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Abundance and diversity of macro-invertebrates in the selected mangrove species along the coast of Mbegani in Bagamoyo District, Tanzania

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Abstract

Background Mangrove forests are highly productive ecosystems that serve as biodiversity points, containing many organisations, contributing to carbon storage, improving water quality and providing ecosystem goods and services to improve local means of subsistence. These resilient ecosystems are characterised by their morphological modification and their particular respiratory structures (pneumatophores), which allow them to proliferate in salt-rich environments. Mangroves play a crucial role in maintaining invertebrate and fishery resources, providing shelter and nutrients to a diverse range of species. However, mangrove ecosystems are threatened by anthropogenic activities such as the extraction of building materials, firewood, crushing plants and salt manufacturing, resulting in the disintegration of ecosystems and the loss of inhabitants. This study aimed to determine the abundance and diversity of macro-benthic invertebrates on the different parts (roots, stems and leaves) of common mangrove species of the Mbegani coast, along the Indian Ocean using a completely randomised design.

Results The sampling was done using a 1 m² quadrat focussed on the three mangrove parts, viz. roots, stems and leaves. The results showed that the highest percentage of macro-invertebrates were recorded on *Bruguiera gymnorhiza* (66.8%), followed by *Avicennia marina* (20.8%) and the least were *Ceriops tagal* (12.4%), such variation differed significantly between the three mangrove species across the selected plots ($F_{(2,524)} = 5.71$, $p = 0.035$). The stems (54.4%) inhabited a large number of macro-invertebrates, followed by roots (32.8%) and the least were leaves (12.8%), which varied significantly between the three mangrove parts sampled across the selected mangrove species ($F_{(2,524)} = 7.25$; $p = 0.008$). The majority of macro-invertebrates were planktonic feeders stuck on stems or herbivores shuttling between the roots and leaves of the plants. Macro-invertebrates recorded on *Bruguiera gymnorhiza* were more diverse than those found in *C. tagal*. The findings emphasise the importance of macro-invertebrates in the ecological balance of mangrove ecosystems.

Conclusion The study concludes that mangroves in the Mbegani ecosystem have a high potential for biodiversity and are important for the coastal community and the ecosystem of the Bagamoyo District. The results contribute to coastal resources management programmes and future surveillance activities.

Keywords Abundance, Diversity, Macro-invertebrates, Mangroves, Mbegani

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Background

Mangrove forests are vital ecosystems for biodiversity, carbon storage, improving water quality and local subsistence (Akram et al. 2023; Hilaluddin et al. 2020; Mohamed et al. 2024). These are communities of halophilic woody plants that thrive along the tropical and subtropical coasts, tolerant of salt (Grigore 2021; Mann et al. 2023). Mangroves are rich in macro-invertebrates and serve as reproductive sites, nurseries and food areas for various species. However, anthropogenic activities such as the extraction of building materials and the manufacturing of salt threaten these ecosystems, causing their disintegration and their loss of inhabitants. The ecosystem also provides a natural coastal buffer due to its ability to reduce tidal flow and stimulate sedimentation (Bourgeois et al. 2019; Hilaluddin et al. 2020). Mangroves are typically considered halophytic wood plant communities that flourish along the tropical and subtropical coastlines (Grigore 2021). Halophytes are salt-tolerant plants and have a remarkable ability to complete their life cycle in saline conditions (Grigore 2021; Mann et al. 2023). Morphological modification of their roots and waxy leaves coupled with anatomical and physiological strategies enables mangroves to proliferate in high-salt environments (Myint et al. 2019). In addition, mangroves also depend on special respiratory organs (pneumatophores), which emerge above water and have small openings/lenticels that are used for air passage (Björn et al. 2022).

Additionally, because they offer food and shelter to a vast variety of species, including terrestrial, estuarine and marine organisms, mangroves play a critical role in preserving fisheries resources and invertebrates (Aung 2022). Accordingly, the mangrove–estuarine ecosystem is one of the intricate relationships between biotic and abiotic elements for biological integrity and sustained productivity, both of which are necessary to maintain the webs of aquatic ecosystems (Peng et al. 2017). In essence, mangroves serve as breeding sites, nurseries and feeding grounds for both resident and migratory species (Sievers et al. 2019). Both invertebrate and vertebrate species, such as annelids, arthropods, molluscs, fish, amphibians, reptiles, birds and mammals, can be found in mangrove habitats (Sievers et al. 2019). According to Mahoharan et al. (2021), the common macro-invertebrates found in mangrove environments include gastropods, bivalves, barnacles, sponges, tunicates and sipunculids as well as brachyuran and hermit crabs. Benthic macro-invertebrates, which are visible to the unaided eye at the bottom of a water column and consist of molluscs, polychaetes, crustaceans and echinoderms, are found close to the mangroves (Chowdhury et al. 2022). According to Alongi (2020), mangrove occupants and bystanders are important participants in the cycling of nutrients and a source

of food for vertebrates, including humans. These ecosystems can produce goods and services, but they are threatened by human activities like building material extraction, fuel wood extraction, seedling squashing and salt production, which cause the mangrove ecosystem to disintegrate and consequently drive out its inhabitants (Scales and Fries 2019). For example, according to Mangora et al. (2016), mangroves in Bagamoyo covered an area of 5635.8 ha in 2016. However, about 50% of this area is presently threatened by the aforementioned anthropogenic activities (Gayo 2022). The capacity of mangrove ecosystems to carry out several crucial ecological tasks is undoubtedly compromised by their degradation. Recall that mangrove trees offer habitats for invertebrates in a variety of locations, including their leaves, stems and roots. Sediments and mangrove features determine the macro-invertebrate availability in various areas of the mangroves (Egawa et al. 2021). However, little is known about the exact areas of the mangroves that macro-invertebrates prefer, or if there is any species specialisation at all. This data is critical to expanding the biodiversity database.

Consequently, the goal of the current study was to ascertain the diversity and abundance of macro-benthic invertebrates on the roots, stems and leaves of the three most prevalent mangroves along the Indian Ocean coast of Mbegani.

Methods

Study sites

This study was carried out in Tanzania's Bagamoyo District, Pwani Region, along the Mbegani shore. The experimental sites were located between latitudes 6° 20' and 7° 35' S and, longitudes 38° 30' and 39° 15' E. According to Gwambene and Karata (2019), the Mbegani coast experiences a mean annual temperature of 26.1 °C and a mean annual rainfall of 965 mm. The area is characterised by the seven species of mangroves, viz. white mangroves (*Avicennia marina*), black mangroves (*Bruguiera gymnorhiza*), tagal mangroves (*Ceriops tagal*), red mangroves (*Rhizophora mucronata*), apple mangroves (*Sonneratia alba*) and cedar mangroves (*Xylocarpus granatum*) (Gwambene and Karata 2019). The first three species of mangroves (black, white and tagal mangroves), which are extremely common, were the subject of the current study. The main economic activities practised in the selected experimental sites include fishing, crop cultivation, livestock keeping, mariculture, charcoal burning, timber sawing and tourism, which are thereafter considered the major anthropogenic activities (Lugendo and Kimirei 2021). Therefore, the selection of the experimental sites was due to the existence of these anthropogenic activities.

Experimental design

The field experiment was conducted using a completely randomised design (CRD) as the most reliable and flexible method that provides a larger number of degrees of freedom for the error source of variation. Three rectangular plots of 30×20 m were randomly established along the coast of Mbegani. Five individuals of each mangrove species, viz. *A. marina*, *C. tagal* and *B. gymnorhiza*, were chosen at random for each plot for the experimentation. As suggested by Gbarakoro and Okene (2020), macro-invertebrates associated with the three species of mangrove trees were visually inspected.

Data collection

Sampling of macro-invertebrates

Macro-invertebrates were purposively taken from the three mangrove tree species that were chosen. To examine the abundance, diversity and distribution of macro-invertebrates, visual observations were done on the roots, stems and leaves of each mangrove tree that was chosen (Fig. 1). For the targeted macro-invertebrates, the three mangrove sections were thought to be hotspot sites. A 1 m² quadrat was positioned over each of the selected mangrove parts as suggested by Johnson et al. (2023). The macro-invertebrates that moved within each quadrat were all closely examined and their statistics were recorded individually to determine the indicators of species abundance and diversity. Six quadrats were used to assess the abundance and distribution of macro-invertebrates. Three quadrats were positioned on the sunny, southern side and the remaining three on the shady, northern side. The positions of the quadrats were maintained throughout the study.



Fig. 1 A schematic representation of some macro-invertebrates sampled on the three mangrove parts at Mbegani coast

Sorting and identification of macro-invertebrates

The sampled macro-invertebrates were identified to species level in situ. The contents of each quadrat were rinsed with distilled water and sieved with a 250 µm mesh. Macro-invertebrate specimens were separated from other arthropods and then sorted into morphospecies using a dissecting microscope at 7× magnification. All macro-invertebrate specimens were stored in a mixture of 70% ethanol and 5% glycerol. Species that were difficult to identify in the field were photographed and later sent to the Department of Biology, University of Dodoma, for further identification. The identification of macro-invertebrates was done using a guidebook with the aid of taxonomic keys and dissecting microscope as recommended by Macpherson et al. (2020). To classify the macro-invertebrates that were sampled, visible morphological characteristics such as body segmentation, appendages, mouth parts and antennae were utilised.

Data analysis

Data were analysed using SAS software version 9.3 (SAS Institute Inc 2011). A generalised linear model (GLM) procedure was used for the analysis. The composition of macro-invertebrate species inhabiting roots, stems and leaves of the selected mangrove tree species was compared using Jaccard's index of similarity (Magurran 1988). Shannon–Wiener index of diversity was used to assess the diversity of the macro-invertebrates on roots, stems and leaves of the selected mangrove trees as recommended by Keerthana et al. (2023). To ascertain the mean difference between mangrove species, mangrove components and their interactions, analysis of variance (ANOVA) was employed.

Similarly, the least significant difference (LSD) test was used to separate means at a significance level of 5%.

Results

Abundance of macro-invertebrates

The study analysed the abundance of macro-invertebrates in three mangrove species along the coast of Mbegani. A total of 20,280 macro-invertebrates were sampled in the chosen mangrove species. The greatest number 13,540 (66.8%) was found on *B. Gymnorhiza*, followed by *A. Marina* 4,220 (20.8%), and the least on *C. tagal* 2,520 (12.4%) (Fig. 2). Abundance varied considerably between the three mangrove species through the selected plots ($F_{(2,524)} = 5.71$, $p = 0.035$). In terms of mangrove parts, high numbers have been recorded on the stems 11,031 (54.4%), followed by roots 6651 (32.8%) and the least on the leaves 2598 (12.8%) (Fig. 3). The abundance of macro-invertebrate species differed

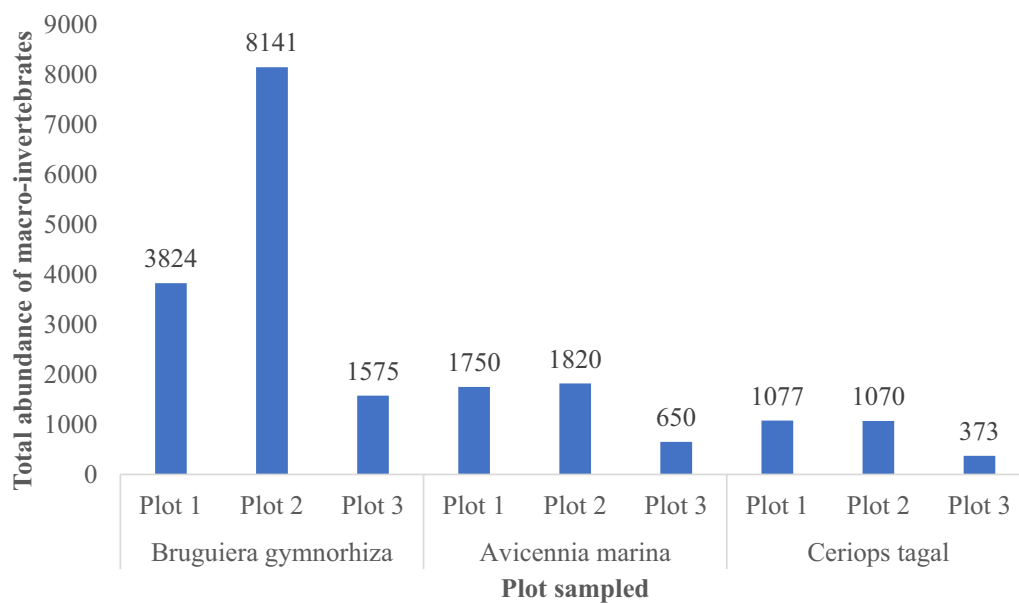


Fig. 2 Abundance of macro-invertebrates sampled on the three mangrove species in the selected plots

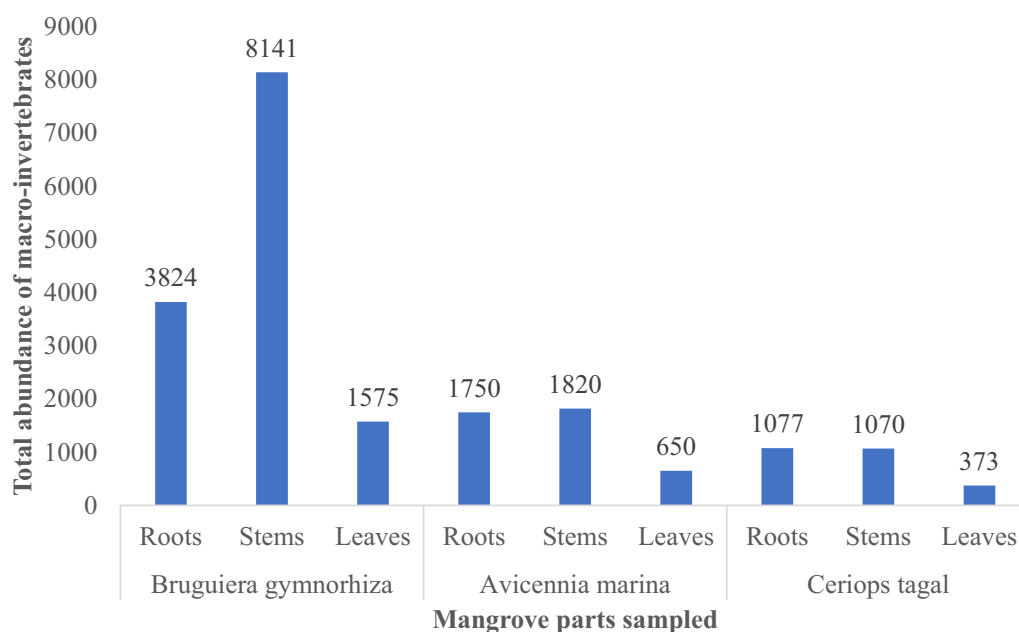


Fig. 3 Abundance of macro-invertebrates sampled on the three mangrove parts of the selected species

substantially among the three mangrove sections sampled (roots, stems and leaves) ($F_{(2,524)} = 7.25$; $p = 0.008$).

The most abundant species were *Phasianella nivos*a and oysters, recorded on the stems, while the least were *Littoraria glabrata*, *L. undulata* and *Metopograpsus messor*, recorded on the leaves and roots. The abundance of macro-invertebrates varied considerably between mangrove species and their parts in

all sampled plots (Figs. 4, 5 and 6) ($F_{(30,524)} = 9.79$, $p < 0.0001$).

Similarity and diversity of macro-invertebrates

The study also sampled different macro-invertebrate species of six orders: Decapoda, Pterioda, Caenogastropoda, Littorinimorpha, Neogastropoda and Trochida. The results have shown that the similarity of the composition

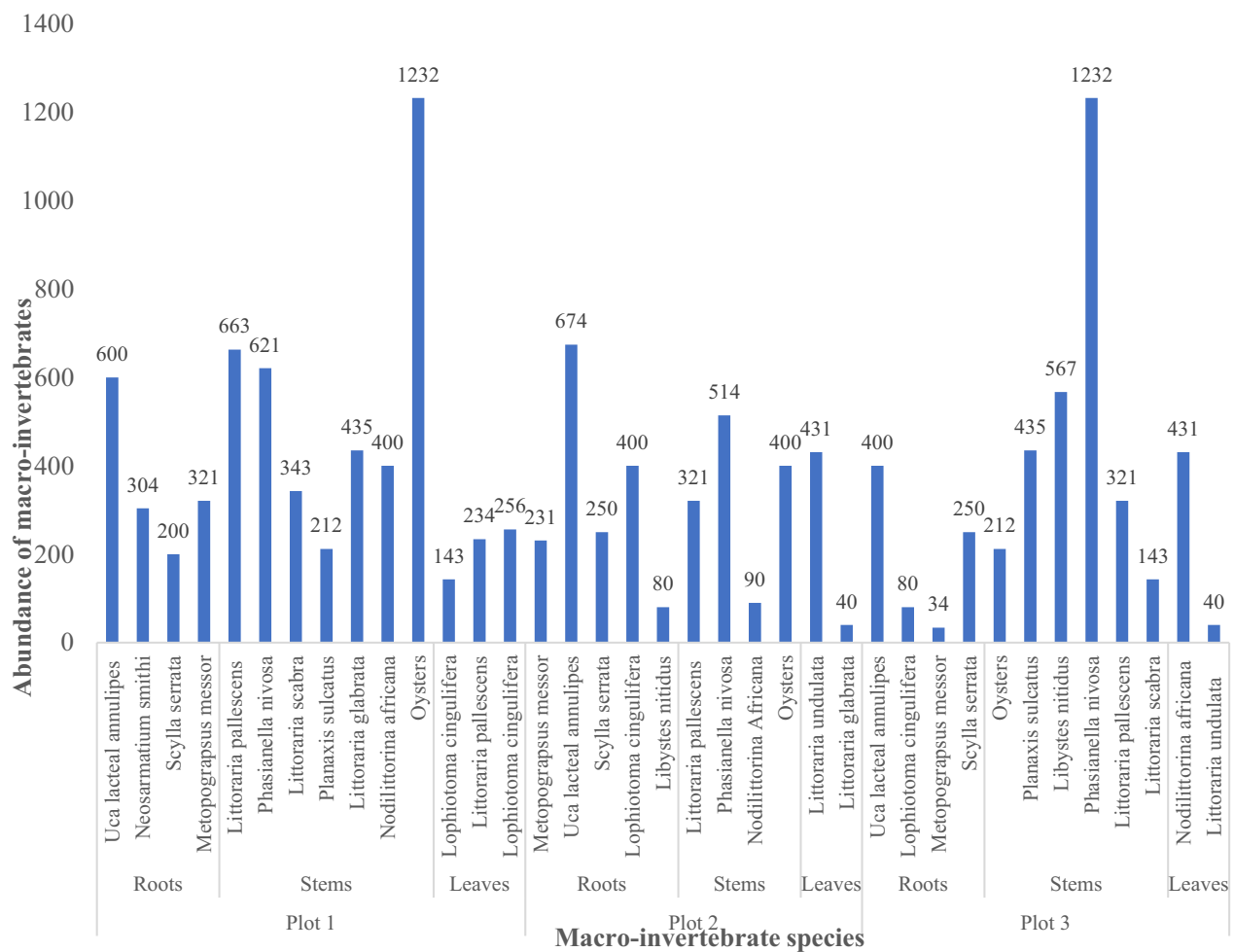


Fig. 4 Abundance of macro-invertebrate species sampled on *Bruguera gymnorhiza* parts in the selected plots at Mbegan

of macro-invertebrate species was higher on the stems/leaves (30%) than on the roots/stems (7.1 to 7.7%). The most similar macro-inverts have been found on the stems and leaves, the least similar being on the roots and the stems.

The diversity of macro-invertebrate species was significantly different ($p < 0.05$) between the three mangrove species. The average diversity indices of macro-invertebrate species were 2.1 ± 0.07 , 2.2 ± 0.04 and 2.3 ± 0.03 for *B. gymnorhiza*, *A. marina* and *C. tagal*, respectively (Table 1). However, no significant difference was observed when macro-invertebrates were sampled in three plots submitted to a multiple comparisons test.

Discussion

Abundance of macro-invertebrates

The study found a high abundance of macro-invertebrates in mangroves, likely due to their feeding habits and the mangrove canopy that provides them shade and

shelter. Roots and stems were the most habitable parts, with most macro-invertebrates being suspension feeders feeding on detritus and plankton. Most herbivorous crabs prefer the leaves of *B. gymnorhiza* and *A. marina*, moving towards the canopy for the tender leaves. Our results are in agreement with Oester et al. (2022) who found that leaves serve as a source of energy for survival, growth and reproduction for different species of macro-invertebrates. Mangrove canopy also provides shade and shelter to macro-invertebrates as they occupy higher canopy and roots during times of danger and are safer, respectively (Aung 2022). The low abundance of macro-invertebrates could be attributed to sampling carried out in the morning during the rainy season, at low tide. Herbivorous macro-invertebrates may add organic matter to the lower parts of mangroves to support abundant suspension feeders, particularly detritivores in the roots. This implies that some other herbivorous macro-invertebrates were not at high canopy during the sampling

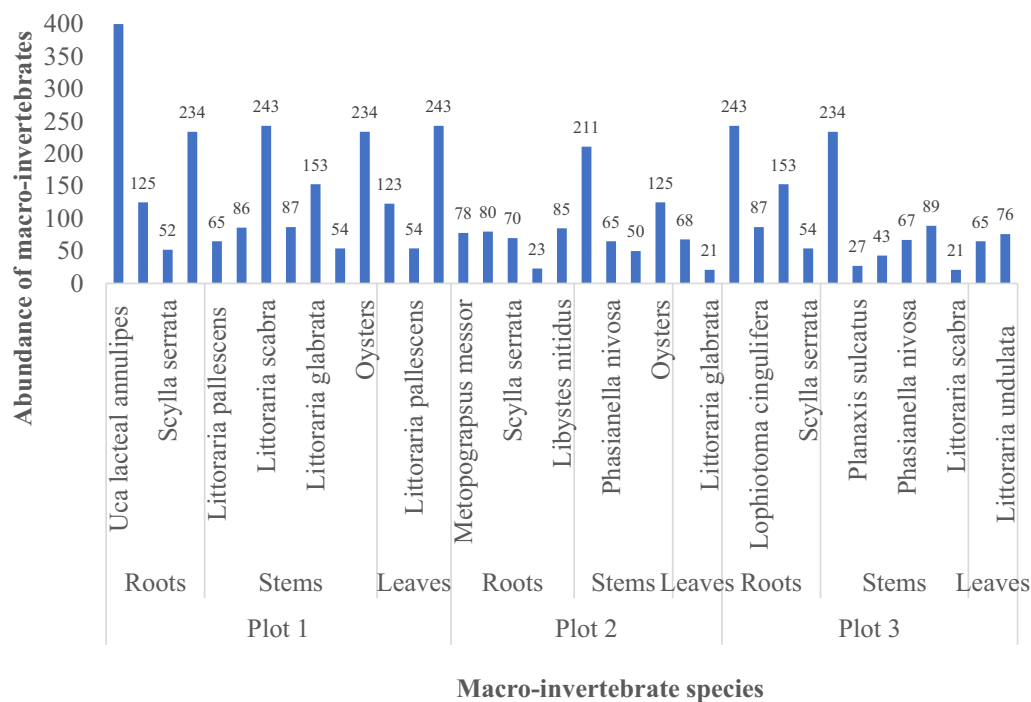


Fig. 5 Abundance of macro-invertebrate species sampled on *Avicennia marina* parts in the selected plots at Mbegani

period. Our results are in agreement with Tokan et al. (2018) who reported that the positioning of macro-invertebrates such as gastropods in high canopy took place during high tide.

This was also reported in different coastlines whereby sediments of *Cerriops* mainly contributed to the organic content of the mangroves (Macintosh and Ashton 2023). In this study, *Uca lacteal annulipes* were recorded abundantly on the roots of the selected mangrove trees. Yet it was reported that *Uca lacteal* was found exclusively in areas where mangroves were removed (Hilaluddin et al. 2020). This implies the decline of mangroves and the need to take immediate intervention measures to conserve this endangered species. The study conducted by Zilius et al. (2020) also showed that members of the genus *Uca* are mainly detritivores. Small-sized crabs tend to be favoured by large-sized pneumatophores and vice versa. The composition of macro-invertebrates is similar to other studies, with some species being by-passers. In this study, members of *Littoraria* were only recorded on the stems and leaves of the selected mangrove species. Littorarians are among the few molluscs mainly associated with mangroves but tend to be translocated from mangroves by living in intertidal anthropogenic substrates (Ramos et al. 2021). Our results on the composition of macro-invertebrates are in agreement with Rumisha et al. (2015) who reported that the mangroves in the coast of Dar es Salaam were dominated by the three species of molluscs,

viz. *Cerithidea decollata*, *Dosinia hepatica* and *Eumarcia paupercula* and two species of crustaceans *Neosarmatium africanum* and *Uca annulipes*.

Similarity and diversity of macro-invertebrate species

The results on the similarity of macro-invertebrate species suggest a resemblance between stem and leaf dwellers. This could be explained by the constant movement of the macro-invertebrates between the two mangrove parts. Shuttling of macro-invertebrates between the lower parts of mangroves and canopy was also observed during the day and night as a mechanism of avoiding desiccation due to the high temperature of the day and vice versa. Leaves of mangroves are leathery and glossy without self-shading because they are oriented at 180° (Dookie et al. 2023). The unique features of leaves enable mangroves to cope with shifting environmental conditions while preserving their general functionality and efficiency. However, some crabs get water in aerial parts of mangroves specifically from water trapped near leaf buds in scales (Bućan and Meliša 2023).

The diversity of macro-invertebrates in mangrove ecosystems depends on the chances of establishment, the nature of the substratum and the level of waves and tides apart from current levels (Kumar and Khan 2013). The diversity of macro-invertebrates in the study area suggests moderate pollution, with values between 1 and 3 indicating high pollution and above 3

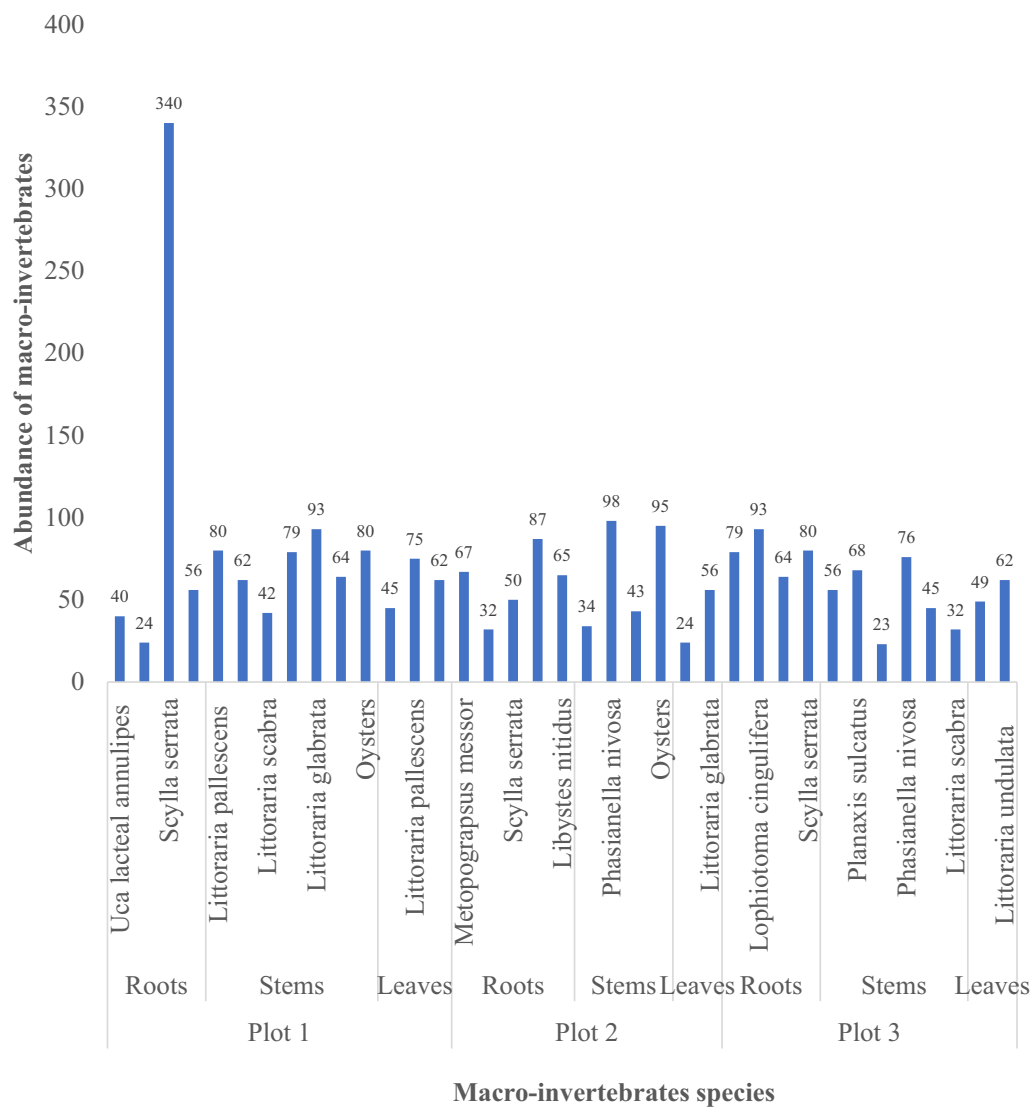


Fig. 6 Abundance of macro-invertebrate species sampled on *Ceriops tagal* parts in the selected plots at Mbegani

Table 1 Diversity of macro-invertebrates for the three mangrove species against their parts and plots (diversity with the same letters is not significantly different)

Mangrove species	Mangrove parts			Plots		
	Roots	Stems	Leaves	Plot 1	Plot 2	Plot 3
<i>B. gymnorhiza</i>	2.34a±0.007	2.34a±0.03	2.37a±0.01	2.34a±0.00005	2.20a±0.00008	2.13a±0.0002
<i>A. marina</i>	1.93b±0.06	2.12b±0.01	2.22b±0.004	2.29a±0.0002	2.22a±0.0003	2.24a±0.0003
<i>C. tagal</i>	1.97c±0.05	2.14c±0.02	2.29c±0.008	2.22a±0.0005	2.31a±0.0003	2.43a±0.0002

indicating unpolluted habitats. According to the study done by Kumar and Khan (2013), values less than 1 for H' indicate heavy pollution; values between 1 and 3 suggest moderate pollution, while above 3 signify non-polluted habitats. Similar diversity indices were

reported in India and the Persian Gulf, which ranged between 1.83 and 3.83 revealing moderate pollution (Kumar and Khan 2013; Hajializadeh et al. 2020). The study sampled benthic macro-invertebrates belonging to different orders of the phyla Annelida, Mollusca

and Arthropoda, mainly crustaceans. The results are consistent with previous studies conducted in the Philippines and India, which reported similar diversity indices Li et al. (2022) who sampled similar groups of crustaceans, molluscs, polychaetes and oligochaetes, which were dominated by gastropods, decapods and tanaidaceans. In the same vein, elsewhere in Philippines, the macro-invertebrates sampled were composed of echinoderms such as lagoon brittle star (*Ophiocoma scolopendrina*) and sea cucumber (*Holothuria pulla*) (Zou et al. 2008). Our findings are also in agreement with Alfaro (2010) who reported macro-invertebrates species such as *Afrolittorina africana*, *Agagus agagus*, *Akera soluta*, *Amaea acuminata*, *Amaea* sp., *Architectonica perspectiva*, *Bulla ampulla*, *Cerithidea decollate*, *Cerithium caeruleum* in mangroves along the coast of Dar es Salaam.

Conclusions

A study on the abundance of macro-invertebrates in three mangrove species on the Mbegani coast found that the most abundant species were found on *B. gymnorhiza*, followed by *A. marina*, and the least on *C. tagal*. Abundance varied considerably between species and their parts. The most abundant species were *Phasianella nivosa* and Oysters, recorded on stems, while the least were *Littoraria messor*, *L. undulata* and *Metopograpsus*, recorded on leaves and roots. Macro-invertebrate species diversity was significantly different between the three species, with the most similar species found on stems and leaves. The study also found that macro-invertebrate diversity in mangrove ecosystems depends on factors such as the chance of establishment, substrate type and wave and tide levels. It can be concluded that the Mbegani mangrove ecosystem has high potential in biodiversity and is significantly important to the coastal community and economy of Bagamoyo District. The results of this study contribute to coastal resource management programmes and future monitoring activities. This study provides baseline information on the biodiversity of macro-invertebrates; there is a need, however, to study in-depth about their interactions. This may contribute to a better understanding of the ecological sound management of the mangrove resources along the coastal areas of the western Indian Ocean.

Abbreviations

ANOVA	Analysis of variance
CRD	Completely randomised design
LSD	Least significance difference
MUCE	Mkwawa University College of Education
SAS	Statistical analysis system
UDOM	University of Dodoma

Acknowledgements

The authors acknowledge the administration of Bagamoyo district for providing permission to conduct field experiments. The second and third authors express their gratitude to UDOM for making this study possible.

Author contributions

MO prepared the manuscript and approved the submitted version, NM contributed substantially to the research design and review process while AS participated in data collection and analysis. All authors have read and approved the final manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

Availability of data and materials

We understand that this information will be freely available online, and accessible to the general public. Data and materials are available and stored at the University of Dodoma.

Declarations

Ethics approval and consent to participate

This study adhered to the National Research Policy and Operational Guidelines. Thus, the researchers involved in designing the study, collecting and analysing the data and producing this manuscript followed all ethical research conducts.

Consent for publication

We hereby provide consent for the publication of the manuscript detailed above, including any accompanying images or data contained within the manuscript that may directly or indirectly disclose our identity.

Competing interests

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript.

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Received: 18 March 2024 Accepted: 22 July 2024

Published online: 13 August 2024

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