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Dissertation Summary

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学 位 論 文 題 目

Title of dissertation

A Study on the Standardization of Catch per Unit Effort (CPUE) in Longline Fisheries
(延縄漁業の単位努力量当たり漁獲量 (CPUE) の標準化に関する研究)

Nominal catch per unit effort (CPUE) is affected by environmental variability, fishing strategies, and gear-related changes, weakening its relationship with true stock abundance. Standardization of CPUE is therefore essential to remove these non-biological effects and produce a more reliable index of resource abundance. In pelagic longline fisheries characterized by wide-ranging and long-duration operations, differences in spatial scale can substantially influence catch and effort statistics, while environmental variables derived from satellite observations and data-assimilative ocean models vary in scale, altering the environmental values matched to fishery data. Moreover, nominal CPUE may differ between data sources such as fishing logbooks and vessel monitoring system (VMS) records due to their distinct reporting structures. These discrepancies can accumulate during the standardization process and subsequently affect downstream analyses based on standardized CPUE, including habitat modeling. To clarify these effects and improve the reliability of standardized CPUE, this study systematically evaluates the impacts of spatial scale selection and nominal CPUE calculation based on different data sources. Using the longline fishery as a case study, daily yellowfin tuna (*Thunnus albacares*, YFT) fishery data collected from three Chinese distant-water commercial longline vessels operating in waters near Micronesia (0°15' N–11°14' N, 143°30' E–163°46' E) during 2019–2022 were analyzed. By comparing CPUE standardization results across alternative spatial scales and data sources, this study aims to improve the accuracy of CPUE standardization in tuna longline fisheries and to provide a more robust scientific basis for tuna stock assessment and fisheries management.

In Chapter II, nominal CPUE for YFT was calculated from fishing logbooks, with hooks between adjacent mainline floats (HBF) representing gear effects, stratified areas representing spatial effects, and year and quarter representing temporal effects. Chlorophyll-a (*Chl*), salinity at sea surface (S_0), temperature and dissolved oxygen within 0–300 m were included as candidate environmental variables. Generalized Additive Model (GAM) were used to evaluate standardized CPUE under three spatial scales (0.25°, 1°, and 2°). The results show that spatial scale has a substantial impact on standardized CPUE, with the spatial scale of 1°×1° providing the most robust model performance when fishing operations span approximately 1° longitudinally. Incorporating gear, spatiotemporal, and environmental effects effectively reduced non-resource variability, and *Chl*, temperature at 300 m (T_{300}), temperature at 200 m (T_{200}), and S_0 were identified as key environmental factors. The areas of standardized CPUE (>10) were mainly concentrated between 4 °N and the equator.

In Chapter III, nominal CPUE derived from fishing logbooks and VMS data at a fine spatial scale ($0.25^\circ \times 0.25^\circ$) were separately incorporated as inputs to CPUE standardization models, and the resulting differences were compared using GAM. To reduce potential model-specific bias arising from reliance on a single framework, bi-directional long short-term memory (BiLSTM) model, which have demonstrated strong predictive capability in fisheries studies, were additionally applied to evaluate the influence of alternative nominal CPUE calculation methods on results of CPUE standardization. Both modeling approaches indicated that nominal CPUE calculated from VMS data produced higher standardization accuracy than that derived from logbook data. Although GAM performed more reliably than BiLSTM given the relatively limited sample size in this study, the deep-learning structure of BiLSTM provided advantages in identifying variable importance. SHAP analysis further revealed that key drivers of CPUE variability included temperature at 300 m (T_{300}), sea surface salinity (S_0), and chlorophyll-a (Chl), which is consistent with the important environmental factors identified in the optimal standardization model in Chapter II. Using GAM-derived standardized CPUE with superior model performance, the spatial distribution patterns obtained from the two data sources were compared with in situ vertical profiles of temperature and dissolved oxygen across the study area. This comparison indirectly validated the ecological plausibility of the standardized CPUE derived from both logbook- and VMS-based nominal CPUE.

In Chapter IV, habitat suitability index (HSI) models were developed using three representative environmental variables under different weighting schemes. Based on the survey extent, the comparative performance of CPUE standardization models, and the spatial distribution of standardized CPUE, the standardized CPUE derived from the optimal $1^\circ \times 1^\circ$ spatial-scale model identified in Chapter II was selected as the baseline dataset. Chl , T_{300} , and S_0 were chosen as key environmental factors, and multiple HSI models were constructed using linear weighted combinations with ten alternative weighting schemes. The spatiotemporal distribution of YFT suitable habitats was examined separately for the dry and wet seasons. To further investigate habitat responses under climate anomalies, interannual variations in HSI during El Niño and La Niña events from 2019 to 2022 were compared. In addition, cross-wavelet coherence (CWC) analysis was applied to time series to explore multi-scale relationships between key environmental variables and YFT resource abundance. The optimal HSI model captured spatial habitat patterns effectively, with more than 80% of resource abundance consistently occurring within high-suitability habitats ($HSI > 0.7$) during both dry and wet seasons, indicating that most waters near Micronesia constitute potential YFT fishing grounds. Suitable habitat areas were smaller during the dry season than during the wet season and exhibited a northeastward shift. Marked differences in habitat extent were observed between El Niño and La Niña events: during El Niño events, suitable habitats were relatively more extensive in the wet season, whereas during La Niña events, larger suitable habitat areas occurred in the dry season, suggesting differing favorable fishing periods under contrasting climate conditions. Under anomalous climate conditions, suitable habitats in both monsoonal seasons consistently shifted eastward, indicating that eastern waters may become increasingly favorable for fishing. CWC analysis further revealed that phase relationships between major environmental drivers and resource abundance varied among years, demonstrating that their interactions are not static but evolve across multiple temporal scales.

The findings of this study provide useful reference for CPUE standardization research; however, they should be interpreted within the context of the underlying assumptions and are not directly generalizable to all longline fisheries. Based on the results of the present study, spatial scale

selection in CPUE standardization should be guided by an integrated consideration of operational range, fishing gear characteristics, and fish behavior, in order to improve the accuracy of standardized CPUE indices. Differences in nominal CPUE arising from alternative data sources further affect standardization outcomes: at fine spatial scales (e.g., 0.25°), nominal CPUE derived from VMS-like operational records that preserve detailed spatiotemporal information is preferable, whereas at intermediate or coarser spatial scales, nominal CPUE calculated from fishing logbook records is generally sufficient to characterize standardized CPUE patterns. By integrating standardized CPUE with key environmental variables, HSI modeling provides a process-oriented ecological interpretation of YFT habitat formation. The observed ENSO-related habitat shifts demonstrate that climate anomalies strongly influence habitat extent and distribution. During La Niña dry seasons, the expansion of high-HSI areas suggests elevated CPUE and underscores the need for enhanced monitoring of fishing effort to avoid concentrated exploitation under favorable conditions. In contrast, during El Niño events, the contraction and eastward–equatorward displacement of suitable habitats indicate that HSI-based forecasts may help guide longline fleets toward more favorable fishing grounds and reduce ineffective fishing effort.