The climate-induced Spatio-temporal Distributions of tuna species in the tropical Atlantic Ocean

Peng Lian [1, 2, a, *], Yurong Mu [3, b], and Wenbo Yang [1, 2, c]

[1] Fishery Resource and Environment Research Center, Chinese Academy of Fishery Sciences, Beijing, 100141, PRC;

[2] Fisheries Scientific Observation and Experiment Station of Remote Sensing, Ministry of Agriculture and Rural Affairs, China;

[3] Institute of Oceanology, Chinese Academy of Sciences, China.

[a, *] lianpeng@cafs.ac.cn, [b] muyurong@qdio.ac.cn, [c] wbyang@cafs.ac.cn

Abstract. The sustainable utilization of tuna resources faces big challenges arising from extreme climatic and oceanic events. As one of the most important regions for global ocean-atmosphere interactions, the ecological effects of changes in the ocean environment in the Atlantic are always underestimated. Meanwhile, the tropical Atlantic Ocean (TAO), as an important fishing ground for tuna, is facing significant challenges to its ecological stability due to the dual pressures of climate change and human fishing activities. This study explores the spatio-temporal correlation and periodicity between sea surface temperature (SST) and tuna resources through the response patterns of three tropical tuna species to different regional marine climate indices. Research has found that there is a clear dipole pattern in the response of tuna to SST. This study provides insights into the changes in tuna resources over multiple years.

Keywords: climate indices; tropical tuna; response patterns; Atlantic Ocean.

1. Introduction

The tropical Atlantic Ocean (TAO) not only exhibits significant seasonal variations but also significant inter-annual and inter-decadal variations, which affect climate change in the Atlantic and even global oceans. Meanwhile, abnormal signals of interannual changes in the tropical Atlantic will interact with the tropical Pacific through the "atmospheric bridge", thereby affecting the global marine ecosystem[3]. Due to special geographical conditions, the annual average SST of the North Atlantic equator is often higher than that south of the equator. On an interannual time scale, there is a mode similar to the Pacific ENSO, known as the Atlantic Niño.

The cycle of Niño in the Atlantic is unstable, with an average cycle of about 30 months. So the annual signals are more vital to the TAO. These complex changes in the marine environment have a profound impact on the fisheries ecosystem. For Atlantic tuna, the Atlantic Multidecadal Oscillation (AMO) has a significant teleconnection effect on tropical and South Atlantic tuna[7, 8, 9]. The surface temperature and ocean heat content of the North Atlantic Ocean are also the main environmental factors affecting the spatiotemporal distribution of tuna[5,6]. These environmental changes and internal climate variability will profoundly affect the ecological habitat choices of top marine predators such as tunas and sharks[10]. There are studies indicating that AMO can affect the spatiotemporal distribution and habitat selection of bluefin tuna, but there is little research on the interannual effects of different marine environmental factors in tropical and subtropical waters[1, 4]. Therefore, we investigated tuna variation in the TAO (Fig.1) to have a better understanding of the ecological response to climatic change effect.

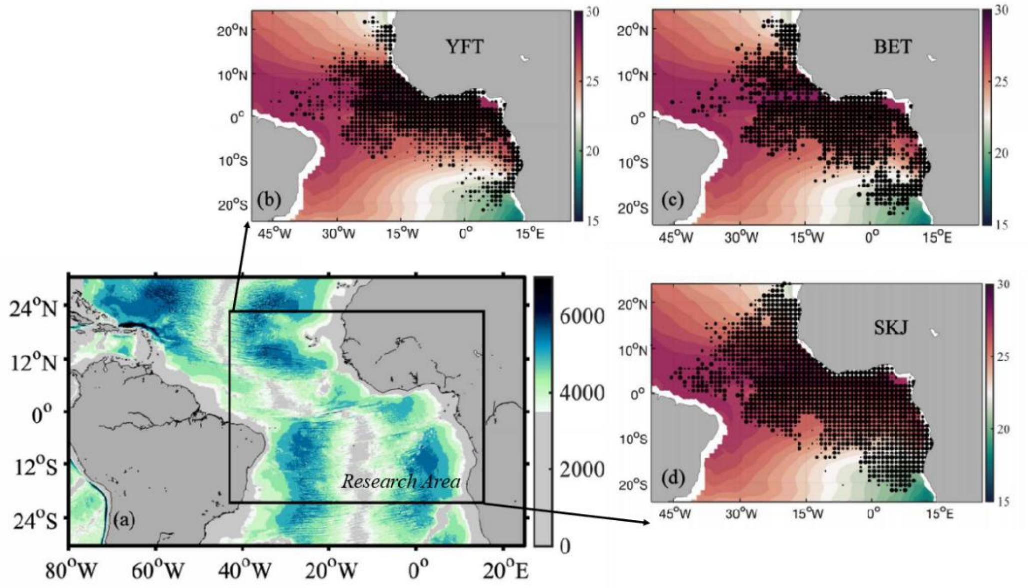


Fig. 1 Research area with bathymetric terrain (a); Yellowfin tuna distributions under the mean sea surface temperature pattern (1991-2021) (b), and bigeye tuna (c), skipjack tuna(d).

2. Materials and Methods

2.1 Data Collection and Processing

This study explores the response mechanisms of three different types of tuna (yellowfin tuna *Thunnus albacares,* YFT; bigeye tuna *Thunnus obesus,* BET and skipjack tuna *Katsuwonus pelam,* SKJ) to changes in climate index in TAO. Three types of tuna fishery data were selected from a spatial area of 20°N-20°S, 45°W-15°E, with a time resolution of the monthly average fishing ground data from 1991 to 2021. The data is sourced from the International Commission for the Conservation of Atlantic Tuna (ICCAT). For longline fishery data, our study uses the monthly average number of individuals captured per thousand hooks to standardize and obtain the nominal Catch Per Unit Effect (CPUE). Meanwhile, the nominal CPUE is standardized using generalized linear models (GLM) (excluding the influence of seasons and latitude on CPUE). The formula is as follows:

$$\log(\mathrm{CPUE}+c)=\mu+\mathrm{year}+\mathrm{month}+\mathrm{latitude}+\mathrm{longitude}+\mathrm{CPUE(BET)}+\mathrm{interactions}+\varepsilon. \qquad (1)$$

Among them, ε is a normally distributed variable with an average value of zero, and μ is the intercept. We used the Minimum Akaike Information Criterion (AIC) to select the model.

We utilized HadiSST data from the Hadley Center's sea ice and sea surface temperature dataset (https://www.metoffice.gov.uk/hadobs/hadisst/). HadiSST data is processed into time series datasets on a monthly and annual basis, using the same regional average method for fishery data. Three climate factors based on SST were calculated, namely the North Atlantic Tropical (NAT) SST index, South Atlantic Tropical (SAT) SST index, and Tropical Atlantic (TASI) SST index.

The NAT SST anomaly index is an indicator of surface temperature in the tropical North Atlantic; the SAT SST anomaly index is an indicator of surface temperature over a wide area of the tropical South Atlantic; and the TASI SST anomaly index is an indicator of the meridional surface temperature gradient in the tropical Atlantic. The NAT and SAT indices are calculated from the 40°W - 20°W, 5°N - 20°N boxes of the SST; the TASI index is calculated from the difference between the NAT and SAT indices[2]. The NAT, SAT, and TASI indices are related to potential decadal "dipole" coupled variability patterns in the tropical Atlantic. In addition, the SST anomalies used for the calculation of the indices are based on the monthly climatic seasonal cycle from 1980-2010.

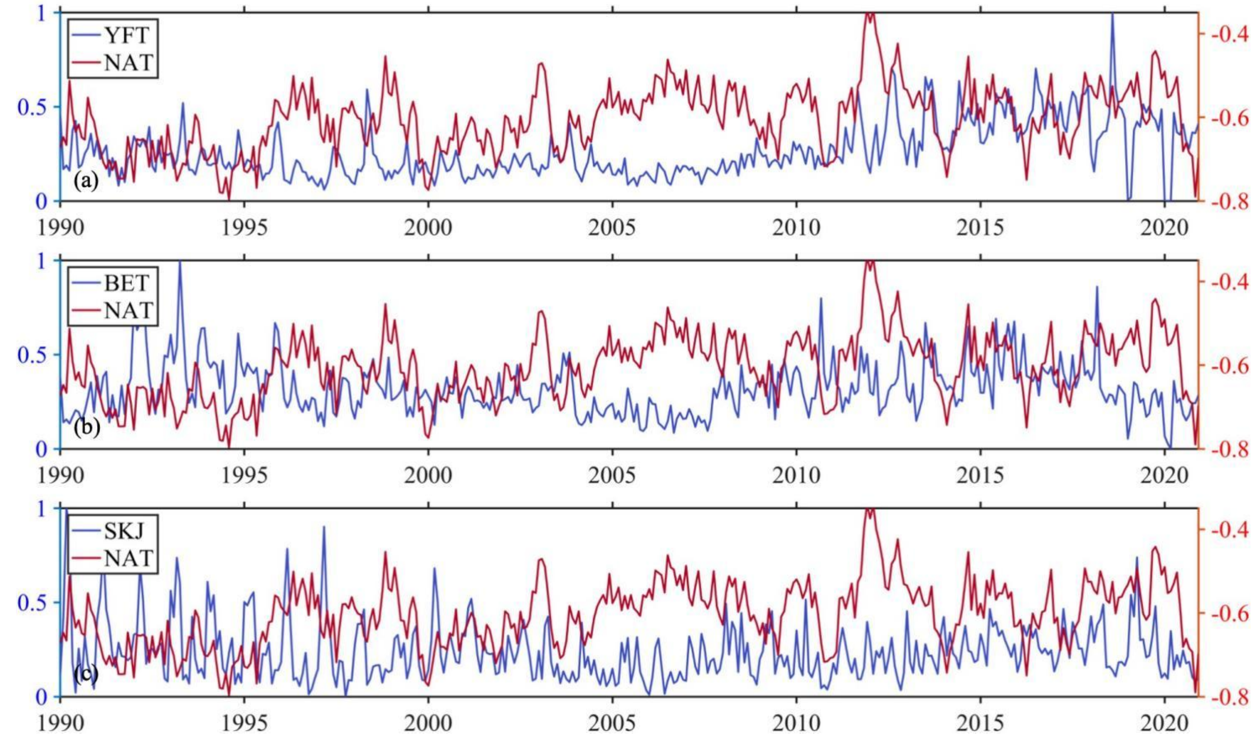


Fig. 2 Time series between the NAT and YFT (a); BET (b), and SKJ (c).

2.2 Spatio-temporal analyses

To explore the relationship between climatic variability and tuna resources, we used nonlinear PCA and spatial correlation analysis. We also used Wavelet Analysis (WA) to explore the periodicity between time series data. WA not only provides frequency domain information of signals but also provides information on signals at different time scales, thus enabling better processing of non-stationary and abrupt signals. Based on the environmental data and the characteristics of tuna fishery data, we explored the selection of appropriate wavelet functions, commonly used wavelet functions include Haar wavelet, Morlet wavelet, etc. For spatial analysis, this study selected Pearson spatial correlation analysis and Empirical Orthogonal Function (EOF, excluding linear trends) analysis. Spatial correlation and EOF analysis can effectively handle the synergistic changes and analyze the spatial coupling relationship between spatio-temporal data of fishing grounds and SST fields. There is good parsing ability for the inherent connections between different tuna's spatio-temporal and surface environmental data.

3. Result

Through analysis of the surface temperature of the Atlantic Ocean, this study found that there is a longitudinal dipole mode in the Atlantic Ocean. The EOF analysis of Atlantic SST (Fig. 3) shows that the first mode is the consistent change mode of the ocean basin, with the variance interpretation rate accounting for 32.44%, while the second mode is the dipole mode, with the variance interpretation rate of 17.06%.

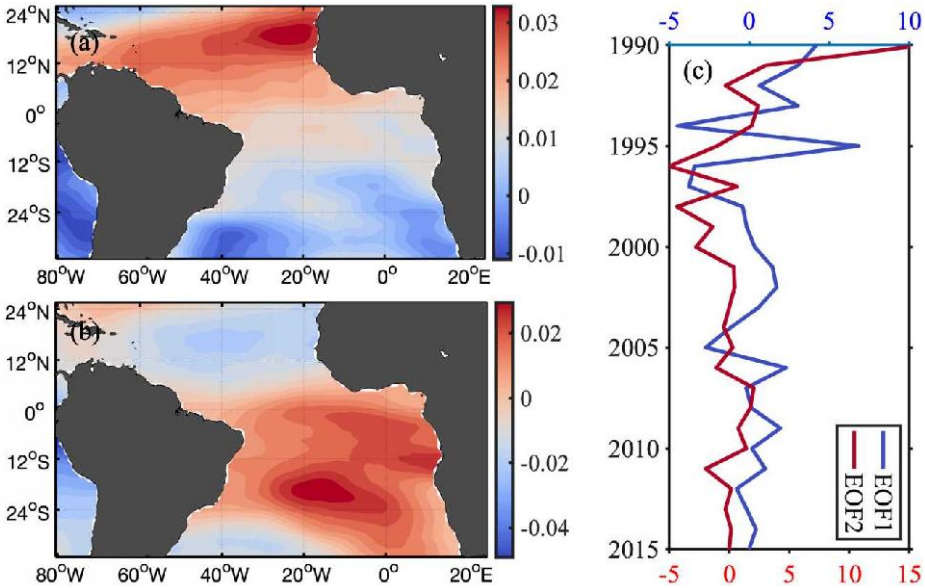


Fig. 3 EOF results of SST in TAO (1991-2015). 1st EOF mode in TAO (a); 2nd EOF mode(b); time series of principal components 1 and 2 (c).

To explore the spatial heterogeneity of the impact of spatial environmental fields on the North-South YFT, BET, and SKJ, the spatial distribution fields of three types of tuna were regressed to the spatio-temporal field of ocean surface temperature. The correlation maps between tuna and SST spatial fields were obtained by exploring the main fishing grounds in the tropical and South Atlantic (Fig. 4). For YFT, the spatial correlation between their fishing grounds and SST is less than 0.2, and the opposite spatial correlation mode is observed between the North and South Atlantic. That is, the warming of the North Atlantic sea surface temperature may lead to a decrease in YFT resources in the South Atlantic, while BET exhibits a similar modal response, manifested by the longitudinal migration of tuna; However, the SKJ shows a higher correlation, that is, the warming of the North Atlantic has a greater response to the skipjack, that is, it is more affected by the first mode of EOF.

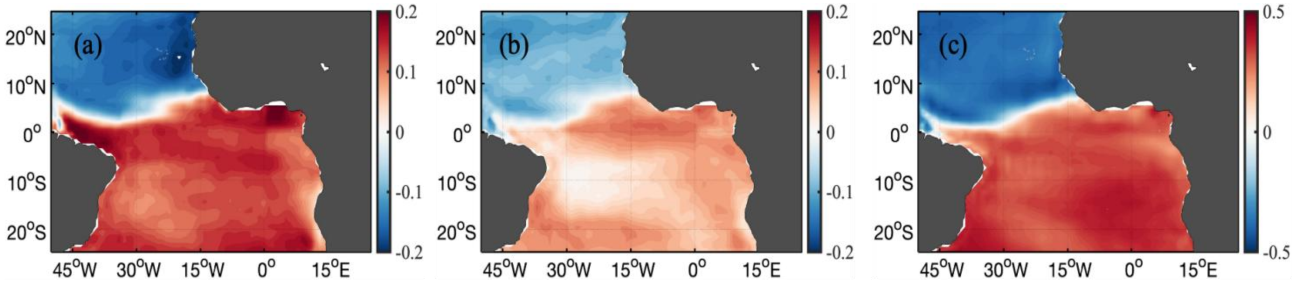
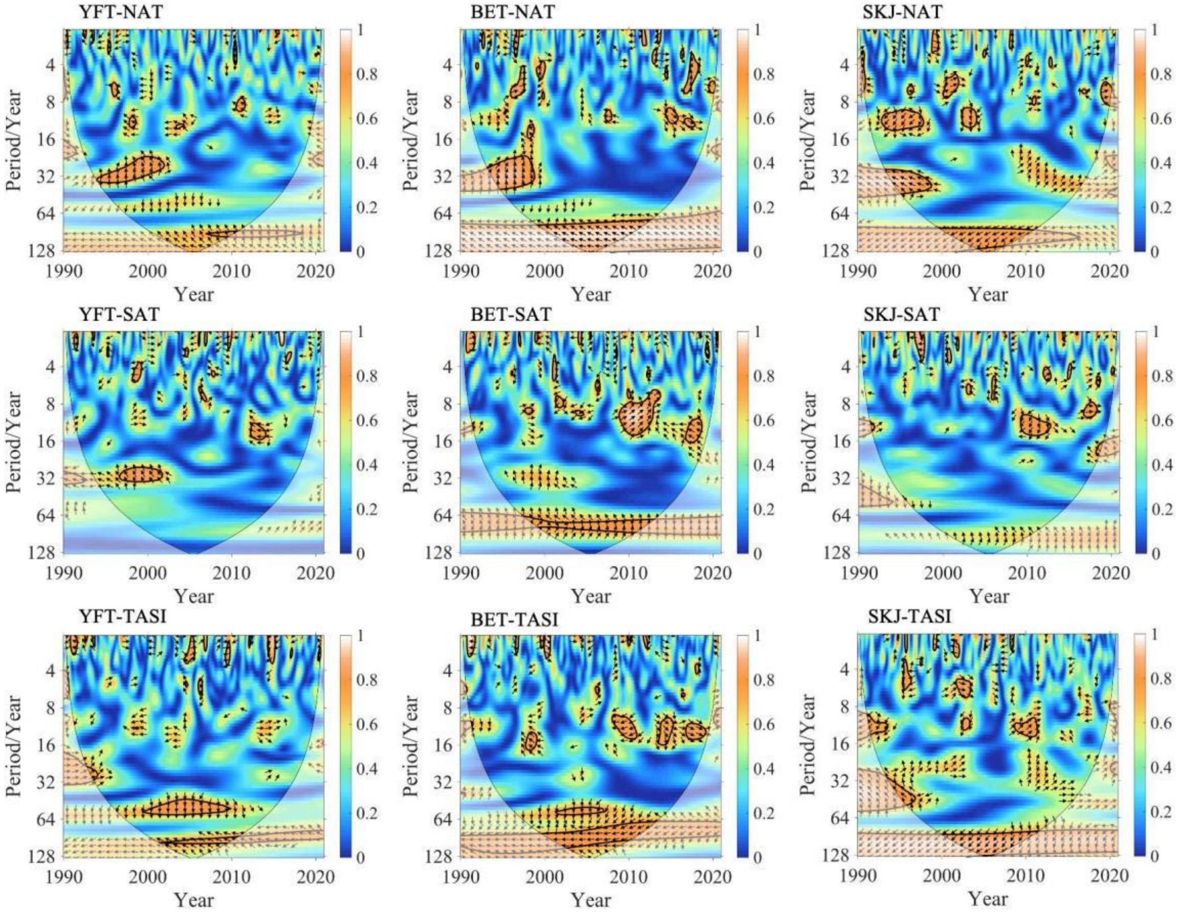


Fig. 4 Spatial correlation pattern (1991-2021) between the SST and YFT(a), BET(b), and SKJ(c).

Meanwhile, we found through wavelet analysis of three ocean surface temperature signal indices (NAT, SAT, TASI) and three tuna species (Fig. 5), the response center of YFT's response to SST tends to shift towards the central tropical Atlantic from 1991 to 2021. The response of BET to the central and southern Atlantic is more pronounced, while SKJ shows a lower frequency response to TASI. And there are lag effects between the NAT and YFT, BET, and SKJ.



YFT-NAT, BET-NAT, SKJ-NAT, YFT-SAT, BET-SAT, SKJ-SAT, YFT-TASI, BET-TASI, SKJ-TASI

Fig. 5 WA results between the YFT, BET, SKJ NAT, SAT, and TASI.

4. Summary

Compared with BET and YFT, the SKJ is more affected by the ocean surface temperature in multi-annual years. As the living waters of skipjack tuna are shallower than the other two tuna species, this response mode may exist for a long time. The study elucidated that SKJ is more susceptible to resource fluctuations due to the influence of climate variability. The results indicate that the response patterns of three tropical Atlantic tuna species to SST are significantly different. YFT showed significant response to NAT with a time lag. On the other hand, BET showed a more pronounced response to SAT, especially from 2008 to 2012. SKJ had a significant response to the entire region, and has the highest spatial correlation with SST, with a positive correlation in the South Atlantic and a negative correlation in the North Atlantic. The center of gravity of SKJ fishing grounds tends to shift southward.

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