 1995 – 2022.

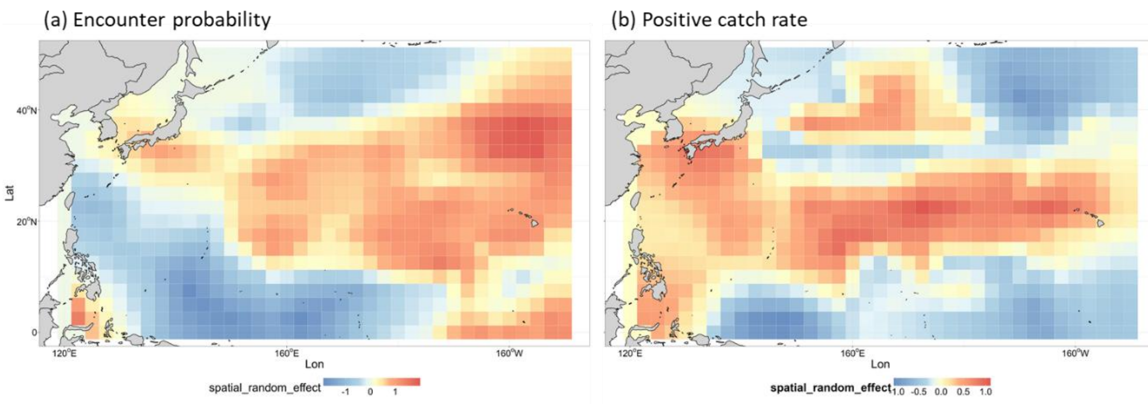

Figure 5. Spatial distribution of spatial random effects for (a) encounter probability and (b) positive catch rate components from the spatio-temporal model for striped marlin in the Western and Central North Pacific Ocean.

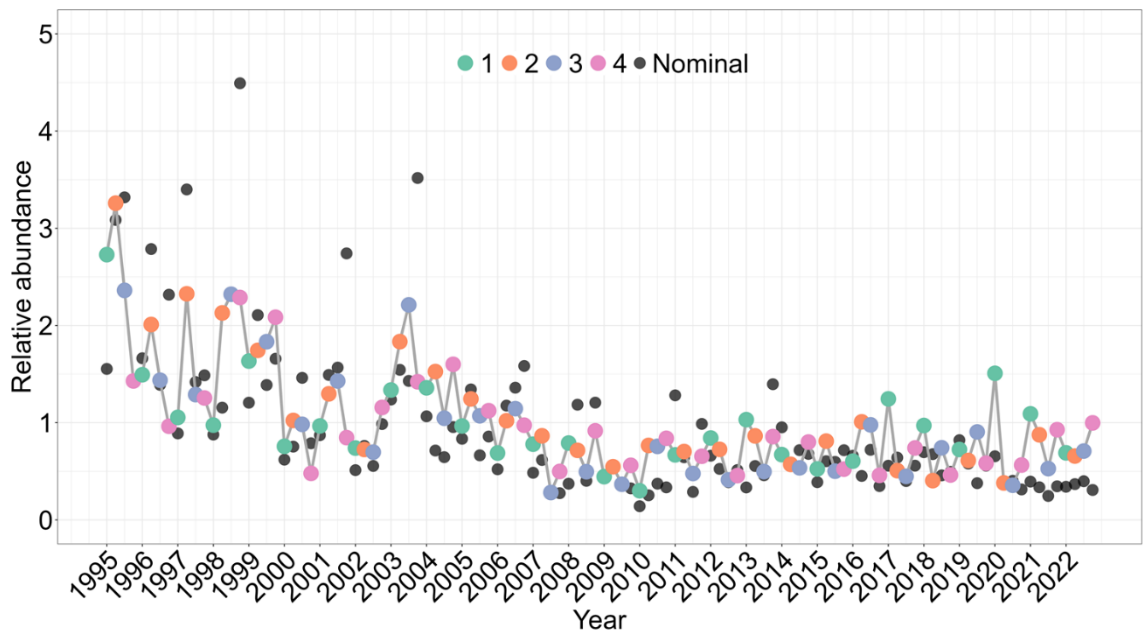

Figure 6. Standardized relative abundance indices for the striped marlin from 1995 – 2022 in the Western and Central North Pacific Ocean.