Community structure of mangroves in Minahasa Peninsula, North Sulawesi, Indonesia

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Abstract. This study used the continuous quadrant method to determine the mangrove community structure in Minahasa Peninsula, North Sulawesi, Indonesia. The methodology employed in this study involved utilizing a quadrant measuring 10 x 10 square meters as the primary observation area. Furthermore, a supplementary line was implemented at a right angle to the shoreline in a specific segment of the mangrove habitat to function as an observation pathway. The study area was found to contain a collective of 11 distinct species of mangroves that fell under the following classifications: the Myrtales (Lythraceae), Lamiales (Acanthaceae), Malpighiales (Rhizophoraceae), Sapindales (Meliaceae) and Arecales (Arecaceae). The study revealed that *Rhizophora mucronata* was the most dominant mangrove species among the three surveyed stations. The species exhibited a high density of 1,220 individuals per hectare. Station 2 exhibited the most extraordinary diversity, while station 3 displayed the least. Station 2 exhibited the most significant species richness, while station 1 demonstrated the lowest. Station 2 displayed the highest level of species evenness, whereas station 3 exhibited the lowest. In contrast, concerning species dominance, station 3 exhibited the highest level of dominance, while station 2 demonstrated the lowest. Thus, utilizing the prevalence of 11 distinct mangrove species, the three designated sampling stations were segregated into two distinct groups. The genesis of these assemblages can be ascribed to the mangrove species' density, sediment type, and the actions of the coastal populace.

Key Words: clustering, diversity, dominance, evenness, richness, species density.

Introduction. The community of species known as mangroves has established itself in intertidal zones of coastal regions, including lagoons, riverbanks, marshes, and shorelines (Strauch et al 2012). Mangroves represent a crucial coastal ecosystem in tropical and subtropical areas (Giri et al 2011). The main characteristic of the mangrove ecosystem is inundation by saltwater (Robert et al 2009). Intertidal environments, including hydrological and geomorphological conditions, define the mangrove ecosystem's structural variation (Feller et al 2010). The mangrove forest is an ecosystem that exhibits high productivity (Carugati et al 2018; Ribeiro et al 2019; Medina-Contreras et al 2020). The assessment of mangrove productivity is based on primary and carbon productivity (Twilley et al 2017). The ecosystem is a significant food source for estuarine consumers (Abrantes et al 2015). The mangrove ecosystem is a habitat for diverse coastal biota, as Onrizal et al (2020) noted. Additionally, Donato et al (2011) have observed that the mangrove ecosystem contributes significantly to fisheries production. It is worth noting that preserving the mangrove ecosystem is crucial for sustaining coastal fisheries production (Manson et al 2005). The mangrove ecosystem is a significant primary resource in coastal regions and serves as the foundation for food webs (Kruitwagen et al 2010; Thilagavathi et al 2013; Bernardino et al 2018).

Mangroves are tropical forests composed of small groups of higher plant species, or entire plant communities, dominated by several species of mangrove trees that typically grow along the coast, in river estuaries, or tidal areas (Djamaluddin 2018a). Indonesia has 3,311,207.45 hectares of mangrove ecosystems, harboring 202 distinct species of mangrove plants, 91 species of mollusks, and 28 species of crabs, including the economically valuable mangrove crab *Scylla serrata*, 62 species of fish, and 167 species of birds, arthropods, and reptiles (Noor et al 2006). The mangroves had a lovely, tranquil landscape and were serene (Yulianda 2019).

Recent studies of the community structure of mangroves in North Sulawesi were conducted on Mantehage Island and Paniki Island (Opa et al 2019). Another research on Mantehage Island examined marine biodiversity, including mangrove species (Wagey et al 2020). Additional studies on the Wori mangrove forest went further to evaluate carbon potential (Sondak & Kaligis 2022). Although research on mangrove community structure has been conducted in various locations, no studies have specifically examined the community structure of mangroves in the Minahasa Peninsula. As therefore, the goal of this study was to look into community structure of mangroves in the Minahasa Peninsula.

Material and Method

Locations of the research sites. The current study provides a thorough depiction of the locations where the study was conducted during the period spanning from January to March of 2023. The study was conducted in the Minahasa Peninsula, in the North Sulawesi Province. The collection of data on mangroves was conducted at three distinct stations. The first station was identified as Arakan, the second was designated as Tiwoho, and the third was labeled Serawet (Figure 1).

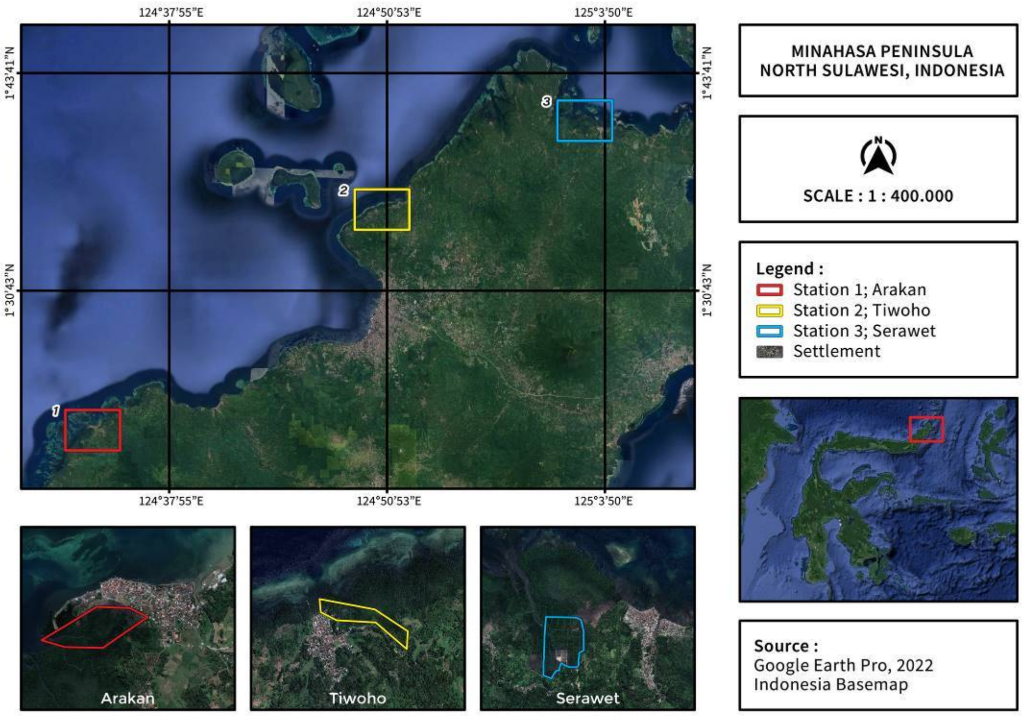

Figure 1. The sampling sites of Minahasa Peninsula, North Sulawesi, Indonesia.

Sampling techniques. The present investigation utilized the continuous quadrant technique (Djamaluddin 2018a; Opa et al 2019). The methodology employed in this study involved utilizing a quadrant measuring 10 x 10 square meters as the primary observational unit. Additionally, an auxiliary line was established perpendicular to the coastline to serve as an observation track within a specific section of the mangrove ecosystem (Figure 2).

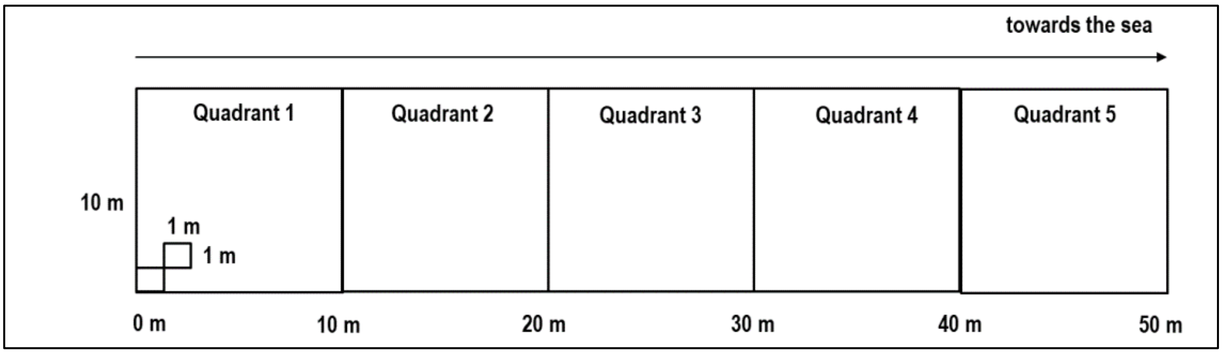

Figure 2. Continuous quadrant method.

Sample identification. Using the references to Djamaluddin (2018a) and Govaerts (2022), this process of identification of mangrove samples was carried out.

Species density. The formula employed for calculating species density was as follows: the calculation of species density involved dividing the aggregate number of individuals by the overall sample area (Krebs 1999).

Richness index. The formula for calculating the richness index (R) was derived by Ludwig & Reynolds (1988). It is expressed as: R = (S - 1) / ln. (n)

The variable S represents a given ecological community's aggregate count of distinct species.

Diversity index. The following formula (Ludwig & Reynolds 1998) was utilized to compute Shannon's index (H'):

$$H' = -\sum\left(\frac{ni}{N}\right)\ln\sum\left(\frac{ni}{N}\right)$$

The abundance of a species within a community was determined using the equation mentioned earlier, where 'ni' represented the number of individuals of the 'ith' species and 'N' represented the total number of individuals encompassing all 'S' species present in the collective.

Evenness index. The following formula (Ludwig & Reynolds 1988) was utilized to compute the evenness index (E):

$$E = \frac{H'}{H'max}$$

The diversity index, denoted as H', is defined as the natural logarithm of the number of species (S) present in a given community. The maximum value of H', represented as H'max, is equivalent to the natural logarithm of S.

Dominance index. The following formula (Odum 1971) was utilized to compute the dominance index:

$$D = \sum\left(\frac{ni}{N}\right)^2 = \sum Pi^2$$

The formula pertains to calculating the number of individuals of the ith species, represented by D, with the total number of individuals across all species, represented by N.

Correspondence analysis. The researched variable was mapped onto points on the cross-axis in a geometric presentation made possible by correspondence analysis (CA). This CA worked well for studying data in matrices or contingency tables, where variables and observations were laid down in a structured format (Lebart et al 1982). The analysis employed the CA methodology to display the species groups (i rows) effectively and station groups (j columns) concurrently, to establish the appropriate correspondence or association between the two variables (species and stations). For the record, this means:

$$k = \Sigma\Sigma k_{ij} = \text{effective total individuals (total amount)}$$
$$f_{ij} = k_{ij}/k = \text{relative frequency}$$
$$f_i = f_j = \Sigma f_{ij} = \text{relative marginal frequency}$$

This scenario involved determining the spatial separation between two distinct species., denoted as i and i', which was calculated using the χ2 formula:

$$d^2(i, i') = \sum_{j=1}^{p} \frac{1}{f_{.j}} \left(f_{ij}/f_{i.} - f_{i'j}/f_{i'.} \right)^2$$

Similarly, the formula provided the distance between two stations, j, and j', as follows:

$$d^2(j, j') = \sum_{i=1}^{n} \frac{1}{f_{i.}} \left(f_{ij}/f_{.j} - f_{ij'}/f_{.j'} \right)^2$$

Lebart et al (1982) stated that using a weighted distance metric provided the benefit of adhering to the "equivalence distribution" principle. When using the distance χ2 metric in CA, the occurrence of multiple absences concerning distance stability did not disrupt the symmetry between the roles of variables and observations.

Two coefficients were computed for each pair of elements in the two groups to contextualize the axes employed in the CA. The present study employed the CA menu selection of the STATGRAPHICS Centurion packaging program to generate a two-way contingency table for data display.

Results and Discussion

Composition of mangrove species. A total of ten mangrove species were identified within the geographical region of the Minahasa Peninsula, belonging to five distinct families, namely Lythraceae, Acanthaceae, Rhizophoraceae, Meliaceae, and Arecaceae. The identified species were as follows: *Sonneratia alba*, *Avicennia alba*, *A. lanata*, *A. marina*, *A. officinalis*, *Rhizophora stylosa*, *R. mucronata*, *R. apiculata*, *Bruguiera gymnorrhiza*, *Xylocarpus granatum*, and *Nypa fruticans* (Table 1).

Table 1

Composition of mangrove species

No.	*Class*	*Order*	*Family*	*Species*
1	Magnoliopsida	Myrtales	Lythraceae	*Sonneratia alba*
2		Lamiales	Acanthaceae	*Avicennia alba*
3				*Avicennia marina*
4				*Avicennia officinalis*
5		Malpighiales	Rhizophoraceae	*Bruguiera gymnorrhiza*
6				*Rhizophora apiculata*
7				*Rhizophora mucronata*
8				*Rhizophora stylosa*
9		Sapindales	Meliaceae	*Xylocarpus granatum*
10		Arecales	Arecaceae	*Nypa fruticans*

Species density. In station 1, five species were discovered. Commencing with the one with the highest density was *R. stylosa* with 540 ind ha^{-1}, *B. gymnorrhiza* with 320 ind ha^{-1}, *A. officinalis* 120 ind ha^{-1}, *S. alba* with 20 ind ha^{-1}, and *X. granatum* 20 ind ha^{-1} (Figure 3). The average density of mangroves in station 1 was 204 ind ha^{-1}.

At station 2, seven distinct species were identified, each exhibiting densities ranging from 20 to 500 ind ha^{-1}. *R. apiculata* exhibited the highest density, recording 500 ind ha^{-1}. *A. alba* had the lowest count of 20 ind ha^{-1} (Figure 4). The mean density of mangroves observed at station 2 was 223.33 ind ha^{-1}.

In station 3, six species were observed to have varying population densities ranging from 20 to 1,220 ind ha^{-1}. *R. mucronata* exhibited the highest density, recording 1,220 ind ha^{-1}. *R. apiculata* demonstrated the least population density, registering 20 ind ha^{-1} (Figure 5). The mean density of mangroves at station 3 was calculated to be 266.67 ind ha^{-1}.

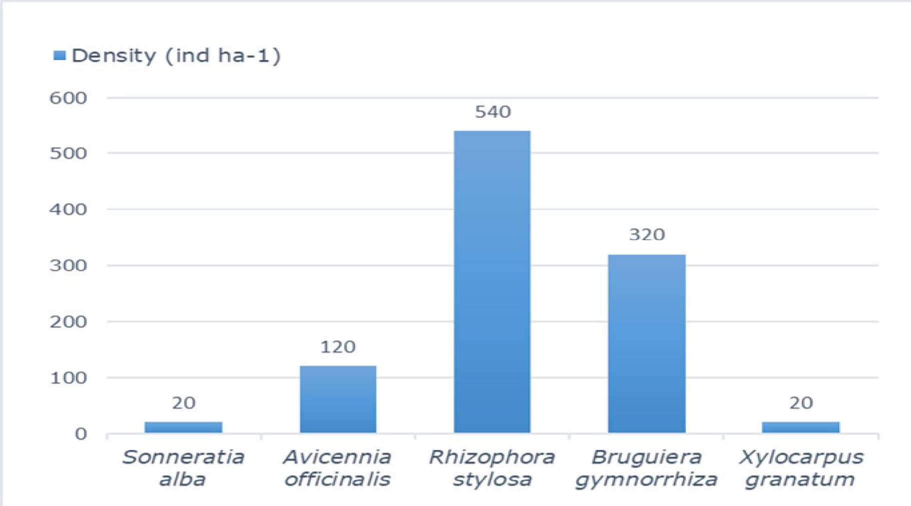

Figure 3. Mangrove density in station 1 (Arakan).

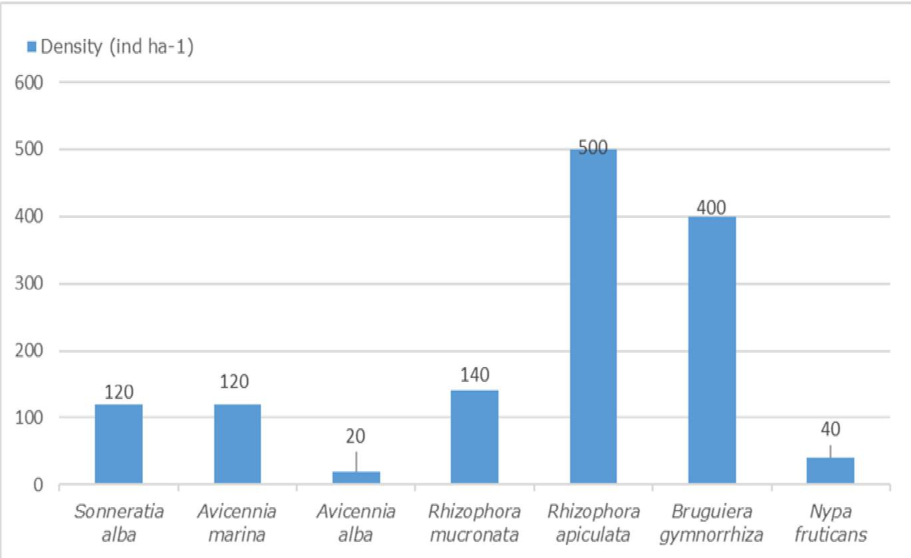

Figure 4. Mangrove density in station 2 (Tiwoho).

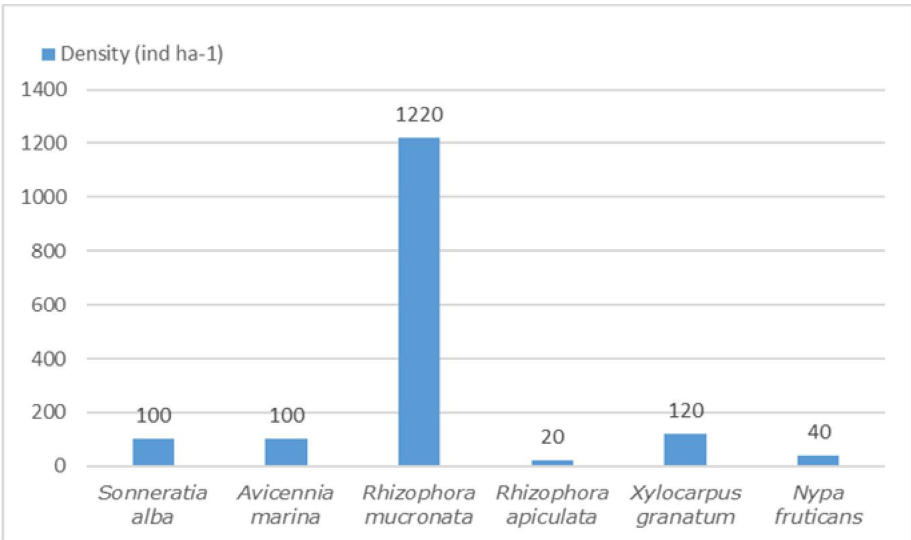

Figure 5. Mangrove density in station 3 (Serawet).

The number of species, diversity index, richness index, evenness index, and dominance index. Table 2 displays the diversity index (H´), richness index (R), evenness index (E), and dominance index (D) values obtained from the computation of various ecological indices for mangroves at each station.

Table 2

Value of mangrove community indices

Station	*H'*	*R*	*E*	*D*
1	1.1063	1.0173	0.6874	0.3933
2	1.5644	1.4269	0.8039	0.2564
3	0.8945	1.1410	0.4992	0.5956

There were three levels of biodiversity: genetic diversity, species, and community (ecosystem) (Ludwig & Reynolds 1988). The diversity determined the population's adaptive strength to become part of species interactions. The concept of diversity can be broken down into two distinct components, specifically the presence of various species and the degree of evenness among them. The concept of species richness pertains to the total number of species in a given area. At the same time, evenness refers to the equitable distribution of abundance across these species, as measured by factors such as the number of individuals, biomass, and other relevant metrics.

The number of species. In total, ten species of mangroves were identified across the three stations. In comparison, the variability in the number of mangrove species across diverse locations in Indonesia has been documented by several authors. The study conducted by Opa & Djamaluddin (2011) in Pohuwato Regency discovered a total of 24 mangrove species. In addition, Djamaluddin's (2018b) investigation in Bunaken National Park identified 27 mangrove species. In contrast, Kepel & Marus (2010) reported that the number of species in Sidangoli was limited to 10, whereas Kepel et al (2012) discovered that Namano and Waisisil had a mere three species. Manado Tua Island and Nain Island exhibited a comparatively low level of mangrove diversity, as they harbor only two species each (Schaduw 2012).

Several sites exhibited moderate levels of mangrove diversity, including Sarawet in North Minahasa Regency and Bunaken Island, each harboring five distinct species (Mangindaan et al 2012). The region of Tumbak located in the Southeast Minahasa Regency was found to possess seven distinct species. Similarly, the region of Sondaken, situated in the South Minahasa Regency, harbored six species (Mangkay et al 2012). According to Dien et al (2016), the North Minahasa Regency's Bahoi region had five species. In contrast, Simbala et al (2017) discovered that the South Bolaang Mongondow's Dudepo Cape region had seven species. According to Puasa et al (2018), Tongkaina, located in Manado, was found to have a total of eight species. Conversely, Rumengan et al (2018) discovered that Totok Bay in Southeast Minahasa Regency had a significantly lower number of species, with only three being identified. Several other areas have been identified to harbor 6-7 species of mangroves, namely Palaes in North Minahasa Regency as reported by Tulenan et al (2018), South Tabulo in Boalemo Regency according to Husuna et al (2019), Gamtala in West Halmahera Regency as documented by Nity et al (2019), and Lansa in North Minahasa Regency (Sondak et al 2019). Opa et al (2019) stated that Mantehage Island and Paniki Island exhibited eight mangrove species. Conversely, Yanti et al (2021) discovered that Jeflio Island in West Papua possessed a comparatively lower number of mangrove species, with only four identified.

Diversity index (H'). The results indicated that station 2 had the highest diversity index value of 1.5644, whereas station 3 had the lowest value of 0.8945. The diversity index values of all stations were found to be within the low to moderate diversity range, with a range of $1 < H' < 3$. According to Odum's (1971) findings, a higher value of H' indicated greater diversity within the community. The diversity index of mangrove vegetation at station 3 was calculated to be 0.8945. This value indicated that the station has low diversity and very low productivity. Additionally, the data suggested a significant ecological pressure, which might indicate an unstable ecosystem. The diversity index of mangrove vegetation at station 1 was 1.1063, while at station 2, it was 1.5644. These numbers indicated a system with moderate biodiversity, production, equilibrium, and ecological pressure (Sipahelut et al 2020).

Richness index (R). The highest richness index value of 1.4269 was in station 2, and the lowest was in station 1, with a value of 1.0173. The area and different habitat conditions could cause this difference in richness values. Eventually, the findings from the three stations were less than 3.5, indicating it was considered low.

Evenness index (E). Station 2 exhibited the highest evenness index value of 0.8039, whereas station 3 demonstrated the lowest value of 0.4992. The results indicated that the evenness index across all stations demonstrated a moderate to high level of species evenness. The evenness index was employed to quantify the level of evenness in the distribution of individual species within a community, thereby characterizing the equilibrium across different communities. Magurran (1988) discussed the significance of evenness in indicating the degree of distribution within a community. A value approaching one suggested a more uniform distribution, while a value closer to zero indicated more significant unevenness. When all species were evenly abundant, no one dominated the others. The disparity in evenness ratings indicated the presence of dominant or highly valued species. The degree of evenness within a community was considered a reliable indicator of the level of dominance exhibited by each species. The dissimilarity in evenness measurements suggested the existence of species that exhibit dominance or possess elevated individual values.

Dominance index (D). It was discovered that station 3 had the highest species richness index value of 0.5956 while station 1 had the lowest of 0.3933. If the value was near to one, the community had a dominating organism; otherwise, there was no dominance hierarchy. As a result, the findings indicated that there was no evident species dominance in any of the mangrove stations.

Correspondence analysis. The present study conducted CA on density data that underwent log (x+1) transformation. Two-way contingency tables were used to structure the data, with ten species rows and 3 station columns. The substrate at station 1 was muddy and slightly sandy, close to a river and a human settlement. The substrate was muddy at site 2. The ground was sandy silt at site 3.

The present study yielded an overall inertia value of 1.3490 for the two axes under consideration, comprising 0.8013 (59.4024%) and 0.5477 (40.5976%), respectively, thus summing up to 100% (Table 3).

Table 3

Inertia and chi-square decomposition

Dimension	*Singular value*	*Inertia*	*Chi-Square*	*Percentage*	*Cumulative percentage*	*Histogram*
1	0.8952	0.8013	160.2684	59.4024	59.4024	******************
2	0.7400	0.5477	109.5329	40.5976	100.0000	*************
Total		1.3490	269.801			

Dendrogram depicted in Figure 6 classified the three sampling stations into two distinct groups, utilizing the abundance of ten species as the basis for classification. Group I (station 1 and station 2) and group II (station 3) were the two groups.

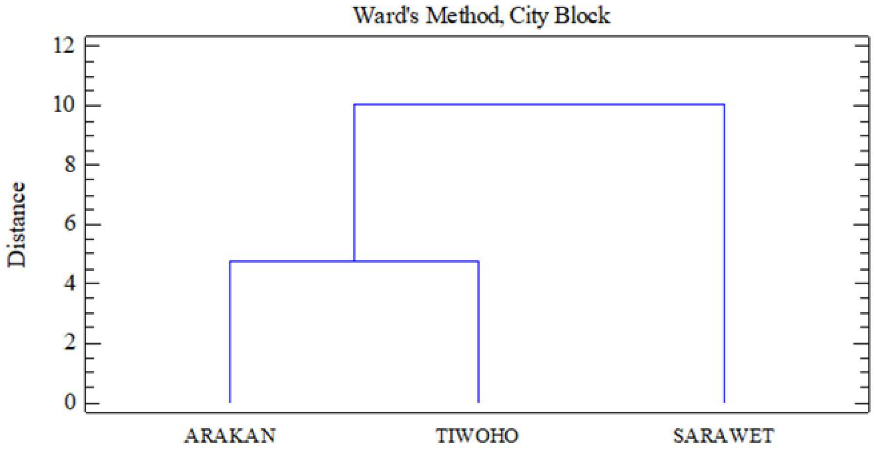

Figure 6. Cluster analysis dendrogram (stations).

In general, the categorization of mangroves was based on the sediment types and the activities of the coastal community, such as village accessibility and ecotourism (Figure 7).

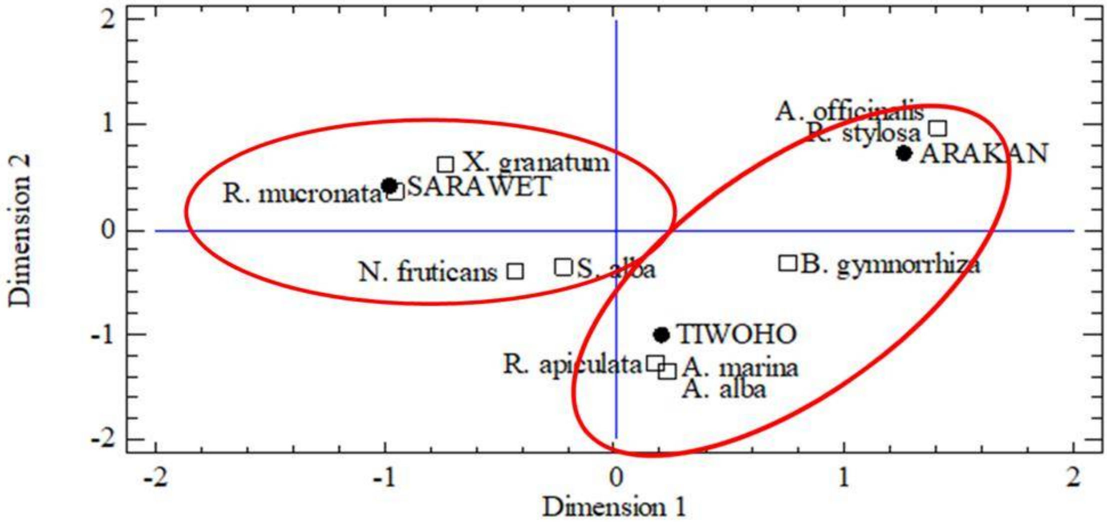

Figure 7. Correspondence map.

Group I was represented by the mangroves that inhabit station 1, with a muddy and slightly sandy substrate consisting of 5 species (*S. alba*, *A. officinalis*, *R. stylosa*, *B. gymnorrhiza*, *X. granatum*), and station 2, with a muddy substrate consisting of 7 species (*S. alba, A. marina*, *A. alba*, *R. mucronata*, *R. apiculata*, *B. gymnorrhiza*, *N. fruticans*). Group II was represented by the mangroves inhabiting station 3, with sandy silt substrate, consisting of 6 species (*S. alba*, *A. marina*, *R. mucronata*, *R. apiculata*, *X. granatum*, *N. fruticans*). The first and second stations of Group I were situated proximate to residential zones, thereby facilitating convenient access to mangroves for the local populace. Station 1 has undergone restoration efforts. Communities close by have worked on station 2's restoration, and as a result, they have turned the area into an ecotourism destination. Mangroves belonging to Group II, situated in station 3, were found to be geographically separated from residential zones. However, it is noteworthy that the local community still retains the ability to access these mangroves. Previous restoration efforts have been undertaken, and the site has been repurposed for ecotourism purposes.

Conclusions. Ten species were identified as the total inventory of mangroves in the Minahasa Peninsula. The structure of the mangrove community exhibited a moderate to low level of diversity. The species richness was high, while the species evenness ranged from moderate to high. Additionally, the species' dominance was observed to be low. The mangroves were classified into two groups: group I (comprising stations 1 and 2), and group II (station 3). The findings of the study provide significant perspectives on the mangrove ecosystem of the Minahasa Peninsula, encompassing aspects such as species richness, diversity, evenness, and dominance. These discoveries have the potential to inform and direct beneficial approaches to conservation and management. Additional investigation may reveal the variables that impact the dispersion and prevalence of species, as well as the environmental benefits provided to nearby populations and ecosystems. Furthermore, the outcomes offer a fundamental reference point for subsequent observation aimed at assessing the efficacy of conservation and management initiatives.

Conflict of interest. The authors declare that there is no conflict of interest.

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