

Species composition and density of mangrove forests in North Minahasa, Indonesia

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ABSTRACT: The study explores the biodiversity of mangrove ecosystems in the North Minahasa District of North Sulawesi, Indonesia, emphasizing their critical roles in coastal protection, biodiversity conservation, and climate change mitigation. The study identifies five key mangrove species *Rhizophora apiculata*, *R. mucronata*, *Sonneratia alba*, *Bruguiera gymnorhiza*, and *Ceriops tagal* distributed across eleven locations in the district. This study measures species density and dominance using line transect methods. The results show that Tamberong Island has a high density of *R. mucronata* at 84.50 trees/m², indicating ecological dominance, while Talise Island has the lowest overall mangrove density at 933 trees/ha. Conversely, Kalinaung Village exhibits the highest density at 4,400 trees/ha. Mangrove coverage varies across the district, with Maen Village and Tanah Putih Village demonstrating high coverage percentages of 85.23% and 84.95%, respectively. In contrast, North Baho Village shows the lowest coverage at 73.36%. The study underscores the importance of maintaining biodiversity within mangrove forests to optimize their ecological functions, such as carbon sequestration and coastal protection.

Keywords: mangrove biodiversity; species density; north minahasa; coastal protection; carbon sequestration

INTRODUCTION

Mangrove ecosystems play a pivotal role in coastal protection, biodiversity support, and carbon sequestration, making them critical components of tropical and subtropical coastlines worldwide (Alongi, 2014). The ability of mangroves to sequester organic carbon in their sediment is particularly significant, as it contributes to mitigating climate change by trapping carbon that would otherwise be released into the atmosphere (Donato et al., 2011). This process not only aids in reducing global carbon emissions but also enhances the resilience of coastal ecosystems to environmental changes and human impacts.

Indonesia, with its vast and varied mangrove forests, stands as a global center for mangrove biodiversity and carbon storage (Giri et al., 2015). Hosting the world's largest mangrove forest, Indonesia's mangroves span roughly 3.3 million hectares. These forests account for about 23% of the global mangrove area, underscoring their crucial role in international conservation efforts. The North Minahasa District in North Sulawesi Province is a distinctive area where mangrove ecosystems flourish and have the potential to act as significant carbon sinks. Notably, North Minahasa District is the largest government-protected mangrove region in North Sulawesi, covering 4,542 hectares. Mangroves in North Minahasa, like in other parts of Indonesia, are subject to pressures from aquaculture, urban development, and agricultural expansion. These activities not only lead to the

loss of mangrove areas but also disrupt the sedimentary processes that facilitate carbon storage (Murdiyarto et al., 2015).

Through this examination, the study seeks to enhance the understanding of mangroves' biodiversity and to provide insights into conservation and management strategies for these essential ecosystems (Kauffman et al., 2020). This understanding is crucial, especially considering the ongoing threats to mangrove forests from deforestation, land conversion, and climate change, which could significantly diminish their ability to sequester carbon and protect coastlines. Finally, this research is very important for supporting local and national efforts in Indonesia to manage and preserve mangrove forests effectively.

MATERIAL DAN METHODS

Data on mangroves were collected from eleven locations in the North Minahasa District. Names of locations are illustrated in Figure 1.

To assess the mangrove community structure, data were collected using the line transect method at 11 distinct stations across the North Minahasa District. At each station, three transects or plots were established, with each plot measuring 10x10 meters (100 m²). This method allowed for systematic sampling of the mangrove species present in the area. Within each plot, data on species identification, the

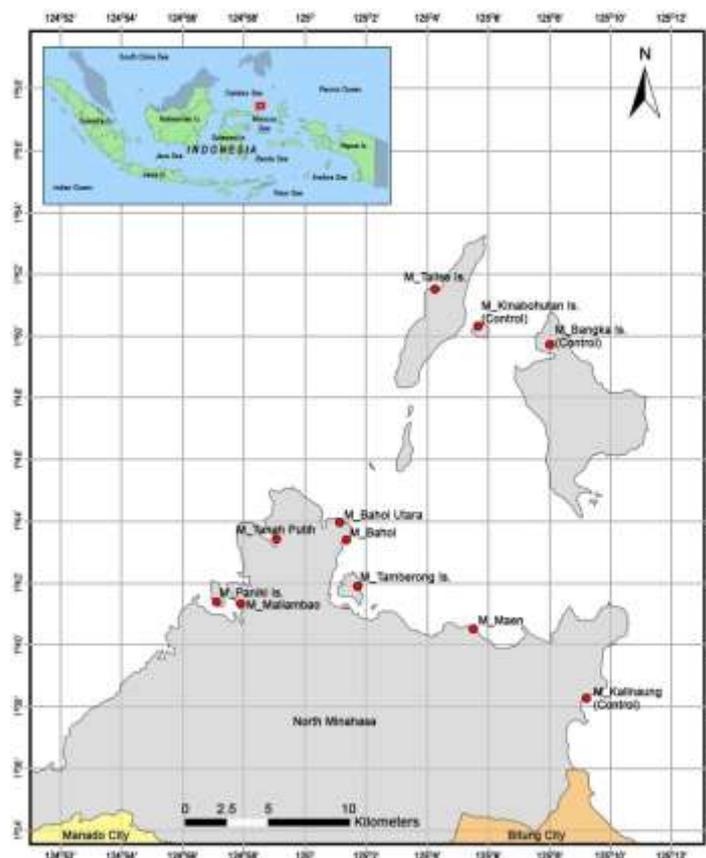


Figure 1. Study locations

number of trees, and tree diameter were recorded. This information was then used to calculate species density (D_i) and species dominance (C_i), following standard methodologies (Bengen, 2000; Kusmana and Sukristijono, 2016).

Species density (D_i) is the number of tree species i within a unit area. Species density (D_i) refers to the number of individuals of a particular species present within a defined area. It is a crucial metric for understanding the population structure of mangrove species. The formula for calculating species density is as follows: $D_i = ni/A$; where D_i is the density of species i , ni is the total number of trees of species i and A is the total area of the sample collection (total area of plot/square sample). This measure provides insight into the relative abundance of different mangrove species within the study area.

Species dominance (C_i) measures the relative basal area coverage of a species within a sampled area, indicating the species' ecological influence or dominance, the formula is: $C_i = \sum BA / \sum A$; where the basal area (BA) is determined using the formula: $BA = \pi DBH^2 / 4$ (in cm^2), π is a constant equal to 3.14, DBH is the diameter of tree species i and A is the total area of the sample collection (total area of plot). The DBH is squared and multiplied by $\pi/4$ to obtain the basal area in square centimeters (cm^2).

Mangrove Coverage is determined by calculating the percentage of mangrove cover using the hemispherical photography method (Dharmawan and Pramudji, 2014). This method is conducted by separating the sky pixels and vegetation cover pixels, allowing the percentage of mangrove

vegetation cover pixels to be calculated in binary image analysis (Ishida, 2004; Chianucci et al., 2014). The photograph results were analyzed using ImageJ software. The formula to calculate the mangrove coverage is as follows: Mangrove Coverage (%) = $P255/SP \times 100$.

RESULTS

This study revealed that five mangrove species were found in study locations: *Rhizophora apiculata*, *Rhizophora mucronata*, *Sonneratia alba*, *Bruguiera gymnorhiza*, and *Ceriops tagal*. The genus *Rhizophoraceae* was widely present across stations, while *C. tagal* was found in Kalinaung Village. Species composition at each station is detailed in Table 1. Furthermore, *R. mucronata* and *S. alba* are the most widely distributed species, present in almost all locations surveyed. Their broad distribution suggests a high degree of ecological plasticity and adaptation to a range of environmental conditions. In contrast, *R. apiculata* and *B. gymnorhiza* exhibit more restricted distributions, with *R. apiculata* recorded only in Maen Village, Kalinaung Village, and Tanah Putih Village, and *B. gymnorhiza* present in Maen Village, Bangka Island, Kinabuhutan Island, and Talise Island. These patterns highlight differences in species' ecological niches and potential environmental tolerances.

The limited distribution of *C. tagal*, documented solely in Kalinaung Village, suggests a more specialized habitat requirement, possibly indicating sensitivity to environmental changes or anthropogenic pressures. The occurrence of

Table 1
Species composition at each station

Locations	Mangrove Species				
	<i>Rhizophora apiculata</i>	<i>Rhizophora mucronata</i>	<i>Sonneratia alba</i>	<i>Bruguiera gymnorhiza</i>	<i>Ceriops tagal</i>
Paniki Island		√	√		
Tamberong Island		√	√		
Maen Village	√		√	√	
Kalinaung Village	√		√		√
Tanah Putih Village	√	√	√		
Bangka Island		√	√	√	
Kinabuhutan Island		√	√	√	
Talise Island		√	√	√	
Bahoi Utara Village		√		√	
Bahoi Village		√	√		
Maliambao Village		√	√		

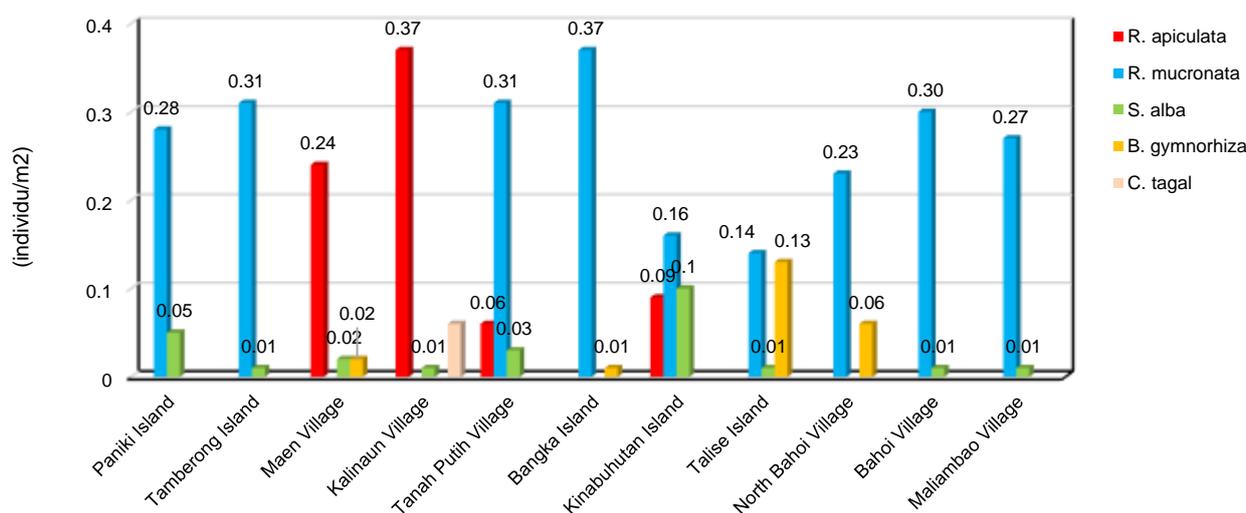


Figure 2. Mangrove species density at each location

multiple species in locations such as Tanah Putih Village and several islands suggests these areas serve as biodiversity hotspots, characterized by a high degree of species richness and ecological interactions. These locations are of particular conservation interest due to their role in maintaining ecological functions, including coastal stabilization, carbon sequestration, and serving as nurseries for marine organisms.

Species Density (D_i)

In terms of species density, different colors represent species: *R. apiculata*, *R. mucronata*, *S. alba*, *B. gymnorhiza*, and *C. tagal* (Figure 2). *R. mucronata* (blue bars) exhibits the highest density among the species across most locations. This species is especially dominant in Tanah Putih Village and Kinabuhutan Island, both recording a density of 0.37 ind/m², and it also shows a significant presence in Bahoi Village (0.30 ind/m²), Maen Village (0.31 ind/m²), and Paniki Island (0.28 ind/m²). The consistently high density of *R. mucronata* indicates its adaptability and favorable growth conditions in

these areas, suggesting it is a key species within these mangrove ecosystems.

Rhizophora apiculata (red bars) shows a notable but less consistent presence compared to *R. mucronata*. The highest density is observed in Kalinaung Village (0.24 ind/m²) and Maen Village (0.31 ind/m²), indicating favorable conditions for this species in these specific locales. Conversely, *S. alba* (green bars) is present at lower densities across most locations, with the highest recorded at Paniki Island (0.05 ind/m²). The lower and more stable densities of *S. alba* suggest it occupies a secondary role in these ecosystems, possibly favoring less competitive or slightly different ecological niches compared to *R. mucronata* and *R. apiculata*.

The densities of *B. gymnorhiza* (yellow bars) and *Ceriops tagal* (brown bars) are markedly lower and more sporadic. *B. gymnorhiza* appears in several locations but with minimal densities, peaking at Talise Island (0.13 ind/m²) and North Bahoi Village (0.06 ind/m²). The minimal presence of

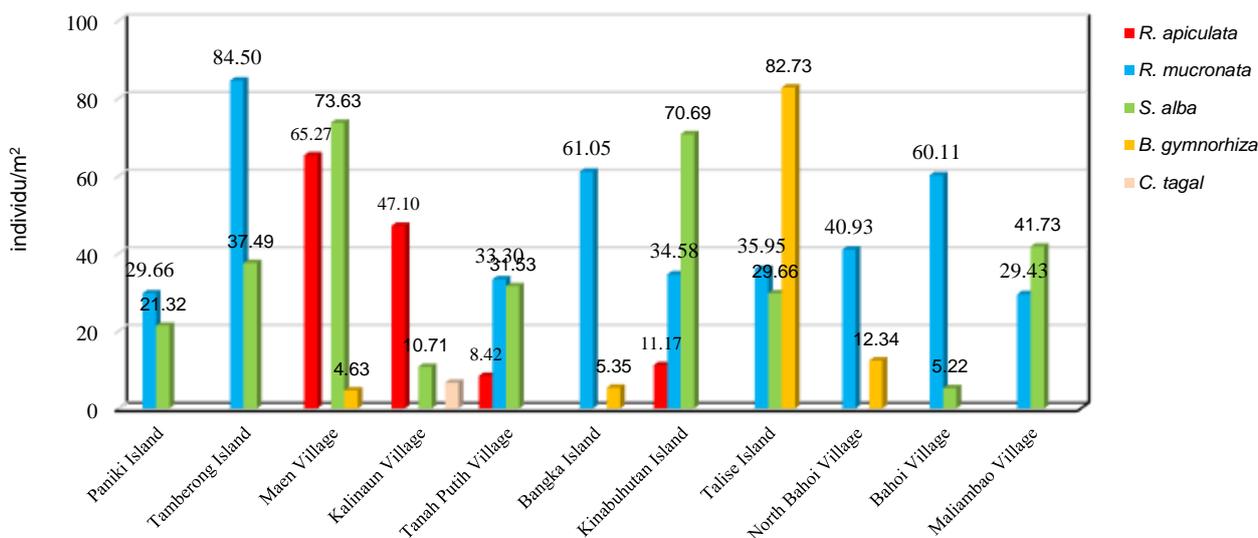


Figure 3. Dominance species at each location

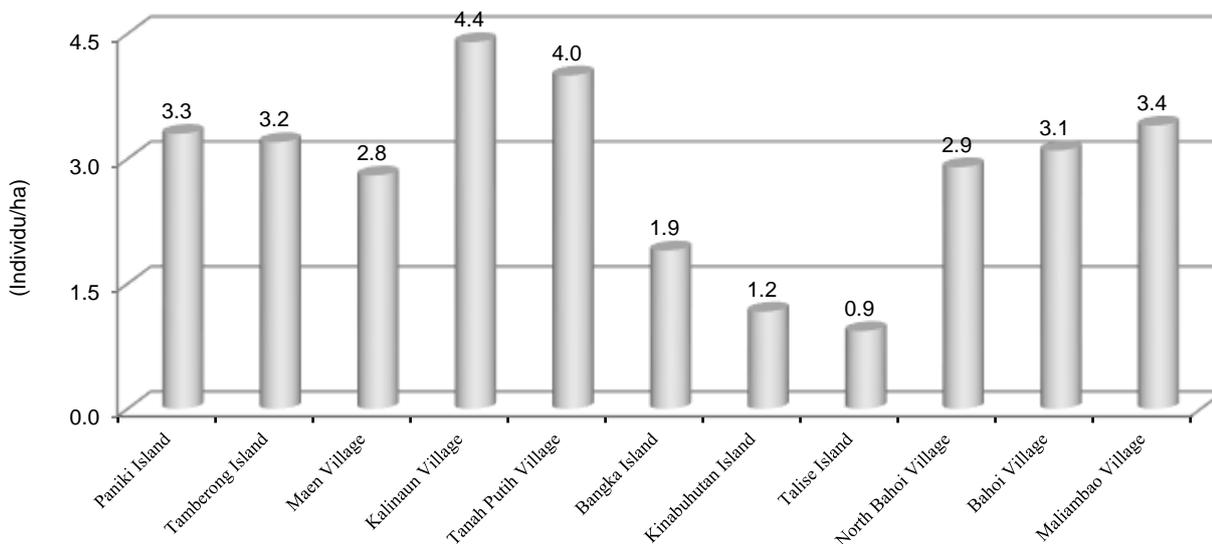


Figure 4. Mangrove density is measured in the number of trees per hectare

C. tagal is observed only in Kalinaun Village (0.002 ind/m²) and Bahoi Village (0.01 ind/m²), indicating this species is the least abundant among those surveyed. The low densities of these species may reflect their lesser competitive ability or specific habitat requirements that are less prevalent in the studied areas.

Dominance Species (*C_i*)

This study revealed that *R. mucronata* predominates in several locations, with notable densities such as 84.50 trees /m² on Tamberong Island being the highest recorded, and 10.71 trees /m² on Tanah Putih Village being the lowest (Figure 3). *R. apiculata*, *S. alba*, and *B. gymnorhiza* exhibit significant presence, indicating a diverse and ecologically rich mangrove ecosystem across the region.

In Paniki Island, *R. mucronata* dominates with a density of 29.66 trees /m², followed by *S. alba* at 21.32

trees/m², highlighting their significant contribution to the mangrove ecosystem's structure. Tamberong Island shows a monospecific stand with high *R. mucronata* density at 84.50 trees /m², emphasizing its ecological dominance in the area. Maen Village displays a balanced community with *R. apiculata* (73.63 trees /m²) and *R. mucronata* (65.27 trees /m²), promoting ecosystem resilience. Kalinaun Village features a mixed-species forest with *R. apiculata* (47.10 trees /m²) and *S. alba* (33.13 trees /m²), enhancing species diversity, while Tanah Putih Village highlights *R. apiculata* dominance (33.13 trees /m²), with lower densities of *R. mucronata* (10.71 trees /m²) and *S. alba* (4.63 trees /m²). Bangka Island shows *R. mucronata* dominance (61.05 trees /m²) alongside *S. alba* (11.17 trees /m²), and Kinabuhutan Island exhibits high *R. mucronata* density (70.69 trees /m²), with lower densities of *R. apiculata* and *B. gymnorhiza*.

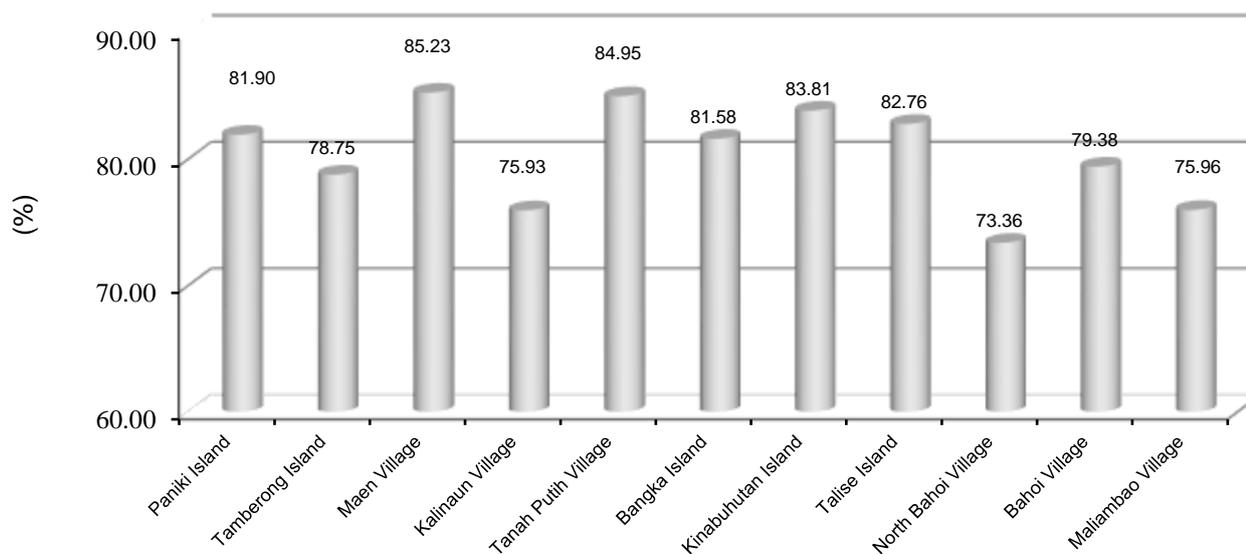


Figure 5. Percentage of mangrove coverage

Talise Island is dominated by *B. gymnorrhiza* (82.73 trees /m²), with a significant presence of *R. mucronata* (34.58 trees /m²) and *R. apiculata* (29.66 trees /m²). North Bahoi Village shows high *S. alba* density (60.11 trees /m²), with contributions from *R. mucronata* (40.93 trees /m²) and *B. gymnorrhiza* (12.34 trees /m²). Bahoi Village and Maliambao Village are dominated by *R. mucronata* (41.73 trees /m² and 29.48 trees/m², respectively), along with a notable presence of *S. alba* and *B. gymnorrhiza*, indicating diverse mangrove ecosystems.

Mangrove Density

Figure 4 illustrates stand density within a given area, also known as the number of stands either per species (*K_i*) or all species (*K*) found within a unit of measurement. For instance, if a plot measuring 100 m² contains 25 stands, the density value is 25 stands per 100 m². This result can be converted into hectares (ha), resulting in 1,500 stands/ha. The tree density values show that the highest density is at station Kalinaun Village, with 4,400 individuals/ha. In contrast, Talise Island presents the lowest density at 933 trees /ha, highlighting significant conservation challenges possibly arising from environmental stressors or anthropogenic activities. Kinabuhutan Island also reflects low density at 1,166 trees /ha, suggesting similar issues. Moderate densities are observed in Bahoi Village (3,100 trees /ha), Maliambao Village (3,400 trees /ha), Paniki Island (3,300 trees /ha), and Tamberong Island (3,200 trees /ha), indicating reasonably healthy mangrove populations. Meanwhile, Bangka Island (1,900 trees /ha) and North Bahoi Village (2,900 trees /ha) demonstrate moderate densities, signifying a need for enhanced conservation efforts. Overall, the mean density is 3109 trees /ha.

According to the Minister of Environment Decree No. 201 of 2004 regarding mangrove damage criteria, the tree density values at each station fall within the criteria of Sparse to Very Dense. The number of trees indicates how high or low the tree density value is within a given area. Other factors also influence this, such as suitable substrate and the ability to

adapt to environmental conditions, which allow for good growth. The factor causing relatively sparse mangrove growth is due to the large root systems, which can hinder optimal growth (Agustini et al., 2016).

Mangrove Coverage

This study revealed that mangrove coverage in North Minahasa is generally high level, ranging from 73.36% to 85.23%. Maen Village and Tanah Putih Village demonstrate exceptional mangrove coverage percentages of 85.23% and 84.95%, respectively, indicating effective preservation efforts likely supported by favorable environmental conditions or community engagement. In contrast, North Bahoi Village shows the lowest coverage at 73.36%, suggesting challenges in conservation possibly due to human activities or environmental stressors. Similarly, Kalinaun Village (75.93%) and Maliambao Village (75.96%) also display lower percentages, highlighting ongoing conservation needs. Locations like Paniki Island (81.90%), Bangka Island (81.58%), Bahoi Village (79.38%), and Tamberong Island (78.75%) exhibit moderate success in mangrove preservation, suggesting room for improvement despite their relatively good conservation statuses. The percentage of mangrove coverage across various islands and villages is illustrated in Figure 5.

DISCUSSION

The predominance of *R. mucronata* across many locations in the North Minahasa District underscores its adaptability and favorable growth conditions. This species' widespread presence indicates its resilience to various environmental conditions, similar to findings in East Kalimantan, where *R. mucronata* was also found to dominate due to its adaptability to different soil properties (Kusmana and Sukristijono, 2016). The presence of *R. mucronata* as a dominant species also indicates a relatively stable and less disturbed ecosystem, as this species often forms the backbone of healthy mangrove

forests (Simard et al., 2019). Furthermore, *R. mucronata* is a significant contributor to coastal protection and carbon sequestration due to its robust growth and structural properties (Alongi, 2002). The significant presence of other species, such as *R. apiculata*, *S. alba*, and *B. gymnorhiza*, reflects the ecological richness of these mangrove communities, a factor crucial for maintaining ecosystem stability (Yulianda et al., 2014). In contrast, areas like Talise Island, with a lower density of 933 trees/ha, may reflect environmental stress or human impacts, which aligns with observations of mangrove degradation in Southeast Sulawesi, where similar factors were noted (Suharsono and Asman, 2015).

The significant presence of other mangrove species, such as *R. apiculata*, *S. alba*, and *B. gymnorhiza*, further highlights the ecological richness and diversity of these mangrove communities. The coexistence of multiple species is crucial for maintaining ecosystem stability and resilience, as it allows the forest to withstand and recover from disturbances more effectively (Feller et al., 2017; Lee et al., 2014). Diverse mangrove species can exploit different ecological niches, reducing competition for resources and allowing the ecosystem to maintain stability despite environmental fluctuations. This biological diversity ensures that the ecosystem can support a wide range of marine and terrestrial organisms, thereby enhancing overall biodiversity (Yulianda et al., 2014). The presence of multiple species also increases the ecosystem's ability to provide various ecological services, such as nutrient cycling, carbon sequestration, and coastal protection, which are vital for both the environment and local human communities (Chen et al., 2013; Mukherjee et al., 2014). The ecological services provided by these diverse species have been crucial for maintaining ecosystem stability and resilience, as seen in various studies across the Indo-Pacific region (Kauffman et al., 2020; Adame et al., 2010). The presence of a diverse array of species suggests that the mangrove ecosystems in North Minahasa are relatively healthy and well-functioning, capable of sustaining their ecological roles (Alongi, 2002).

The observed mangrove densities offer a crucial indicator of the health and productivity of these ecosystems. Higher densities, such as those at Kalinaung Village, suggest that the environmental conditions are conducive to mangrove growth, including factors like suitable substrates, adequate water flow, and minimal pollution levels. These favorable conditions promote vigorous growth, which is essential for the ecosystem's role in carbon sequestration and shoreline stabilization (Donato et al., 2011; Mafi-Gholami et al., 2017). In contrast, lower densities, such as those observed at Talise Island, may indicate suboptimal growing conditions or environmental stressors, such as pollution, sedimentation, or human disturbance (Suharsono and Asman, 2015). Such conditions can hinder seedling establishment and growth, leading to a sparser mangrove cover that is less effective in performing critical ecological functions. The correlation between mangrove density and ecosystem services underscores the importance of maintaining high-density mangrove areas to maximize their ecological benefits (Sanderman et al., 2018; Kauffman and Donato, 2012). For example, McKee (2011) highlights that denser mangrove stands are more effective at trapping sediments and protecting coastlines from erosion.

These findings are supported by similar studies emphasizing the importance of mangrove density as an indicator of ecosystem health and resilience (Alongi, 2002; Kauffman et al., 2020). Conversely, areas like Talise Island, with the lowest density at 933 trees /ha, reflect potential environmental stress or human impact, which is consistent with observations in regions facing similar challenges (Gilman, 2008). Overall, the observed densities meet the national criteria, highlighting a predominantly healthy state of mangrove ecosystems in the district.

Mangrove density is a critical parameter for assessing the health and productivity of mangrove ecosystems. Higher densities, such as those observed at Kalinaung Village, suggest favorable growing conditions, including suitable substrates and optimal hydrological regimes that support robust mangrove growth. Conversely, lower densities, like at Talise Island, may indicate suboptimal conditions or environmental stressors such as pollution or human disturbance. As highlighted by studies in East Java, human activities can significantly alter the structure and composition of mangrove forests, necessitating targeted conservation and restoration efforts (Arifanti et al., 2012). Mangrove density directly impacts the ecosystem's capacity to sequester carbon and provide coastal protection (Donato et al., 2011; Kauffman and Donato, 2012; Alongi, 2014).

Maintaining the diversity and density of mangrove species is crucial for the ecological stability and resilience of these forests. The Indonesian government's criteria for mangrove health, as outlined in the Minister of Environment Decree No. 201 of 2004, provide a valuable framework for assessing the condition of mangrove ecosystems (Agustini et al., 2016). Most locations in North Minahasa meet the criteria for healthy mangrove ecosystems, indicating a generally good environmental status. However, the variability in mangrove coverage and density across different sites highlights the need for targeted conservation and restoration efforts. Effective management strategies are essential to address areas with lower mangrove density and coverage, as these areas are more vulnerable to environmental stressors and degradation (Giri et al., 2015). As seen in Central Java, where specific conservation strategies have been implemented, such measures can significantly improve the health and resilience of mangrove ecosystems (Setyawan and Widyastuti, 2012). These efforts are critical not only for maintaining biodiversity but also for ensuring the continued provision of essential ecosystem services, such as coastal protection, carbon storage, and habitat for marine and terrestrial species (Vo et al., 2013; Lovelock, 2005). Furthermore, maintaining high levels of species richness and structural diversity is vital for sustaining the complex interactions within the mangrove ecosystem, which contribute to its overall resilience (Friess et al., 2012; Murdiyarso et al., 2015).

The frequency of mangrove species, which refers to the regularity of their occurrence within the sampling plots, provides insight into species distribution patterns. The frequency and coverage of mangrove species are critical metrics for evaluating the ecological services provided by these forests, including their role in coastal protection, habitat provision, and carbon storage (Adame et al., 2010; Murdiyarso et al., 2015). Sampling stations with higher frequencies of dominant species like *R. mucronata* reflect stable and resilient mangrove forests. The dominance of a few

species, as observed in several stations, underscores the ecological importance of these species in maintaining the structure and function of the mangrove ecosystem (Ellison et al., 2000; Feller et al., 2017; Friess et al., 2012). In Central Java, effective mangrove conservation and management strategies have been proposed to address these concerns, highlighting the need for similar approaches in North Minahasa to sustain the health and diversity of its mangrove ecosystems (Setyawan and Widayastuti, 2012).

Coverage, or the spatial extent of mangrove species, is crucial for understanding the overall health and ecological services provided by mangrove forests. Extensive coverage indicates well-established forests that offer critical benefits such as coastal protection, carbon sequestration, and habitat provision for various marine and terrestrial species (Adame et al., 2010; McKee, 2011; Murdiyarso et al., 2015). The variability in coverage across the studied stations highlights the need for targeted conservation and restoration efforts, particularly in areas with lower coverage and density.

The results of this study recommend that conservation efforts should focus on protecting areas with high species diversity and promoting reforestation with a variety of mangrove species. Areas with low diversity may need interventions to increase species variety and improve resilience.

Maintaining high biodiversity within mangrove ecosystems is crucial for optimizing their carbon sequestration potential. Conservation and restoration efforts should focus on protecting diverse species assemblages and mitigating factors that reduce biodiversity, such as habitat destruction and pollution. By doing so, the mangrove forests can continue to provide essential ecological services, including climate regulation through carbon storage (Feller et al., 2017; Lovelock, 2005).

CONCLUSION

The study on mangrove biodiversity in North Minahasa District highlights the rich and diverse mangrove ecosystems present in the region. The predominant species, such as *R. mucronata*, *R. apiculata*, *S. alba*, and *B. gymnorhiza*, showcase the ecological richness and adaptability of these forests. The observed variation in species density and dominance across different locations underscores the complex ecological dynamics and varying environmental conditions within the district.

High mangrove densities, particularly in areas like Kalinaung and Tanah Putih Villages, indicate robust ecosystems likely benefiting from effective conservation measures. Conversely, lower densities observed in regions like Talise Island point to potential environmental stresses or human disturbances. The study also reveals generally high mangrove coverage across the district, with some areas requiring targeted conservation efforts to enhance their ecological resilience.

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