# Climate Change Response of Pacific Ocean

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## Abstract

Climate change is transforming the distribution and changing the migration of marine species, the dynamics of which are critical for sustainable development and marine resource management. However, how Pacific Ocean squids, which have a one-year life span and great adaptation capacities and sustain more than 25% of world squid captures, respond to climate change is disregarded. We fill this information gap by building spatiotemporal generalised additive mixed models using hundreds of thousands of digitised Chinese squid-jigging logbooks from three Pacific populations of two squid species (*Ommastrephes bartramii* and *Dosidicus gigas*) from 2005 to 2018.

**Keywords:** Climate change • Ocean • Environment • Squids

## Introduction

Climate change is altering marine biological response patterns in a number of ways, including changing the physical and chemical features of habitats and magnifying climatic fluctuations. As a result, it has been identified as a key driver of changes in marine fisheries through changes in primary production, food web interactions, life history, and distribution. Numerous studies have explored the distributional responses of various species to climate change and shown that temperature is one of the most important limiting habitat factors for most poikilothermic creatures. As a result of the poleward shift in the geographical distribution of fish populations, global warming is expected to boost fisheries harvest potential in higher latitudes while decreasing in tropical regions. Because of the peculiar biological traits of Ommastrepes squids, which are short-lived, semelparous, rapid growing, extremely fecund, gluttonous, and metabolically efficient, it is uncertain whether or not ocean warming will result in distributional changes.

Long-term changes in fishing grounds were shown by the contour of annual suitable habitat area (SUA, the region with scaled catch>0.6). We estimated the annual gravitational centre locations (LonG- longitude of gravity, LatG- latitude of gravity), then built linear models with LatG as the response variable and LonG as the explanatory variable to see if there was a poleward shift. The geographical response maps were created to demonstrate fundamental distributional patterns throughout the five ONI levels (by simultaneously changing longitude and latitude, akin to environmental response curves).
Oceanic El Nino indices (ONI), which characterize ENSO events in the Pacific Ocean, downloaded from Climate Prediction Center spanning from 2005–2018, to quantify the effects of climate change on the squids' distribution.

The Ocean Nino Index (ONI) values were divided into five levels (fONIs) including "Strong La Nina", "Moderate La Nina", "Normal", "Moderate El Niño", "Strong El Niño"20 During this period, strong La Niña and El Nino events both occurred twice. According to a simulation study, the monthly aggregated catch in 0.5° longitude 0.5° latitude cell can serve as a robust local abundance index to represent the dynamics of spatial distribution for squids; thus, the original fisheries datasets were grouped into monthly 0.5° 0.5° cells, and the environmental data were converted into 0.5° 0.5° for each month to correspond to the spatial resolution of the fishery data. Finally, for each record, we modelled 6048, 3334, and 8878 fished cells across ten variables: 'Year', 'Month', 'Longitude', 'Latitude', 'SST', 'SSS', 'Chl', 'ONI', 'fONI', 'Effort', and 'Catch'.

## Quantifying the preferred habitat distribution of squids

We created a set of Generalised Additive Mixed Models (GAMMS) to quantify preferred habitat distributions and see if poleward variations in habitat distribution correspond to climate changes. We utilised GAMMs with a gamma distribution and log-link because squid is continuous (catch weight in metric tonnes), asymmetrical, and the variances often increase with bigger catches . For each stock, the models included Catch as a response variable, Month, Longitude, Latitude, SST, SSS, Chl as fixed random effects, and fONI as a random effect. A hierarchical technique was used to verify model structure, using five types of smoothers for each fixed variable. We were able to investigate characteristics that impacted squids' preferred habitat dispersion using this method. In the R software environment, we fitted the models with the'mgcv' package version 1.810. Using AIC values, we identified the best-fitting model. The resulting model forecasted the preferred habitat distribution for each squid from 2005 to 2018. We discovered sinusoidal yearly distribution patterns for two populations of *D. gigas* in the Southeast Pacific Ocean: acceptable habitat areas rise from April to November, then drop from December to the following April, but unsuitable habitat areas had the reverse seasonal variations.

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## Environmental response curves of squids

Environmental response curves were generated by graphing the scaled catch against the predictor of interest while keeping all other variables at their median values from the distribution models for each ONI level and squid. The majority of response curves were bell-shaped or were somewhat bell-shaped because to sampling data contrast. We discovered that environmental response curves are species and stock dependent. Furthermore, the calculated environmental response curves varied substantially between climatic regimes. Across all stocks and environmental factors, scaled abundance indices for strong La Nia years were generally 2 times-3 times greater than strong El Nio occurrences. Interestingly, reaction curves for *O. bartramii* were most clustered (similar) throughout regimes, but rose considerably in strong La Nia years.

## Evaluating the dynamics of habitat for squids under climate change

To show the long-term trends in fishing grounds, the contour of annual suitable habitat area (SUA, the area with scaled catch > 0.6) was presented.

We estimated the yearly gravitational centre locations (LonG - longitude of gravity, LatG-latitude of gravity), then built linear models with LatG as the response variable and LonG as the explanatory variable to see if a poleward shift occurred. The geographical response maps were created (by adjusting longitude and latitude concurrently, similar to environmental response curves) to reflect fundamental distributional patterns under the five ONI levels. The contour of yearly suitable habitat area (SUA, the area with scaled catch>0.6) was shown to indicate long-term changes in fishing grounds. We calculated the yearly gravitational centre positions (LonG-longitude of gravity, LatG-latitude of gravity), then created linear models with LatG as the response variable and LonG as the explanatory variable to examine if there was a poleward change . The geographical response maps were developed to depict fundamental distributional patterns under the five ONI levels (by altering longitude and latitude concurrently, analogous to environmental response curves).

## Discussion

This study combined climate and Ommastrepes squid fisheries data from the Pacific Ocean over a 14-year period to show how short-lived squid species are responding to climate change. Using GAMMs and the oceanic El Nio index as a random effect, we forecasted the spatiotemporal distribution and then the habitat metrics for O. *bartramii* in the Northwest Pacific Ocean and D. *gigas* in the Southeast Pacific Ocean. Our findings demonstrate significant changes in distribution patterns and habitat parameters based on species. The three target stocks' apparent poleward shift in geographical distribution in the Pacific Ocean. In the study of ecology, nested structures or non-independence are common. Mixed models with random effects are helpful inference tools that are becoming easier to design and tailor for specific fisheries situations by adjusting for data dependency structure. One of the issues is determining how to choose predictor variables for use as a random factor. In practise, if the primary goal is to estimate variances, variables are represented as random effects, whereas fixed factors are utilised to estimate the mean effect of a treatment. We are interested in the distribution pattern variants for squids across distinct climatic modes (ONI levels) that are influenced by local environmental factors such as SST, SSS, and Chl. If ONI is regarded as a fixed variable, it would be difficult to explain the effects of different amounts of ONI on squid distributions. As a result, we postulate that the fONI may be considered as a random variable that separates the fishery data into various groups. As a result, the results of mixed models, such as response curves and habitat distribution patterns, would be more robust than those of previous research that did not take this "grouped characteristic" into account.

The life cycle features of squid species may have both positive and negative effects on environmental change since they may be both sensitive (quick reaction) and robust (rapid recovery) to various uncertainties like as overfishing or climatic fluctuation. In comparison to long-lived species, we could test the effectiveness of alternate management methods more rapidly and flexibly. However, this needs precise knowledge about squid distribution and preferred environment, which may be provided from our findings. Based on our research, we have various recommendations for squid management in the Pacific Ocean. To begin, integrating ONI random effects significantly enhanced the accuracy and robustness of distribution models; consequently, if squid relative annual / monthly abundance obtained from distribution models is used for stock assessment models, climatic variability should be addressed. Second, variations in acceptable habitat area associated with distinct climatic phases may impact squid hatching and growth, changing model spawner-recruitment relationships and growth curves.

To support the deployment of 'climate-ready' integrated stock assessment models, research should emphasise strengthening predictive capabilities in this area. Third, the changed response curves and continuous poleward migration of squids in low latitude seas imply that movement patterns should be taken into account in future evaluation models. In general, the proportions of SUA overlap with climatic phases revealed that La Nia events boost squid abundance by increasing appropriate habitat regions, but El Nio events are less beneficial due to opposing causes. As squid stock assessment models are established, managers should be aware that Total Permitted Catches (TPCs) may increase in La Nia years and decrease in El Nio years, and the magnitude of this should be carefully and systematically examined.

In summary, the consequences of climate change in the Pacific Ocean had a significant impact on the environmental response curves and preferred habitat distribution patterns of squids. Squids have clearly moved poleward during the previous two decades. Such observed patterns in geographic distributions should be properly regarded as components of long-term development and management of Pacific squid resources.

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