Effects of freshwater replenishment on the *Fenneropenaeus indicus* CPUE the west coast of Madagascar based on structural equation modeling

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Introduction

Madagascar, located in the southwestern Indian Ocean, is renowned for its shrimp fishing grounds, nourished by inland rivers such as Betsiboka and Tsiribihina, which bring nutrient-rich organic matter to the ocean. Environmental factors such as sea surface temperature (SST), surface height anomaly (SSHA), and chlorophyll-a concentrations (Chl-a) play vital roles in determining shrimp distribution and abundance . Additionally, freshwater replenishment from precipitation and runoff significantly influences nearshore fisheries by affecting nutrient flows and marine primary productivity. This paper explores the relationships between environmental factors, particularly freshwater replenishment, and F. indicus resources off Madagascar's west coast using Structural Equation Modeling (SEM).

Data sources

Fisheries data were collected from the trawl fisheries logbooks by the Madagascar representative office of China National Fisheries Corporation ranging from 2014 to 2019.

The fishery data are limited to March to November, with fishing trawlers being operational from 43°~48°E, 11°~21°S (Fig. 1). The trawl fisheries logbook data include information on the time of net deployment and retrieval, vessel operating locations, towing durations, and the composition and quantities of major target species caught.

Freshwater replenishment data (precipitation and runoff), accessible at https://psl.noaa.gov/, were sourced from the NCEP/NCAR reanalysis dataset. This dataset covers a spatial range of 42° to 50°E and 10° to 22°S, with a spatial resolution of 2.5° × 2.5° and a monthly temporal resolution. Data for sea surface temperature (SST), sea surface height anomaly (SSHA), and chlorophyll-a (Chl-a) were obtained from the global remote sensing data website of the National Oceanic and Atmospheric Administration (NOAA). This dataset, which is available at https://coastwatch.pfeg.noaa.gov/, also has spatial range of 42° to 50°E and 10° to 22°S, with a finer spatial resolution of 0.5° × 0.5° at a monthly temporal resolution.

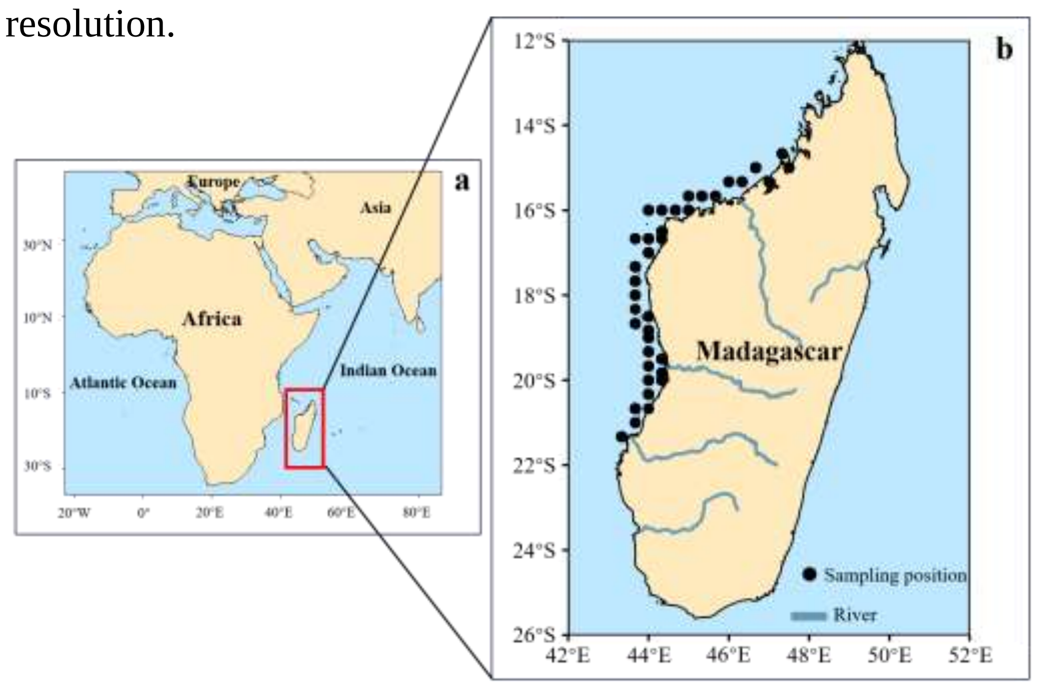

Fig. 1. (a) The study area is located in southeastern Africa, specifically Madagascar. (b) The inset shows the main rivers of Madagascar and the areas where F. indicus were fished from 2014 to 2019.

Method

CPUE

$$CPUE_{y,m,i} = \sum C_{y,m,i} / \sum E_{y,m,i}$$

where ΣC_{ymi} represents the total catch volume in the fishing area unit *i* for the year y and month m, with the unit in kilogram (kg); and ΣE_{ymi} denotes the total operational duration within the fishing area unit *i* for the year *y* and month *m*, measured in hours (h).

Correlation Among Environmental Factors

Pearson's Correlation analysis was used to assess the strength of the relationships between the different environmental factors (Wu et al., 2022).

Construction of SEM Model

$$ln(CPUE_i + 1) = \beta_0 + \beta_1 SST_i + \beta_2 SSHA_i + \beta_3 Chl\text{-}a_i + \beta_4 Precipitation_i + \beta_5 Runoff_i + \varepsilon_i$$

where β_0 is the intercept, β_1 to β_5 are the regression coefficients for each variable, and ε_i represents the residual term; while $ln(CPUE_i + 1)$ transforms the CPUE to avoid zero values.

Model Fit Assessment

A comparison of the p-values derived from the chi-square distribution was used to evaluate the goodness-of-fit of the model(Spitale et al., 2009). The GFI, [0,1], CFI, [0,1], SRMR, and RMSEA were used to validate the model's quality in this study. GFI and CFI values closer to 1 indicate a better model fit, with a common threshold for model adequacy being GFI > 0.90. A well-fitting model should have an SRMR < 0.09 and an RMSEA < 0.05. These values indicate a satisfactory adaptation to the model.

Results

The results show that the runoff, SST, SSHA, and Chl-a concentrations had a significant direct influence on the CPUE of F. indicus. However, significant indirect effects of precipitation, through pathways such as SST on CPUE were also observed (Fig. 2).

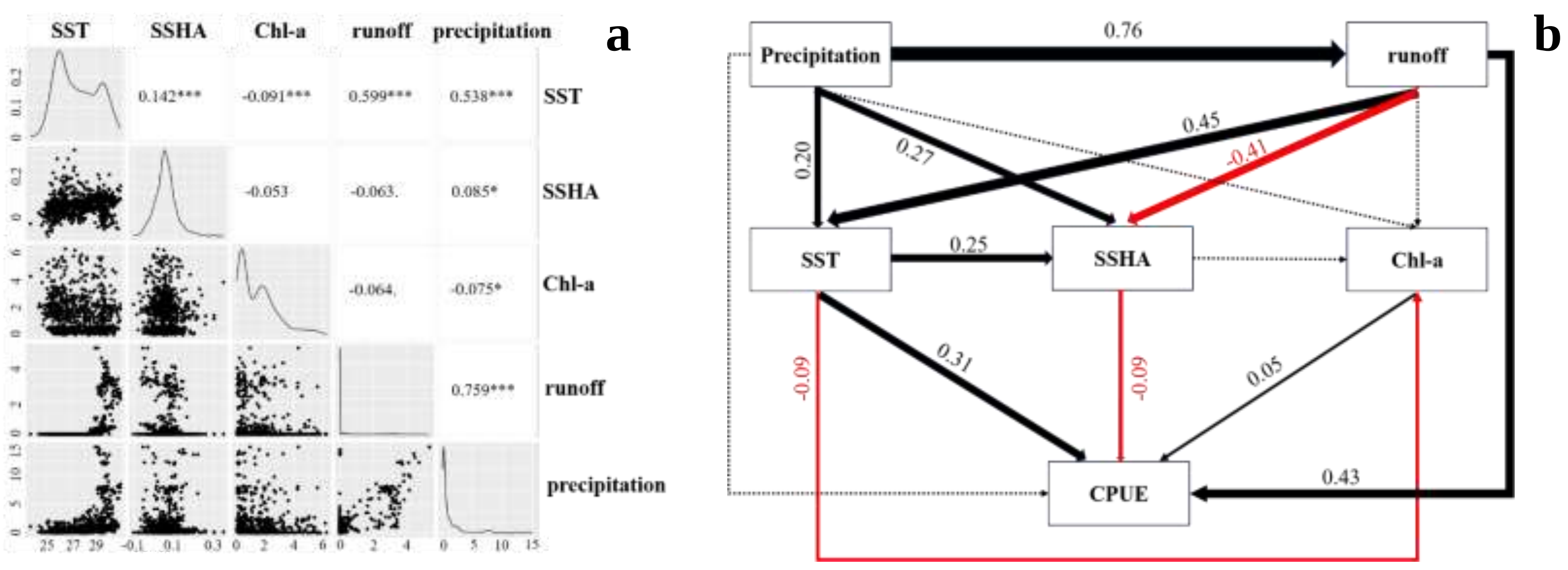

Fig. 2. (a) Pearson correlation plot between all variables.. (b) Path diagram based on structural equation model. (Note: Black, red, and dashed arrows indicate positively significant, negatively significant, and non-significant path relationships, respectively. The values on the arrows are the standardized path coefficients, and the thickness of the arrows indicates the relative size of the standardized path coefficients. The indirect influence is obtained by multiplying the path coefficients)

Conclusions

This study used SEM to analyze the correlation between freshwater replenishment and other marine environmental factors with CPUE, based on trawl data off the west coast of Madagascar from 2014 to 2019 for F. indicus. It explored potential drivers of CPUE variability due to multiple environmental factors. Freshwater replenishment was found to be a significant driving factor affecting the CPUE. These results highlight the complex and multi-level impact of environmental factors on fishery resources.

A deeper exploration of these direct and indirect connections provides a more comprehensive understanding of the impact of environmental changes on the coastal fisheries off the west coast of Madagascar.

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References

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