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Impacts of marine heatwaves on the abundance and distribution of *Illex argentinus* on the Patagonian Shelf

Background

Marine heatwaves (MHWs) are extreme ocean warming events that are becoming more frequent and intense under global climate change. By enhancing stratification and reducing nutrient availability, MHWs disrupt marine ecosystems, decrease species productivity, and shift fishing grounds. These events have already caused widespread ecological and economic impacts, exemplified by the 2014–2016 North Pacific MHW that forced major fishery closures. The Patagonian Shelf, shaped by the confluence of the Brazil and Falkland Currents, is one of the world's most productive fishing grounds and supports the major squid fishery of *Illex argentinus*. This species is highly sensitive to temperature (2.1–13.5 °C) and productivity changes, making it vulnerable to warming extremes. While previous studies have examined environmental effects on its distribution and abundance, gaps remain in understanding how MHWs influence its habitat and population dynamics.

This study analyzes 2013–2019 MHW patterns in the Patagonian Shelf and explores their impacts on habitat suitability and abundance.

Methods

This study focuses on the Patagonian Shelf, a key habitat and fishing ground for *Illex argentinus*. Fishery data (2013–2019, January–April) were obtained from the China Distant-Water Fisheries Data Center, including catch, fishing effort, location, and date. Catch per unit effort (CPUE) was used as a proxy for stock abundance. Environmental variables—sea surface temperature (SST), temperature at 200 m (T200), and chlorophyll-a (Chla)—were sourced from NOAA OISST and Copernicus Marine databases and standardized to a 0.25° ×0.25° grid. Marine heatwaves (MHWs) were defined following Hobday et al. as periods when SST exceeded the 90th percentile for ≥5 days, and five MHW metrics were calculated: mean intensity (MeanInt), maximum intensity (MaxInt), cumulative intensity (CumInt), frequency (Freq), and duration (Dur). Fishery records were matched to MHW-affected grid cells, and outliers were removed. To avoid multicollinearity, univariate Generalized Additive Models (GAMs) with a Tweedie distribution were used to examine the effect of each MHW metric on squid abundance. Habitat suitability was assessed using a Suitability Index (SI) and Habitat Suitability Index (HSI) framework, trained on 2013–2018 data and applied to 2019–2020, with HSI values classified as unsuitable, moderately suitable, or highly suitable. Temporal and spatial patterns of MHWs, CPUE, and HSI were analyzed, including representative MHW case studies, to evaluate the environmental impact on squid habitat and abundance.

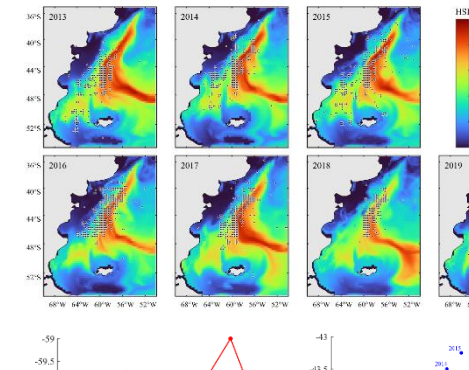

Figure 2 The correlation between MHW parameters and CPUE based on the GAM analysis (n.s. indicates not significant).

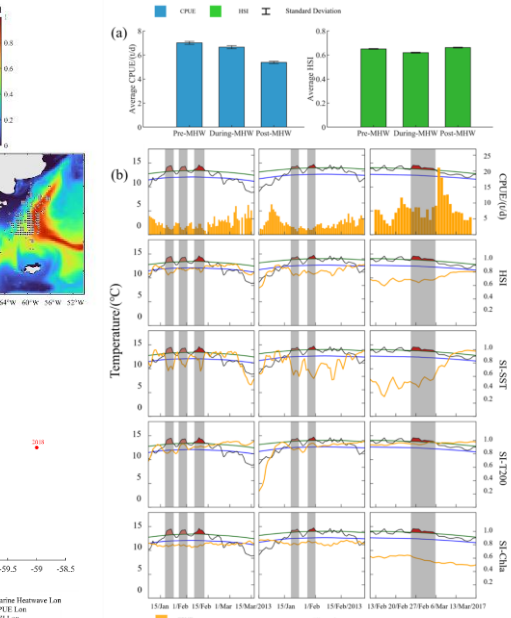

Figure 3 Interannual changes in suitable habitat area and catch of *Illex argentinus* in the Southwest Atlantic (2013-2019). (a) Annual proportion and trend of high habitat suitability (HSI ≥ 0.6), (b) Annual catch of I*llex argentinus* by major fishing countries operating in the Southwest Atlantic, based on FAO capture statistics (FAO, 2024).

Results and discussion

The abundance of *Illex argentinus* was significantly affected by MHW characteristics, with MeanInt, CumInt and MaxInt showing negative correlations, and Duration had no significant effect. High-HSI areas fluctuated over 2013–2019, with a notable contraction in 2018 and partial recovery in 2019. Case studies of MHW events showed that CPUE and HSI decreased during MHWs, with spatial correlations between MHW and environmental suitability indices highlighting region-specific responses.

Figure 4 The distribution of HSI with overlaid fishery points from 2013 to 2019.

Figure 5 The centers of MHWs, CPUE, and HSI from 2013 to 2019.

Figure 6 Changes in CPUE, HSI, and SI before, during, and after MHW events. (a) Average CPUE and HSI values before, during, and after MHWs, (b) Time series of CPUE, temperature, HSI, and SI for SST, T200, and Chl-a (SI-SST, SI-T200, SI-Chla) during MHW events in January-February 2013 and February-March 2017. Shaded areas indicate MHW durations, with darker red marking peak MHW days. All events occurred within 59-60°W and 44-46°S.

CPUE responses of *Illex argentinus* to marine heatwaves (MHWs) were nonlinear. Mild MHWs had little effect on abundance, whereas strong or cumulative events led to substantial declines, indicating that the species can tolerate short-term temperature anomalies but is sensitive to prolonged thermal stress. MHW duration alone did not significantly influence CPUE, but extended or repeated events caused notable ecological responses. During strong MHWs, slope and offshore regions emerged as increasingly important habitats, overlapping with key fishing grounds. High MHW intensity was associated with contraction of high-HSI areas and shifts in CPUE centers, suggesting that squid migrate to maintain access to suitable habitats. Overall, a negative relationship was observed between MHW characteristics and CPUE.

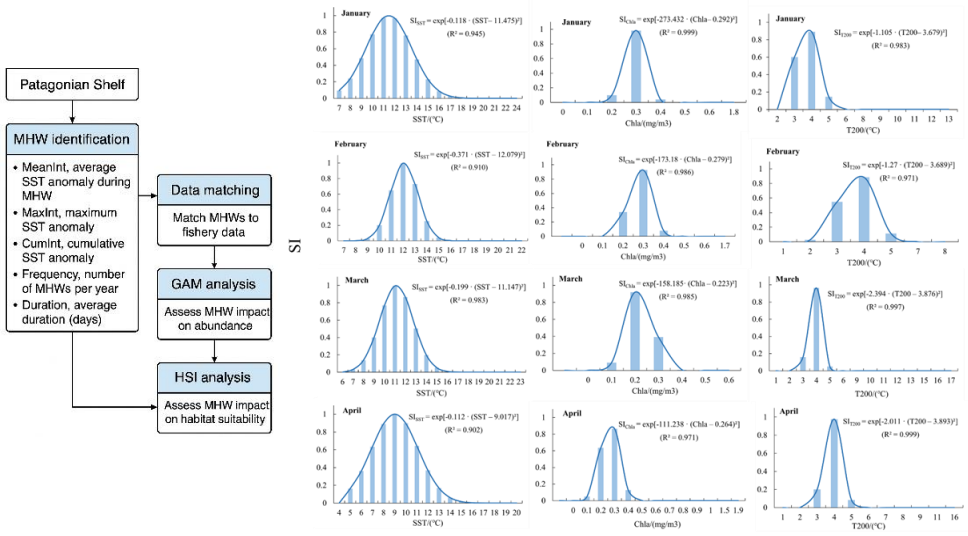

Figure 1 Monthly habitat suitability index (SI) curves and model expressions for three environmental variables (SST, T200m, and Chla) during January to April. Figure 1 Each panel shows the fitted Gaussian SI curve (blue line), derived from the equation SI =exp[a · (x-b)^2] and the corresponding discrete SI values (blue bars) based on binned environmental classes. The vertical bars represent SI values calculated at each environmental class centroid, and are overlaid on the continuous SI curve to visualize consistency between modeled and categorized suitability. The figure is redrawn and adapted from Zhang et al. (2025), with permission, to facilitate interpretation and reproduction of the suitability model.

Acknowledgements

This study was financially supported by the Natural Science Foundation of Shanghai (23ZR1427100), the National Key R.D Program of China (2023YFD2401303), Shanghai talent development funding for the project (2021078), the 2024 International Cooperation Seed Funding Project for China's Ocean Decade Actions (GHZZ3702840002024020000024) and the AI Special Program of Shanghai Municipal Education Commission for Wei Yu in Shanghai Ocean University (A1-3405-25-000303).

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