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A GEOSPATIAL APPROACH TO THE DISTRIBUTION, DENSITY, AND HOTSPOTS OF FRESHWATER CRABS (DECAPODA: GECARCINUCIDAE) IN SRI LANKA

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Abstract

Sri Lanka harbors a notable diversity of freshwater crab species. 50 endemic species out of 51 described species in seven genera are found in Sri Lanka. In this study, freshwater crab distribution, densities, and hotspots were identified using geospatial techniques with a collection of data consisting of field surveys and available literature from 1960 to the present. The distribution of freshwater crabs shows distinctive patterns across the country, with spatial distribution clustered in the wet zone. Genus *Oziothelphusa* exhibited a widespread distribution over Sri Lanka. Density maps reveal high-density clusters in the wet zone, exhibiting a preference by crabs for wetter conditions. Ultimately, the hotspot analysis revealed that the central highlands, southwestern, and western lowlands of the wet zone of the country are the hotspots for freshwater crabs with 99% confidence. The results emphasize the importance of prioritizing conservation plans for the long-term survival of freshwater crabs in Sri Lanka.

Keywords: Arthropoda, conservation, Crustacea, endemic, GIS, Kernel density, Malacostraca

Introduction

Freshwater ecosystems are major components of global biodiversity (McAllister *et al.* 1997). Among the diverse freshwater inhabitants (Collen *et al.* 2014), the family of freshwater crabs exhibits unique morphological (Yeo *et al.* 2008), ecological (Marijnissen *et al.* 2009), and

behavioral (Singh *et al.* 2022) diversity, with more than 1,475 described species belonging to 14 families around the globe (Yeo *et al.* 2008). Sri Lankan freshwater ecosystems (Seeger 1971), including tanks, rivers, streams, wetlands, etc., constitute suitable habitats for freshwater crabs (Bahir *et al.* 2005). Despite the size of the

country, Sri Lanka is home to a notable diversity of freshwater crab fauna, and remarkable endemism (Bahir & Ng 2005). Fifty-one freshwater crab species belonging to seven genera (*Ceylinthelphusa*, *Clinothelphusa*, *Mahatha*, *Oziotelphusa*, *Pastilla*, *Perbrinckia*, and *Spiralothelphusa*) have been described, and 50 of them are endemic to Sri Lanka (Udagedera *et al.* 2015), which constitutes the highest endemism for any group of animals in Sri Lanka. Environmental pollution and habitat degradation threaten the long-term survival of freshwater crabs (Cumberlidge *et al.* 2009). Previous studies in Sri Lanka have focused on taxonomic description, ecology, etc. (Bahir 1999, Udagedera *et al.* 2015), yet the spatial distribution of freshwater crabs is understudied, leaving a significant knowledge gap. A comprehensive spatial study is needed to understand and evaluate their distribution, population dynamics, and habitat preferences, and to inform effective conservation plans to ensure their survival into the future.

Freshwater crabs show high endemism because of their low dispersal ability and limitations in crossing natural barriers (Cumberlidge *et al.* 2011b). Their distribution is influenced by environmental and hydrological factors (Cumberlidge *et al.* 2004, Cumberlidge *et al.* 2011a, Udagedera *et al.* 2015), such as temperature, rainfall, and elevation. Human alterations to land use and land cover mainly lead to habitat degradation and affect the food sources of these creatures (Schlacher *et al.* 2016). Freshwater crabs play a key role in nutrient cycling as they are detritivores and scavengers, which break down organic matter and accelerate the process of nutrient recycling in aquatic ecosystems (Weigand *et al.* 2014). They are also an integral part of food webs, serving as predators and prey (Wehrtmann *et al.* 2019). Some of the freshwater crab species are restricted to montane and submontane regions of the wet zone of Sri Lanka, while others generalize into a range of freshwater ecosystems such as wetlands, paddy fields, moist soil areas in proximity to freshwater sources, water bodies, etc. (Bahir *et al.* 2005). Freshwater crabs in Sri Lanka likely make important contributions to natural litter decomposition (Yang *et al.* 2020) and can serve as bioindicators of water quality (Sanders *et al.* 1999).

The main objective of this study was to map the hotspots of freshwater crab diversity in Sri Lanka utilizing geospatial techniques in GIS. Our

specific objectives were to identify the island-wide spatial distribution of freshwater crabs and to determine the distribution density of each genus of freshwater crabs. The findings of this study will help to fill key knowledge gaps of freshwater crab distributions in Sri Lanka. This knowledge can help to safeguard the habitats of freshwater crabs in changing environments and develop effective conservation plans in the future.

Materials and methods

Study area. Sri Lanka is an island nation located in the Bay of Bengal, south of the Indian subcontinent, between 5°55'–9°51'N and 79°41'–81°53'E. The country has a tropical climate (Punyawardena 2009). The annual rainfall varies between 900 mm and more than 5,000 mm (Fig. 1A), with the driest parts located in the southeastern and northwestern regions and the wettest parts on the western slopes of the central highlands (Burt & Weerasinghe 2014, Karunathilaka *et al.* 2017). The annual average temperature varies between 16°C and 27°C from the coastal lowlands to the montane regions in central Sri Lanka (Naveendrakumar *et al.* 2018). Based on the annual rainfall, Sri Lanka is divided into three zones (Warnasekara *et al.* 2021; Fig. 1A). The dry zone is the largest zone, extending from the northern regions to the southeastern parts of the country, where the annual rainfall is less than 1,750 mm. Two arid zones in the northwestern and southeastern areas can be found within the dry zone. The intermediate zone is located between the wet and dry regions of Sri Lanka and receives annual rainfall between 1,750 mm and 2,500 mm. The southwestern part is the wet zone of Sri Lanka, with an annual rainfall of more than 2,500 mm. Some parts of the western and southern slopes of the central highlands receive more than 5,000 mm of rainfall annually. Rainforests and grasslands are distributed in the wet zone (Fig. 1B). In contrast, intermediate rainforests are located in the intermediate zone, and semi-evergreen forests, dry grasslands, and monsoon scrub jungles are spread throughout the dry zone.

Data collection. The dataset for the study comprised the geographical locations of records of freshwater crabs. This dataset was a collection of historical data, field surveys, and reports published between 1990 and 2024. Historical data records covering all of Sri Lanka were obtained from the published literature and museum records. Field surveys were conducted

for three consecutive years from January 2021 for a total survey effort of about 1,000 hours. A group of four observers participated in the surveys, covering 420 distinct locations in the major freshwater ecosystems in the wet zone such as rivers, streams, wetlands, agricultural lands, and areas with high soil moisture. Unpublished records were collected from local naturalists. Each record included species names, survey dates, and geographic coordinates.

We performed our analyses in the ArcGIS Pro 2.9 environment. As the first step, we conducted data cleaning to ensure the accuracy and reliability of the dataset. This process started with merging data from published literature, museum records, field surveys, and unpublished records. Then we cross-checked species names with the latest International Union for Conservation of Nature (IUCN) Red List and removed duplicate location records. We replaced missing or out-of-range longitude and latitude values by cross-checking with published records. The dataset was then converted into a spatial database and standardized by projecting it onto the WGS84 coordinate system (Kumar 1988). Thus, the spatial distribution map of freshwater crabs was created. We used a spatial technique called kernel density analysis (Okabe *et al.* 2009) to estimate the distributional density of each freshwater crab genus based on species occurrences across Sri Lanka. The kernel density is calculated using a function that calculates the influence of each point on its neighboring points to create a continuous density layer. The function also conducts smoothing to reduce abrupt changes in density. This process was repeated across the study area, resulting in a smooth, continuous density map.

Hotspots of freshwater crabs in Sri Lanka were identified by hotspot analysis. Hotspot analysis is a GIS technique used in biodiversity and ecological studies to identify areas with rich biodiversity and high numbers of species. The analysis used is called the *Getis-Ord G_i^** in the ArcGIS Pro environment (Ahmad & Rizvi 2023). *Getis-Ord G_i^** measures the degree of spatial clustering using a statistical method, resulting in statistically significant hotspots and coldspots using a *G_i^** value. The method calculates a z-score and p-value for every spatial unit (we defined a unit of 1 km² for the current study) across the study area using the freshwater crab occurrence of nearby units. It is considered a hotspot when the *G_i^** value is high and positive, whereas a low and negative *G_i^** indicates

coldspots. When the *G_i^** is 0 or close to 0, it is considered an area with a random distribution. We then used Moran's I test to validate the hotspot analysis. A positive Moran's I value indicates a clustered hotspot, while a negative Moran's I value shows a dispersed spatial distribution.

Results

Spatial distribution. The freshwater crabs exhibited a scattered distribution across the country (Fig. 1C). The map was overlaid with the layers of climatic zones (wet, intermediate, and dry zones) and elevation (between 0 and 2,475 m) to aid in interpreting their distributions. The southwestern part of the country, which is primarily the wet zone, has the highest number of genera. The genera *Ceylonthelphusa*, *Mahatha*, *Pastilla*, *Clinothelphusa*, *Perbrinckia*, and *Spiralothelphusa* are highly clustered in this zone. Genera like *Ceylonthelphusa*, *Mahatha*, and *Oziotelphusa* show dispersed distributions towards the intermediate zone. In contrast, the dry zone of Sri Lanka showed lower taxonomic distribution, with only the genus *Oziotelphusa* occurring broadly across the study area. The occurrences of *Ceylonthelphusa*, *Mahatha*, and *Perbrinckia* are clustered at higher altitudes, while *Pastilla*, *Spiralothelphusa*, *Clinothelphusa*, and *Oziotelphusa* tend to occur at lower altitudes (Fig. 1C).

Distribution density. *Ceylonthelphusa* (Fig. 2A) showed a higher density of distribution extending from central Sri Lanka towards the southwestern region of the country. *Mahatha* (Fig. 2B) showed a similar distribution, while *Pastilla* (Southwest Sri Lanka) and *Clinothelphusa* (Southwest gradient of central Sri Lanka) can only be found in the wet zone and exhibited a very limited distribution density compared to other genera (Fig. 2C, 3E). In contrast, *Oziotelphusa* (Fig. 2F) exhibited a scattered distribution over Sri Lanka, with the highest density in western Sri Lanka but moderate densities in the southern region and north-central parts of the dry zone. *Spiralothelphusa* (Fig. 2D) showed a notable density cluster in western Sri Lanka, and *Perbrinckia* (Fig. 2G) exhibited density patches in the southwest of the country.

Freshwater crab hotspots. Since the density of the majority of freshwater crab species was clustered in the wet zone of the country, hotspot analysis was carried out to examine the statistical significance of the region (Fig. 1D). Statistical

Plate 17

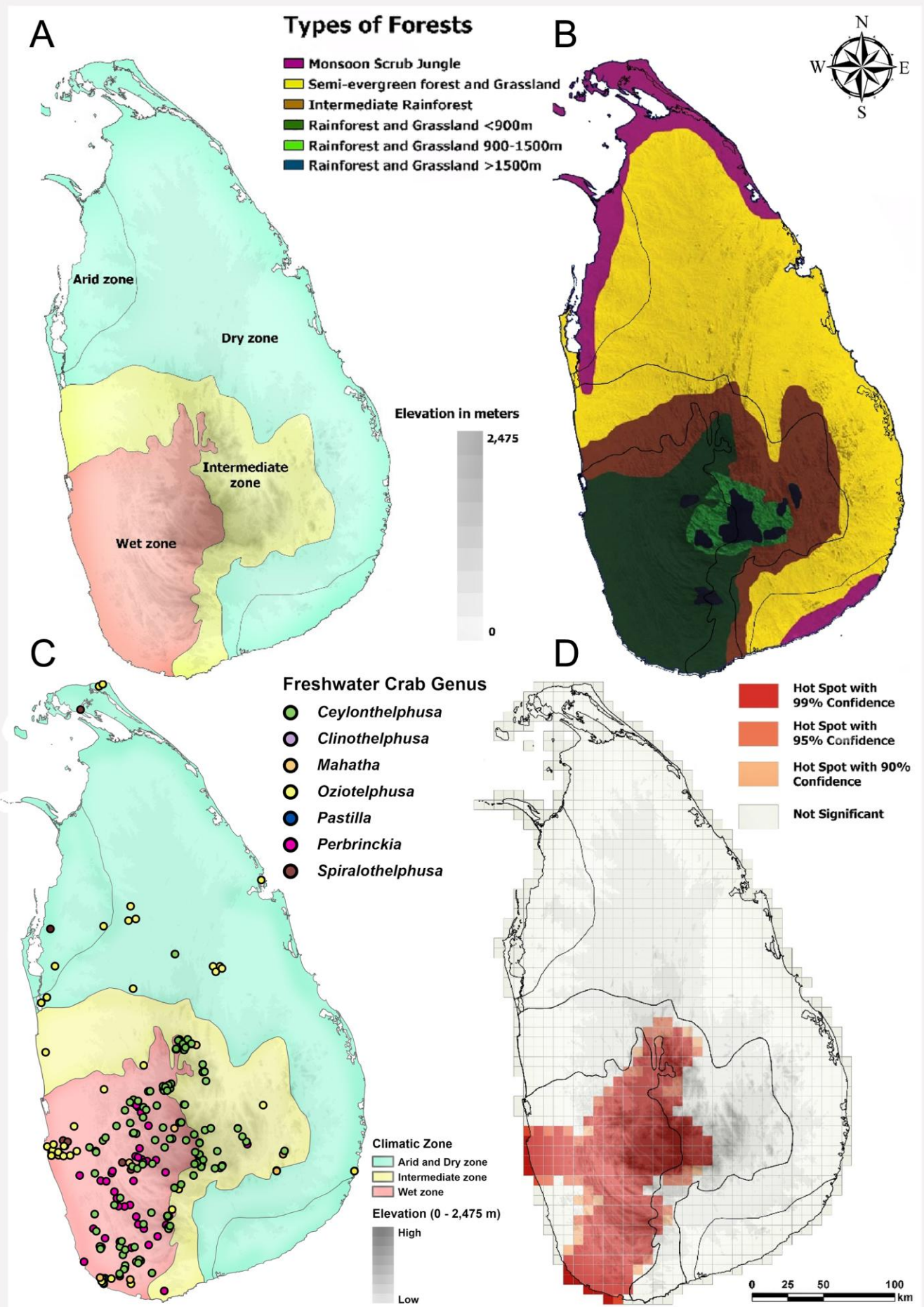


Figure 1. Map of Sri Lanka (study area) showing (A) climatic zones, (B) forest types, (C) distribution pattern of the freshwater crab genera, and (D) freshwater crab hotspots

Plate 18

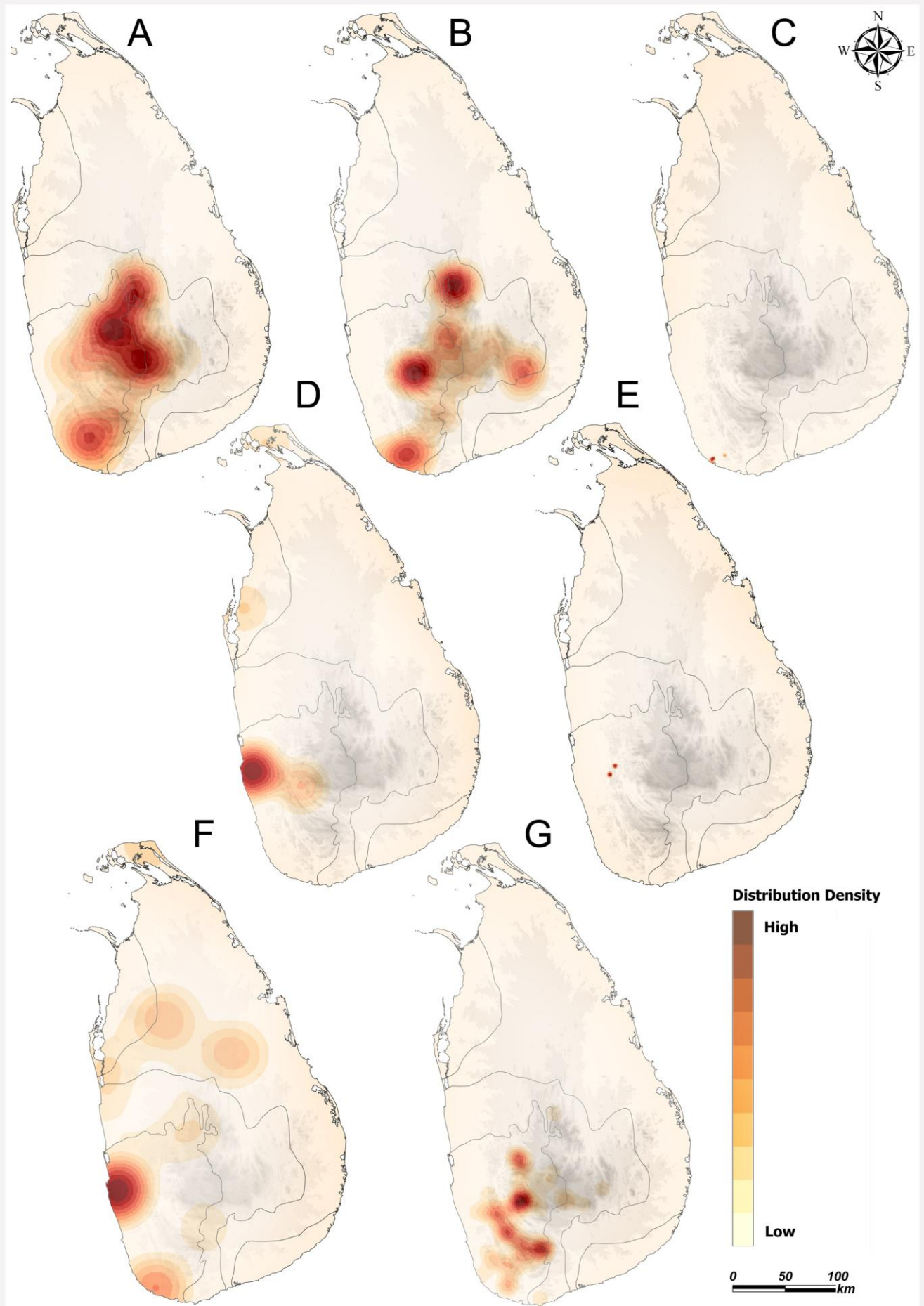


Figure 2. The distributional density of freshwater crab genera in Sri Lanka: (A) *Ceylonthelphusa*, (B) *Mahatha*, (C) *Pastilla*, (D) *Spiralothelphusa*, (E) *Clinothelphusa*, (F) *Oziotelphusa*, and (G) *Perbrinckia*

validation showed the hotspots are reliable and statistically significant at 0.01 significance level (Moran's $I = -.62$, $z\text{-score} = 69.52$, and $p\text{-value} < 0.01$). The central Sri Lanka in the intermediate zone, extending through the southwestern slopes and western parts of the wet zone, is a hotspot of freshwater crabs with 99% confidence (Fig. 1D). Hotspots with 95% and 90% confidence are also located in the wet and intermediate zones surrounding the 99% confidence hotspot. The dry zone of Sri Lanka is not a significant hotspot for freshwater crabs.

Discussion

We conducted a comprehensive geospatial assessment of freshwater crab distribution, genus-level density, and hotspot analysis using geospatial techniques in GIS. The analysis revealed distinctive variations in spatial distribution and density patterns among freshwater crab genera. The highest species occurrence and densities were clustered in the wet zone of Sri Lanka, particularly in the central and southwestern parts of the country. In contrast, the dry zone of the island displayed a lower distribution density of freshwater crabs. Only the genus *Oziotelphusa* exhibited a widespread distribution across the island. In contrast, genera such as *Pastilla* (Southwest Sri Lanka) and *Clinothelphusa* (Southwest gradient of central Sri Lanka) were restricted in their distribution to specific areas inside the wet zone of Sri Lanka, suggesting that factors such as rainfall, soil moisture, and wetness play a key role in freshwater crab distribution (Grinang *et al.* 2016). The hotspot analysis resulted in a relatively large hotspot with 99% confidence in the central and southwestern regions of the country, particularly within the intermediate and wet zones, with the majority of the hotspots clustered in the wet zone. Since the species found in the dry zone is a subset of those species in other zones, the dry zone of Sri Lanka did not exhibit hotspots for freshwater crabs.

The correlation between freshwater crab distributions and climatic zones highlights the importance of hydrological conditions to the survival of these species. Beenaerts *et al.* (2010) showed similar results in their study. The wet and intermediate zones associated with higher-elevation regions provide year-round wet and humid conditions, providing a suitable habitat for a healthy freshwater crab population. Okano *et al.* (2003) and Padghane (2018) studied the habitat preferences of freshwater crabs, similarly

finding that species from the genera *Pastilla* and *Clinothelphusa* are restricted to habitats located in the wet zone. These results also emphasize the need to preserve riparian ecosystems (Harlloğlu *et al.* 2018). Anthropogenic threats such as habitat degradation due to deforestation and urban expansion may affect the population of freshwater crabs (Bridhikitti *et al.* 2023). Additionally, changes in rainfall and temperature could further impact freshwater crab habitats (Fang *et al.* 2013). Therefore, conservation efforts might be prioritized in the hotspots found in the study.

Spatial analysis, such as geospatial mapping, kernel density, and hotspot analysis in GIS, has provided a sturdy approach to comprehensively identify the distribution of freshwater crabs in Sri Lanka. However, several limitations of the study need to be acknowledged. Sampling gaps in the dry zone, especially in the northern and eastern parts of the country, are a major limitation. Most of the historical surveys were focused on the central, western, and southern regions of the country. The current study lacks temporal variation of species distribution and changes in environmental variables such as climate change patterns, water quality, land use, habitat structure, etc. Future studies should focus on the effect of environmental change and anthropogenic pressure on freshwater crabs in Sri Lanka. Predictive models could be used to understand the shifts of freshwater crab distribution and habitats under changing environmental and climate scenarios.

This study provides a comprehensive understanding of the spatial distribution of freshwater crabs, offering valuable insights into their occurrence hotspots, critical habitats, and key areas for conservation priorities in Sri Lanka. We hope the findings will be used in conservation strategies and habitat restoration actions in the future, ensuring the long-term well-being of this ecologically important species in Sri Lanka.

Author contributions

All the authors contributed to data collection, study conception, and design. TIL performed data preparation, analysis, and manuscript writing, and all the authors commented on the draft manuscript.

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