

Variation in Community Structure and Mollusk Diversity in Several Mangrove Ecosystems on the Northern Coast of East Java

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ABSTRACT

This study aims to analyze the variation in community structure and mollusk diversity in several mangrove ecosystems along the northern coast of East Java. Mollusk samples were collected from five different locations: Pasuruan, Probolinggo, Gresik, Tuban, and Banyuwangi, using purposive sampling with transect and plot sampling methods. The tools used included raffia string, transects, shovels, tape measures, writing instruments, thermometers, pH meters, and a Microsoft Excel 2010 working sheet. Physical and chemical water parameters such as salinity, pH, temperature, and water clarity were measured to identify environmental factors influencing mollusk distribution. The results showed that the Mangrove Center in Banyuwangi had the highest mollusk diversity, while the Mangrove Center in Tuban showed a lower and more uniform diversity. Principal Component Analysis (PCA) indicated that salinity, dissolved oxygen, and water temperature are major factors influencing mollusk community variation at the study locations. These findings provide insights into the importance of suitable environmental conditions to support mollusk diversity in mangrove ecosystems.

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1. INTRODUCTION

Mangroves are unique coastal vegetation that thrive in tidal muddy areas, playing vital ecological and economic roles. These ecosystems act as natural barriers, protecting coastlines from erosion caused by waves and tides, while also shielding coastal areas from the devastating impacts of large waves, storms, and tsunamis (Searly et al., 2021; Asari et al., 2021). Indonesia, recognized as the largest archipelagic nation globally, boasts extensive mangrove forests, covering approximately 3.3 million hectares. This area constitutes about 24% of the world's total mangrove ecosystems, as reported by the Ministry of Environment and Forestry in 2021 (Permana et al., 2024). The significance of these mangrove forests extends beyond their sheer size; they play a vital role in supporting biodiversity, protecting coastal areas, and mitigating climate change impacts. These mangroves are distributed across various provinces and islands, making Indonesia's mangrove ecosystems significant not only regionally but also globally (Naibaho et al., 2022). These vast mangrove forests provide critical benefits, from stabilizing shorelines to offering habitats for numerous marine species. Furthermore, they act as carbon sinks, sequestering large amounts of carbon dioxide, which helps mitigate climate change effects. Despite their critical importance, these ecosystems face numerous threats from human activities, such as deforestation, coastal development, and aquaculture, as well as natural factors like rising sea levels.

Among the many organisms that depend on mangroves, mollusks stand out as essential components of these ecosystems. Mollusks, which include species such as clams, snails, and mussels, play critical roles in maintaining the ecological balance within mangrove forests. Acting as filter feeders, mollusks contribute to the purification of water by filtering out suspended particles, thereby improving water quality. This process not only benefits the mangroves themselves but also supports other aquatic organisms that rely on clean water. Mollusks are also an integral part of food webs, serving as a source of nutrition for a variety of predators, including fish, crabs, and birds. Additionally, mollusks provide habitats and substrata for other benthic organisms, enhancing biodiversity within mangrove ecosystems. Their presence and abundance are often used as biological indicators to assess the health and stability of mangrove environments (Renda et al., 2022). When mollusk populations thrive,

it often reflects the overall well-being of the ecosystem, while their decline can signal environmental stress or degradation.

Indonesia's northern coast of East Java, which directly faces the Java Sea, is one of the regions where mangroves play a crucial protective role. However, this area is highly susceptible to coastal abrasion, a process in which land along the shoreline is eroded by wave action, tidal forces, and currents. Abrasion poses a significant threat to both the mangrove forests and the communities that depend on them for livelihood and coastal protection. The loss of mangroves not only exacerbates erosion but also diminishes their capacity to support mollusk populations, leading to a cascading effect on biodiversity and ecosystem functions. Research on the variations in mollusk community structure and diversity across different mangrove ecosystems in this region is vital. Such studies provide insights into the resilience and adaptability of mangrove ecosystems under stress, while also helping to identify conservation priorities. By understanding the relationship between mangrove health and mollusk diversity, conservation strategies can be better tailored to ensure the sustainability of these critical ecosystems. This approach not only contributes to biodiversity conservation but also ensures the protection of the vital ecological services that mangroves provide to coastal communities. Mangroves are critical ecosystems that contribute significantly to biodiversity conservation and the provision of essential ecological services to coastal communities. They serve as vital habitats for numerous marine species, with approximately 90% of marine organisms relying on mangroves at some stage of their life cycle, and about 80% of global fish catches being dependent on these ecosystems (Beys-da-Silva et al., 2014). Furthermore, mangroves enhance biodiversity through their complex structures, which support various macrobenthic communities, thereby promoting ecological resilience (Chen et al., 2023).

In Indonesia, the northern coast of East Java, which directly faces the Java Sea, is one of the coastal areas prone to abrasion. Coastal abrasion, which refers to the process of land erosion along the shoreline due to wave action, currents, and tidal movements, poses a serious threat to the sustainability of mangrove ecosystems in the region (Sahidin et al., 2020). Research on the variations in community structure and mollusk diversity across different mangrove ecosystems on the northern coast of East Java is crucial to understanding ecosystem dynamics and supporting evidence-based conservation efforts. By uncovering the relationship between mangrove ecosystem conditions and mollusk communities, this study aims to provide tangible contributions to preserving the strategic coastal ecosystems in this area.

2. RESEARCH METHOD

Research Time and Location

This research was conducted from January to July, with mollusk samples collected from five beaches along the northern coast of East Java Province, Indonesia. The selected locations include Mangrove Center Pasuruan (Nguling), Mangrove Center Tuban (Jenu), Mangrove Center Probolinggo (Randutatah), Mangrove Center Gresik (Mengare), and Mangrove Center Banyuwangi (Baluran National Park). The selection of these sites was based on their varying levels of anthropogenic influence, mangrove forest coverage, and ecological conditions, which allow for a comparative analysis of mollusk community structures in different environmental settings. These locations also represent key conservation and restoration areas, providing insights into how different mangrove management strategies impact biodiversity and ecosystem function. Environmental parameters were analyzed at the Ecology and Tropical Ecosystem Restoration Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Brawijaya University.

Description of Sampling Sites

The study focused on five mangrove centers along East Java's northern coast, each exhibiting unique ecological and anthropogenic characteristics. For example, Nguling Sub-district in Pasuruan has undergone significant mangrove expansion, increasing from 3.5 hectares in 1985 to 84.6 hectares in 2005, predominantly in Penunggul Village. This transformation resulted from community-driven conservation efforts, which helped restore degraded areas that were previously impacted by shrimp farming and coastal erosion. This restoration has not only enhanced biodiversity but also provided coastal protection, increased fishery production, and improved local livelihoods (Ihinegbu et al., 2023).

Data Collection and Analysis

This study employed an ex post facto research design to assess mollusk diversity, habitat conditions, and environmental influences. To ensure comprehensive data representation, three sampling stations were established within each site, capturing different levels of anthropogenic influence and environmental variation.

Mollusk Sampling Techniques

Mollusk samples were collected using quadrant transect sampling, a widely used method for benthic organism studies. At each station, five quadrats (1 m² each) were randomly placed along a 50-meter transect, covering areas with dense, moderate, and sparse mangrove vegetation. The mollusks within each quadrat were

carefully collected by hand and sieved through a 1 mm mesh sieve to retain smaller specimens. Specimens were then preserved in 70% ethanol for further identification. Mollusks were identified to the species level based on shell morphology, including: Shape, color, and radial ribs, internal features such as hinge and pallial lines (Carpenter & Niem, 1998), diversity indices were calculated to assess mollusk biodiversity, including:

Taxa richness (S) and the Shannon-Wiener Diversity Index (H') were calculated to assess mollusk biodiversity. Environmental parameters were analyzed both in situ and ex situ to evaluate habitat conditions. Water quality parameters, including temperature (measured with a thermometer), dissolved oxygen (DO) (measured with a DO meter), salinity (measured using a refractometer), and pH (measured using a portable pH meter), were recorded at each station using calibrated probes. To assess nutrient availability and sediment characteristics, chemical and sediment samples were collected for ex situ analysis, where phosphate and nitrate concentrations were measured using spectrophotometry techniques, and sediment grain size analysis was conducted through dry sieving and hydrometer methods.

Data Analysis Techniques

To identify environmental drivers influencing mollusk distribution, a Principal Component Analysis (PCA) was conducted to reduce correlated environmental variables into independent components for further analysis (Ceuro et al., 2021; Toosi et al., 2022). PCA helped in identifying key environmental factors shaping mollusk community structures across different mangrove sites.

3. RESULT AND DISCUSSION

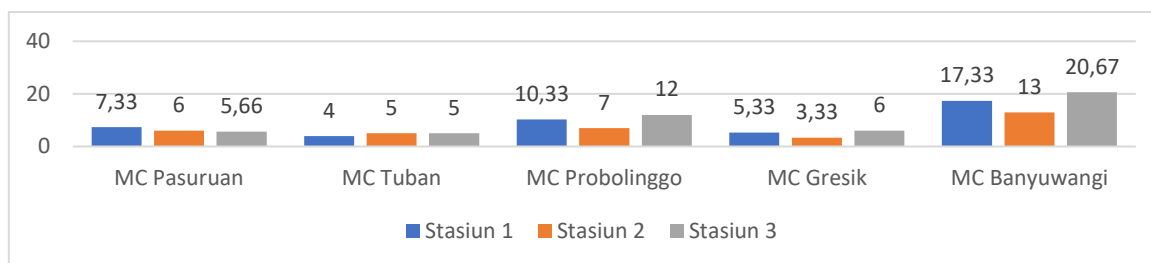


Figure 1. Mollusk Species Diversity

The data presented in Figure 1 indicates that the Pasuruan location (MC Pasuruan) at Station 1 has the highest biodiversity index (7.33), followed by Station 2 (6) and Station 3 (5.66). These values are relatively close to each other, suggesting a similar level of biodiversity across all stations. In contrast, Tuban (MC Tuban) shows uniform biodiversity across its stations, with both Station 1 and Station 3 having a biodiversity index of 5, while Station 2 is slightly lower at 4. This uniformity suggests a more consistent biodiversity profile across Tuban's locations. Probolinggo (MC Probolinggo) presents the highest biodiversity index at Station 3 (12), followed by Station 1 (10.33) and Station 2 (7), showing more variation in biodiversity compared to the other locations.

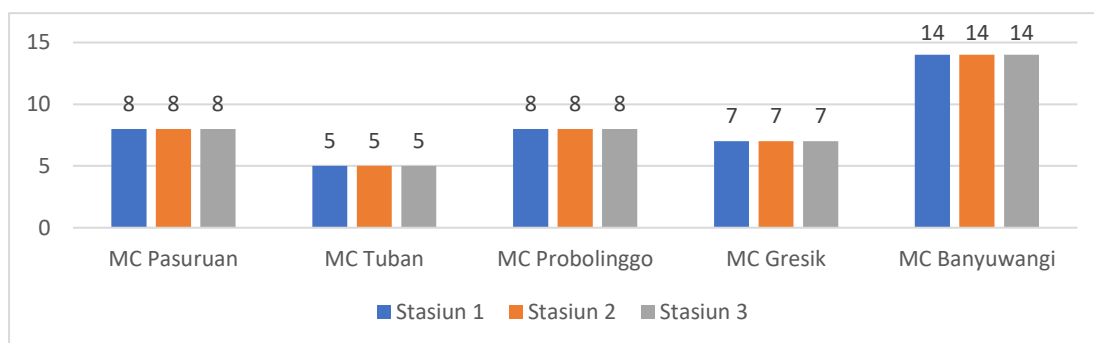


Figure 2. Taxa Richness

Taxa richness, defined as the number of different species in a given area (de Oliveira et al., 2020), is depicted in Figure 2. It does not consider species abundance but instead focuses on species diversity. At MC Pasuruan, all three stations (Station 1, Station 2, and Station 3) show the same taxa richness of 8, indicating uniform species richness across the stations within this area.

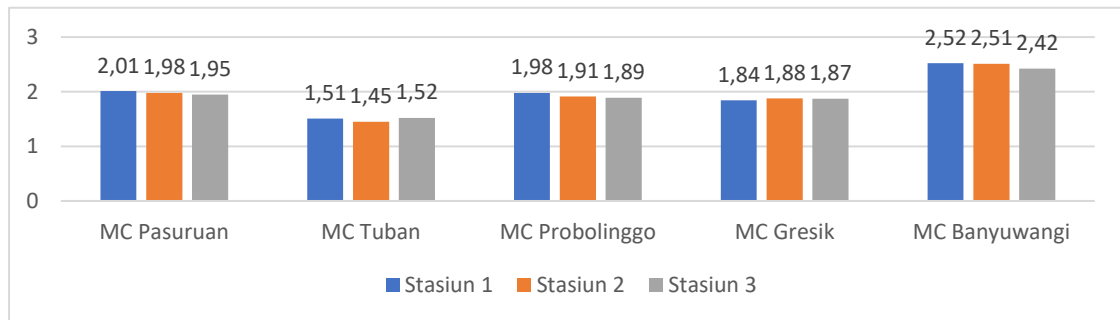


Figure 3. Mollusk Species Diversity Index at Various Beaches in North Java

Figure 3 highlights the diversity index for mollusks at several beaches along North Java. In Pasuruan, Station 1 has the highest diversity index (2.01), followed closely by Station 2 (1.98) and Station 3 (1.95), showing relatively high and consistent diversity. MC Tuban exhibits lower diversity indices, with Station 3 being the highest at 1.52, followed by Station 1 (1.51) and Station 2 (1.45). The proximity of these values suggests lower biodiversity across Tuban's stations compared to Pasuruan. In MC Probolinggo, Station 1 has the highest diversity index (1.98), followed by Station 2 (1.91) and Station 3 (1.89), reflecting a similar pattern of moderate diversity across all stations.

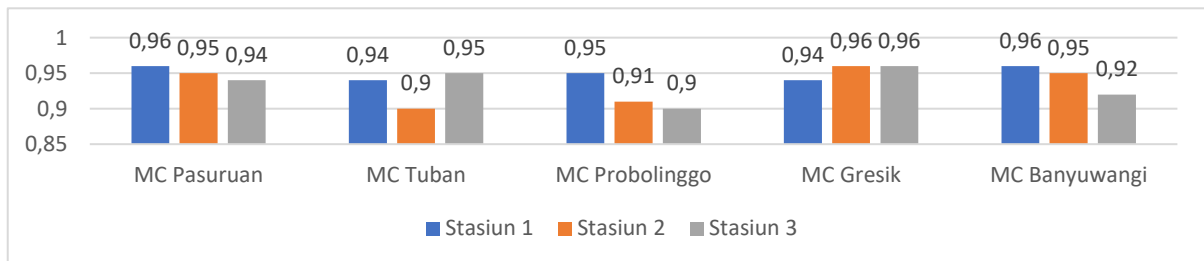


Figure 4. Evenness Index of Mollusk Species at Various Beaches in North Java

The Evenness Index (or species evenness) provides an indication of species dominance in a community (Latumahina et al., 2020). Figure 4 demonstrates that MC Pasuruan shows similar evenness values across its stations, with Station 1 at 0.96, Station 2 at 0.95, and Station 3 at 0.94, suggesting a balanced distribution of species. In contrast, the dominance index of mollusks across different beaches varies significantly, as seen in Figure 5.

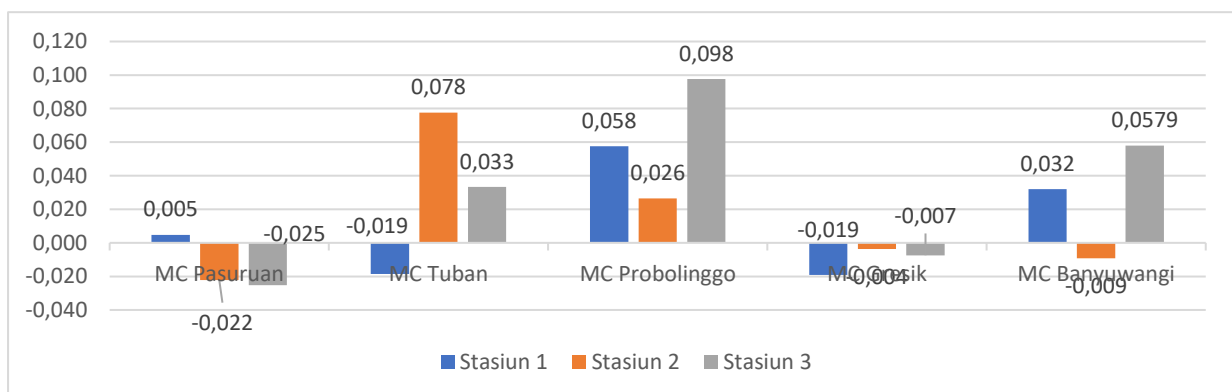


Figure 5. Mollusk Species Dominance Index at Various Beaches in North Java

The dominance index reveals variations in species dominance at different stations. In Pasuruan, Station 1 shows a low positive dominance index (0.005), while Stations 2 and 3 have negative values (-0.024 and -0.025), indicating a lack of dominance by any specific species. Tuban's Station 2, however, exhibits the highest dominance index (0.078), followed by Station 3 (0.033), while Station 1 shows a negative value (-0.019). In

Probolinggo, Station 3 has the highest dominance index (0.098), indicating a very high dominance of certain species, while Stations 1 and 2 exhibit lower positive values (0.058 and 0.026), reflecting less dominance.

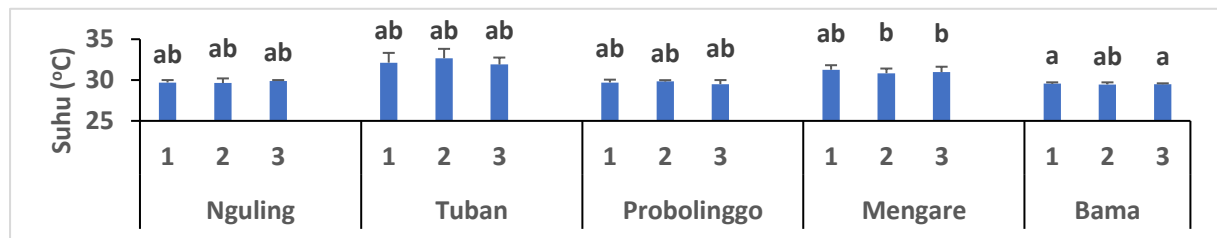


Figure 6. Average Water Temperature at Various Beaches in North Java

The average water temperature in mangrove ecosystems typically ranges from 25°C to 32°C, influenced by geographical location, season, and environmental conditions. Figure 6 displays the average water temperatures at various beaches along North Java, indicating that the temperature falls within this general range, affecting the ecological conditions and species distribution in the area.

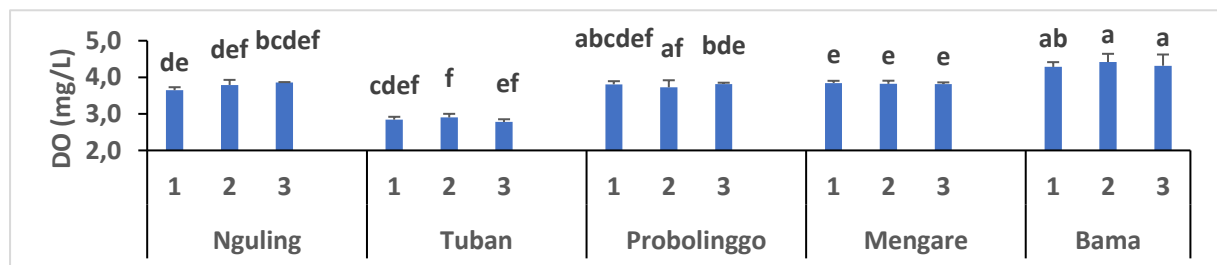


Figure 7. Average Dissolved Oxygen (DO) Levels at Various Beaches in North Java

Dissolved Oxygen (DO) levels in mangrove ecosystems usually range between 3 and 7 mg/L, depending on factors such as salinity, temperature, tides, and microbial activity (Wailisa et al., 2022). Figure 7 presents the average DO levels, showing that Nguling exhibits a range between 3.5 and 4.0 mg/L, with statistical analysis indicating significant differences between measurement points.

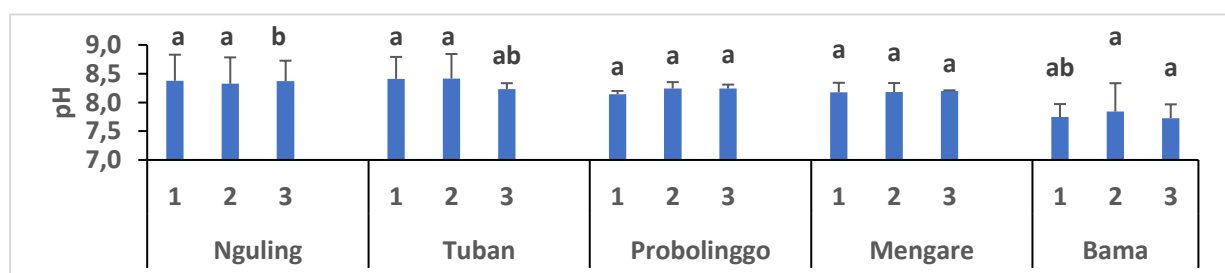


Figure 8. Average pH Levels at Various Beaches in North Java

The average pH in mangrove ecosystems typically ranges from 6.5 to 8.5, leaning towards slightly acidic to neutral conditions (D'Souza et al., 2022). Figure 8 shows that Nguling and Tuban have pH levels ranging from 8.0 to 8.6, while Probolinggo's pH is more stable across all stations within the same range. Mengare also maintains a stable pH between 8.2 and 8.6, showing no significant differences between its measurement points.

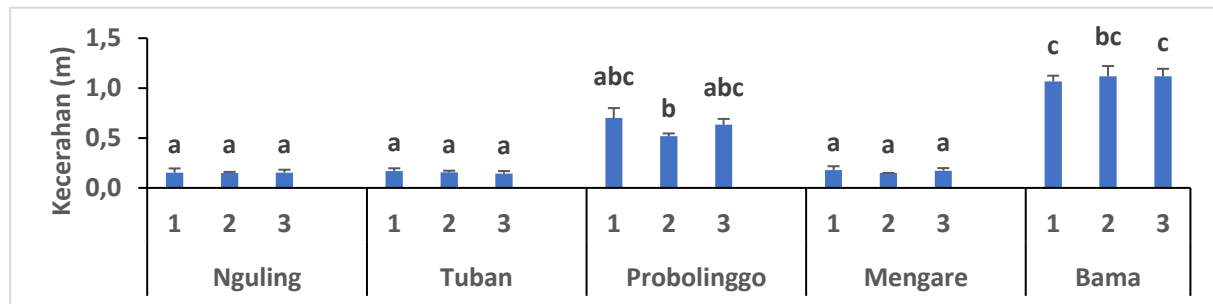


Figure 9. Average Water Clarity at Various Beaches in North Java

Water clarity in mangrove ecosystems typically ranges between 10 to 100 cm. The clarity affects mollusk diversity, as light penetration is vital for habitat quality (Pruden et al., 2021). Figure 9 shows that Nguling has relatively low water clarity, with all stations (1, 2, and 3) reporting an average of 0.2 meters. This low clarity could potentially impact mollusk species in the area.

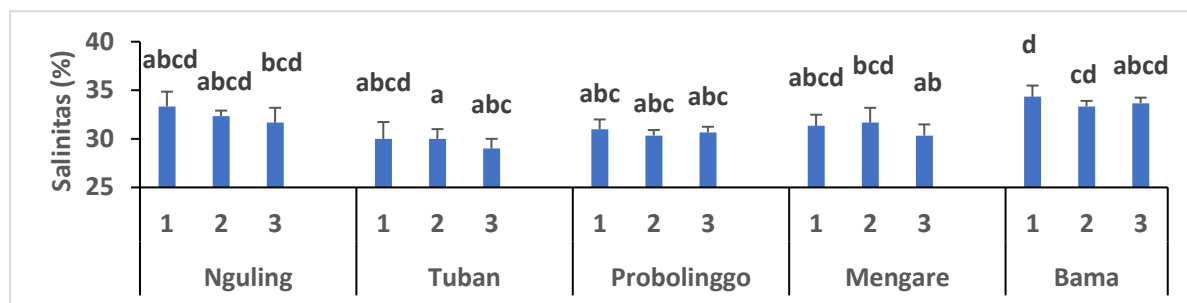


Figure 10. Average Salinity Levels at Various Beaches in North Java

Salinity levels in mangrove ecosystems generally range from 5 to 35% ppm, influencing species diversity, as different mollusk species have varying salinity tolerances (De Jesús-Carrillo et al., 2020). Figure 10 shows that salinity levels in the mangrove ecosystems of the northern Java beaches are consistent across the stations, affecting species distribution and behavior in these environments.

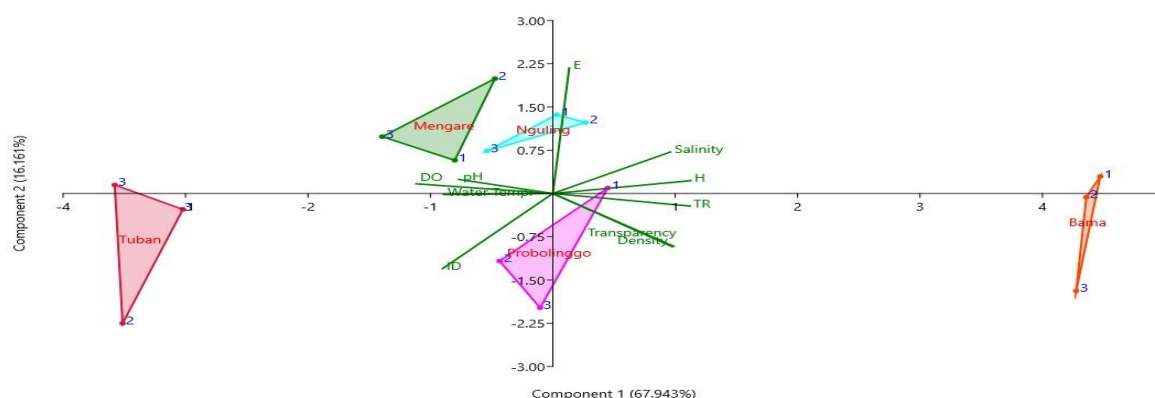


Figure 11. Principal Component Analysis (PCA) of Several Northern Beaches in East Java

The Principal Component Analysis (PCA) conducted on the mollusk communities in various mangrove ecosystems along the northern beaches of East Java provides a comprehensive understanding of how biotic factors influence community structure and diversity. The analysis revealed that the first two principal components account for approximately 84% of the total variation, with Component 1 explaining 67.943% and Component 2 accounting for 16.161% of the variance (Bai et al., 2021). This significant proportion underscores the importance of identifying the key environmental variables that shape mollusk diversity in these ecosystems.

The positive quadrant of Component 1 is dominated by biotic variables such as salinity, dissolved oxygen (DO), pH, and water temperature, which are critical in determining the variability of mollusk communities at specific locations, particularly Bama and Nguling (Taketani et al., 2018). These findings are consistent with previous research indicating that salinity and DO levels are vital in structuring mollusk communities in mangrove habitats (Yuan et al., 2023). The favorable conditions at Bama, characterized by high salinity, DO, and pH, suggest that these factors create an environment conducive to greater mollusk diversity. Conversely, Tuban, located on the negative side of Component 1, exhibits lower biotic values, which may correlate with reduced mollusk diversity and altered community structures (Zhang et al., 2021).

The analysis also highlights the role of transparency and density, particularly at the Probolinggo location, where these factors appear to exert a more substantial influence on mollusk communities. This observation may relate to murkier water conditions or specific community compositions that favor certain mollusk species (Li et al., 2022). The Evenness Index (E) and Shannon-Wiener Diversity Index (H') are positioned closer to Nguling and Mengare, indicating higher biodiversity and ecosystem stability in these areas compared to others. This suggests that locations with optimal biotic conditions are more likely to support diverse and stable mollusk communities (Cheung et al., 2018).

Nguling and Mengare's positioning towards the positive side of Component 2 further emphasizes the influence of pH and DO on biodiversity. These biotic factors likely contribute to more stable habitats, allowing for increased species richness and evenness (Basyuni et al., 2024). In contrast, Probolinggo's intermediate position among the biotic factors indicates that transparency and density play a more prominent role in shaping its mollusk community structure, aligning with research that emphasizes the importance of water clarity and nutrient levels in mangrove ecosystems (Yulianda et al., 2019).

Overall, the PCA results illustrate that the variation in community structure and mollusk diversity across these mangrove locations is strongly influenced by biotic factors such as salinity, dissolved oxygen, pH, water temperature, and transparency. Locations with optimal conditions for these parameters, like Bama, tend to exhibit higher mollusk diversity, while areas like Tuban, with less favorable environmental conditions, may experience reduced diversity (Michaud et al., 2022). This relationship between biotic variables and mollusk communities provides valuable insights into how these organisms adapt to environmental changes in mangrove ecosystems, reinforcing the ecological significance of biotic factors in shaping community structures (Lu et al., 2022).

The implications of these findings extend beyond mere academic interest; they highlight the necessity for effective conservation strategies aimed at preserving mangrove habitats. As mangroves face increasing threats from anthropogenic activities and climate change, understanding the intricate relationships between biotic factors and mollusk diversity becomes crucial for developing targeted restoration and management efforts (Chen et al., 2021). By prioritizing the maintenance of favorable biotic conditions, conservation initiatives can enhance the resilience of mangrove ecosystems and the diverse communities they support (Adgie & Chapman, 2021).

In conclusion, the PCA analysis serves as a powerful tool for elucidating the complex interplay between biotic factors and mollusk diversity in mangrove ecosystems. The findings underscore the critical role of environmental variables in shaping community structures and highlight the need for ongoing research and conservation efforts to protect these vital ecosystems (Layugan et al., 2018). As we continue to explore the dynamics of mangrove habitats, it is essential to integrate ecological insights into management practices to ensure the sustainability of these invaluable resources for future generations (Hilmi et al., 2021).

4. CONCLUSION

The findings of this study indicate that the variation in community structure and mollusk diversity in the mangrove ecosystems along the northern coast of East Java is strongly influenced by environmental factors such as salinity, dissolved oxygen, water temperature, and pH. Data from five locations—Pasuruan, Probolinggo, Gresik, Tuban, and Banyuwangi—reveal that the Mangrove Center in Banyuwangi exhibits the highest mollusk diversity, whereas the Mangrove Center in Tuban has lower and more uniform diversity. Principal Component Analysis (PCA) confirms that salinity and dissolved oxygen are the most significant factors affecting the distribution of mollusk communities in these study locations.

Given these findings, it is crucial to implement conservation and management strategies to maintain water quality and preserve the ecological balance of mangrove ecosystems. Efforts should include reducing industrial and agricultural runoff to prevent water pollution, restoring degraded mangrove areas to enhance habitat suitability for mollusk species, and promoting sustainable aquaculture practices that minimize adverse environmental impacts. Additionally, community-based mangrove conservation programs should be strengthened to encourage local participation in maintaining ecosystem health. Ensuring the stability of water parameters will not only support mollusk biodiversity but also enhance the overall resilience of mangrove ecosystems, which play a vital role in coastal protection and biodiversity conservation.

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