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Biodiversity and Ecosystem Status of Mangroves in the Belawan Estuary, North Sumatra Province, Indonesia

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ABSTRACT

Estuaries function as sediment deposition zones that provide essential substrates for mangrove development. Consequently, estuaries and mangroves constitute integral components of coastal ecosystems. The mangrove ecosystem in the Belawan Estuary, North Sumatra Province, is increasingly threatened by rapid urban expansion in Medan City. This study aimed to assess mangrove biodiversity, structural characteristics, and ecological status in the Belawan Estuary. Field surveys were conducted in November 2023 across 28 sampling stations representing seaward, middle, and landward sections of the estuary. Vegetation data were analyzed using density, diversity, evenness, dominance, and Importance Value Index (IVI). A total of 26 mangrove species were recorded, comprising 21 true mangrove species and 5 associated species. The most widely distributed species were Avicennia marina, Avicennia lanata, and Nypa fruticans. Mangrove density ranged from 533 to 2,733 ind ha^{-1}, with an average of 1,420 ind ha^{-1}. Shannon–Wiener diversity values ranged from 0.04 to 1.95, indicating relatively low diversity in several landward stations dominated by N. fruticans. Although the overall condition of mangroves in the Belawan Estuary is classified as good, the ecosystem remains highly vulnerable to land-use conversion under the revised spatial planning framework. Strengthening conservation-oriented spatial policy is therefore essential to ensure long-term ecosystem sustainability.

Keyword: *Avicennia*, Belawan Estuary, Diversity, Mangrove, *Nypa*, Zonation

1. Introduction

An estuary represents a transitional ecotone between marine and freshwater environments, formed through the mixing of river discharge and seawater. As a result, estuarine waters exhibit salinity levels lower than those of adjacent open seas. Estuaries located at river mouths are ecologically unique because they serve not only as mixing zones but also as critical habitats for mangrove establishment and growth [1]–[3]. The periodic influx of freshwater and seawater, combined with high sediment deposition rates, creates favorable substrates for mangrove colonization and development [3], [4]. Thus, estuaries and mangroves are intrinsically linked components of coastal ecosystems.

Mangrove ecosystems play a vital ecological role by providing feeding grounds, nursery habitats, and spawning areas for numerous marine and estuarine organisms [4]-[6]. Degradation of mangrove forests can therefore disrupt ecological connectivity and reduce biodiversity within coastal systems.

Indonesia supports one of the largest mangrove areas globally. According to the Ministry of Environment and Forestry, Indonesia's mangrove area in 2023 reached approximately 3.3 million hectares, with additional potential habitat identified [7]. Despite recent rehabilitation efforts, long-term assessments indicate historical declines in mangrove extent in several provinces, including North Sumatra [8], [9]. Land conversion for aquaculture, settlements, industrial expansion, oil palm plantations, and sand mining remains the primary driver of mangrove degradation in the region [3].

Previous studies along the eastern and western coasts of North Sumatra have documented mangrove status and distribution patterns [7]-[10]. However, research in the Belawan Estuary has predominantly focused on land-cover change using remote sensing techniques [11], [12], while comprehensive field-based assessments of biodiversity and ecosystem status remain limited. Therefore, this study aims to evaluate the biodiversity, distribution patterns, and ecological status of mangroves in the Belawan Estuary, North Sumatra Province

2. Methods
2.1. Time and location of the study
Fieldwork was conducted in November 2023 within the mangrove ecosystem of the Belawan Estuary (3°48'0.03"N; 98°42'24.26"E and 3°43'35.48"N; 98°39'8.09"E), North Sumatra Province, Indonesia. Sampling stations were selected using purposive sampling based on geomorphological features and environmental gradients relevant to mangrove zonation. Geographic coordinates were recorded using a handheld GPS device. A total of 28 stations were established to represent the seaward, middle, and landward sections of the estuary.
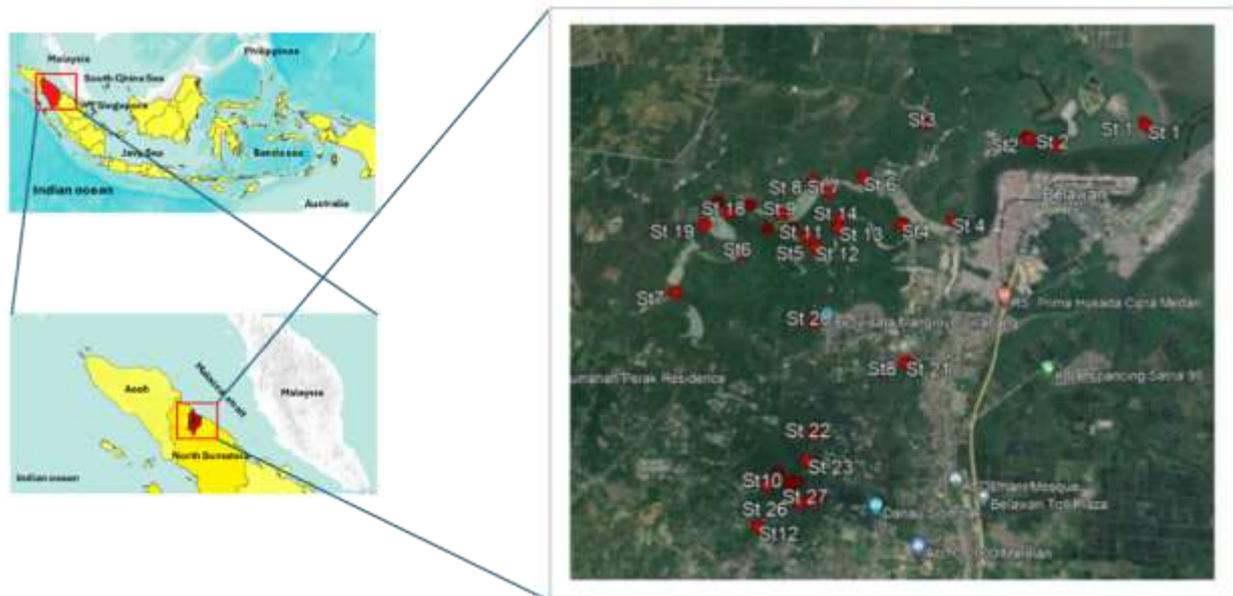
Figure 1. Map of the study area in the Belawan Estuary, North Sumatra Province

2.2. Mangrove Vegetation Data Collection
Mangrove species were identified in situ using the Field Guide to Indonesian Mangroves [4]. Vegetation structure was assessed using a nested transect-plot method adapted from [13], with plot sizes adjusted according to growth stages:
- 10 × 10 m plots for trees (DBH > 10 cm; height > 1.5 m)
- 5 × 5 m plots for saplings (DBH < 10 cm; height > 1.5 m)
- 1 × 1 m plots for seedlings

Density, frequency, cover (basal area), and Importance Value Index (IVI) were calculated following standard ecological procedures [3], [15]. Mangrove status classification was determined according to the Regulation of the Minister of Environment No. 201/2004 concerning mangrove damage criteria [14].

2.3. Data Analysis
The mangrove vegetation data collected in the field will be subsequently analysed to determine the values of Species Density (Di), Relative Density (RDi), Species Frequency (Fi), Relative Frequency (RFi), Species Cover (Ci), Relative Cover (RCi), and the Importance Value Index (IVI) [3], [13].

2.1.1. Species density (Di)

Species density (Di) is defined as the number of individuals of species i within a given unit area. The analysis of mangrove species density is conducted by growth category seedlings, saplings, and trees. The species density is determined using the following [3], [13]:

$$Di = \frac{ni}{A} \tag{1}$$

Where:
Di : Density of species i
ni : Total number of individuals of species i
A : Total sampled area (m²)

2.1.2. Relative density (RDi)

Relative density (RDi) is the ratio between the number of individuals of species i and the total number of individuals of all species. The determination of relative density (RDi) is calculated using the following formula [3], [13]:

$$RDi = \frac{Di}{\sum n} \times 100 \tag{2}$$

Where:
RDi : Relative Density
Di : Density of species i
$\sum n$: The total number of individuals of all species

2.1.3. Species frequency (Fi)

Species frequency (Fi) is the probability of finding a specific species i in all sample plots compared to the total number of sample plots made. The calculation of species frequency (Fi) is done using the following formula [3], [13]:

$$Fi = \frac{pi}{\sum F} \tag{3}$$

Where:
Fi : Species Frequency
Pi : Total number of plots where individuals of species i are observed
$\sum F$: The total number of sample plots created (3 plots).

2.1.4. Relative frequency (RFi)

Relative frequency (RFi) is the ratio of the frequency of species i compared to the total frequency of all species. To calculate relative frequency (RFi), the following formula is used [3], [13]:

$$RFi = \frac{Fi}{\sum F} \tag{4}$$

Where :
RFi : Relative Frequency
Fi : The frequency of species i
$\sum F$: The total number of sample plots created (3 plots).

2.1.5. Species cover (Ci)

Species cover (Ci) refers to the area covered by species i within a given unit area. To calculate species cover (Ci), the following formula is used [3], [13]:

$$Ci = \frac{\sum BA}{A} \tag{5}$$

Where :
Ci : Species cover
$\sum BA$: $\pi d^2/4$ (d = Diameter at breast height (DBH) (d = Circumference/π), π = 3,14)

2.1.6. Relative cover (RCi)

Relative Coverage (RCi) is the ratio of the coverage of species *i* to the total coverage for all species. To calculate RCi, the following formula is used [3], [13]:

$$RCi=\frac{Ci}{\sum C}x100 \tag{6}$$

Where :
RCi   : Relative Cover
Ci   : The coverage of species *i*
C   : The total coverage for all species

2.1.7. Importance value index (IVI)

According to Bengen [15], the formula for calculating the Importance Value Index (IVI) of mangroves is as follows [3], [13]:

1. For the tree level, the formula used is: IVI=RDi+Rfi+RCi   (7)
2. For the seedling and sapling levels, the formula used is: IVI=RDi+RFi   (8)

Where :
IVI   : Importance Value Index
RDi   : Relative Density
RFi   : Relative Frequency
RCi   : Relative Cover

Mangrove status refers to Regulation of the Minister of the Environment No. 201 of 2004 concerning Standard Criteria and Guidelines for Determining Mangrove Damage. The mangrove community index which consists of: diversity, uniformity and dominance [1], [15]

3. Result and Discussion

3.1. Mangrove Species Richness

The mangrove survey in the Belawan estuary identified 26 species, consisting of 21 true mangrove species and 5 associate mangrove species (Table 1). One of the interesting findings in the Belawan estuary is the discovery of *Barringtonia racemosa*, a species rarely found in Indonesia, particularly in North Sumatra. Previous studies did not report its presence on Bali Beach (Batubara)[16], Percut [17], Mursala Island, and Tapian Nauli Bay [10], nor in the Nias Islands [9], but it was found at Labu Beach, Bagan Serdang [18]. The families Rhizophoraceae and Avicenniaceae are the most species-rich, with 5 and 4 species, respectively. Rhizophoraceae exhibits a high distribution across mangrove ecosystems [3], [19]. Muhtadi et al. [12] identified 7 mangrove species from the Rhizophoraceae family at Sambilan Island (Langkat Regency) [20] and in Tapian Nauli Bay [10]. In the Nias Islands, up to 9 species of Rhizophoraceae were found [9]. However, according to the mangrove identification guide by Wetland International, at least 12 mangrove species from the Rhizophoraceae family are reported, a family known for its widespread distribution across Indonesia [4].

Based on previous studies, the mangrove species richness in Belawan is the highest compared to other areas in North Sumatra, except for the Sembilan Islands, which has 28 species [20], and the Nias Islands, where 33 species were found [9]. The number of mangrove species found at Bunga Beach, Batubara was 10 species [16], at Tapian Nauli Bay (Central Tapanuli) there were 17 species [20], at Labu Beach (Deli Serdang) 18 species [18], and at Percut, Deli Serdang 15 species [17]. In other regions, the mangrove species richness reported for Sungai Apit (Siak, Riau) was 35 species [21]. In the Segara Anakan estuary, only 15 species were found [22], and in the Musi River estuary, only 10 species were observed [23].

**Table 1.** Mangrove species found in the Belawan estuary

No	Family	Species	Indonesia Name	Local Name	Description
1	Acanthaceae	*Acanthus ilicifolius*	Jeruju	Jeruju	PM
2		*Acanthus ebracteatus*			
3	Avicenniaceae	*Avicennia alba*	Api-api		
4		*Avicennia marina*			
5		*Avicennia officinalis*			
6		*Avicennia lanata*			
7	Arecaceae	*Nypa fruticans*	Nypah	Nipah	PM
8	Asteraceae	*Wedelia biflora*		Beluntas	SM
9	Combretaceae	*Terminalia catappa*		ketapang	SM
10	Euphorbiaceae	*Excoecaria agallocha*	Mata buta/ Garu	Buta-buta	PM
11	Lecythidaceae	*Barringtonia racemosa*		Putat	PM
12	Malvaceae	*Thespesia populnea*	Waru laut	Baru	SM
13	Meliaceae	*Xylocarpus granatum*			
14	Pteridaceae	*Acrostichum aureum*	Paku laut	Piayi	SM
15		*Acrostichum speciosum*			
16	Rhizophoraceae	*Bruguiera gymnorrhiza*			
17		*Bruguiera cylindrica*			
18		*Rhizophora apiculata*	Bakau	Bako	PM
19		*Rhizophora mucronata*	Bakau besar	Bako	PM
20		*Rhizophora stylosa*	Bakau merah	Bako kurap	PM
21	Rubiaceae	*Morinda citrifolia*			SM
22		*Scyphiphora hydrophyllaceae*			
23	Sonneratiaceae	*Sonneratia alba*			
24		*Sonneratia caseolaris*	Pedada	Berembang	PM
25		*Sonneratia ovalis*			PM
26	Sterculiaceae	*Heritiera littoralis*		Dungun	PM

Note: PM: primary mangroves; SM= secondary mangroves

3.2. Distribution and Zonation of Mangroves

Mangroves with a wide distribution in the Belawan estuary include *A. marina*, *A. lanata*, and *N. fruticans*. *A. marina* and *A. lanata* are widely distributed in the front (mouth) section of the Belawan River, while *N. fruticans* is spread across the back part of the Belawan estuary (Figure 2). In addition to *N. fruticans*, *E. agallocha* and *S. alba* are also found. Interestingly, in Siombak Lake, a unique coastal lake in Indonesia, a greater mix of species is observed, including *B. racemosa*, a species rarely found in Indonesia. Furthermore, previous studies have identified at least 14 mangrove species around Siombak Lake [24]. Based on zonation, the vegetation from the seaward edge to the middle of the Belawan estuary is dominated by the families Avicenniaceae and Rhizophoraceae, particularly *A. marina* and *A. lanata*. Meanwhile, the innermost zone is dominated by *N. fruticans*, interspersed with members of the Sonneratiaceae and Euphorbiaceae families. Fern species (*A. ilicifolius* and *A. ebracteatus*) are mangrove species that grow further inland, in areas rarely inundated by seawater [20].

In the estuary (river mouth) area, mangroves are predominantly from the family Avicenniaceae (Figure 2). This pattern is also observed in the Segara Anakan estuary [22] and the Musi River estuary [23], where Avicenniaceae dominate the river mouths. In contrast, mangroves in coastal, island, or bay areas are typically dominated by Rhizophoraceae [9], [10], [20]. Spatially, mangrove species richness is highest in the middle section of the estuary, where 5–9 species are found, compared to 6–8 species at the river mouth and only 3–5 species in the upper/landward section. An exception is the area around Siombak Lake, which supports up to 14 species. *E. agallocha* is geographically well-distributed, ranging from the middle to the back sections of the Belawan estuary. This mangrove species typically grows along coasts that receive substantial freshwater input throughout the year. It is commonly found at the landward edges of mangrove areas or occasionally above the high-tide line [4], [20]. This distribution aligns with the dynamic hydrology of the Belawan estuary, which benefits from consistent freshwater input year-round from the Belawan River [25]. Areas flooded only during high tides, further inland, are generally dominated by *Bruguiera* spp. and *X. granatum*.
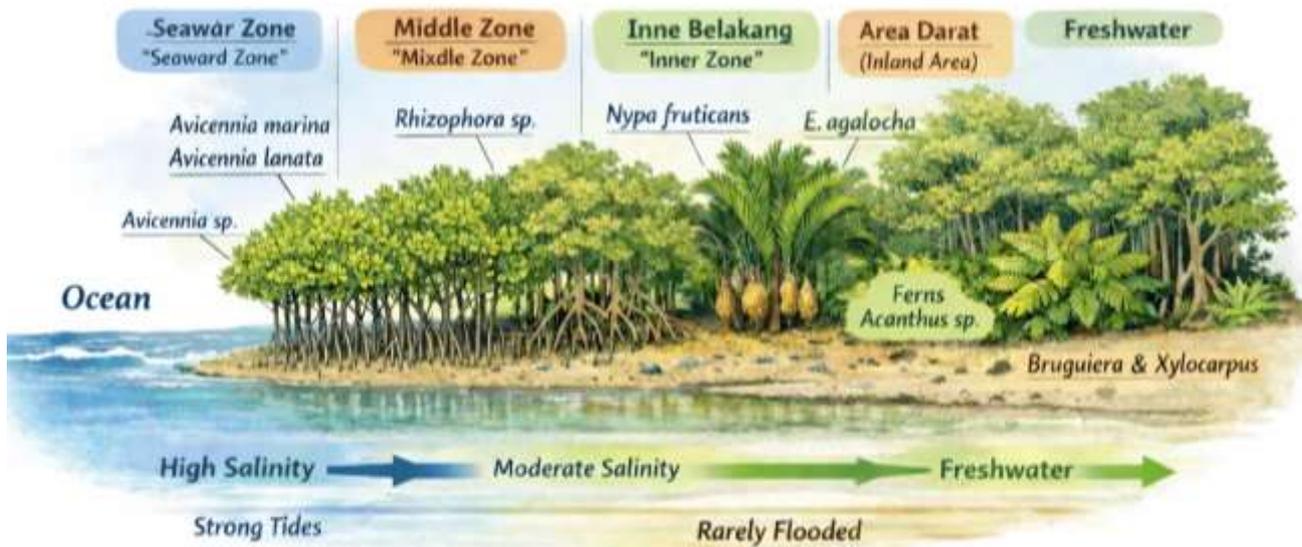
Figure 2. Conceptual zonation model of mangrove distribution along the salinity gradient in the Belawan Estuary.

3.3. Density and Frequency of Mangrove Presence

Mangrove density in the Belawan estuary ranges from 533 to 2,733 individuals/ha, with an average density of 1,420 individuals/ha for trees; 0- 4,800.0 individuals/ha for saplings, and 20,000 - 236,667 individuals/ha for seedlings (Figure 3). Generally, the highest density is found in the middle to the river mouth/estuary areas, while the lowest density is in the upper sections. This pattern occurs because, in the upper areas, the mangroves consist primarily of *Nypa fruticans*, whose fronds are periodically harvested by local communities. The highest mangrove density in the Belawan estuary was recorded at Station 25, with 1,733 individuals/ha of *N. fruticans* and a relative density of 100%. Mangrove density is determined by the number of individual mangroves per unit area. High species density is attributed to suitable substrates [3], [20] and the species' adaptability to environmental conditions, particularly the highly fluctuating salinity [3], [23]. Similar findings were reported in Mursala Island, Tapian Nauli Bay, and the Nias Islands [9], [10], where substrate suitability and freshwater input (river discharge) significantly influenced mangrove growth and development.

The mangrove species density in the Belawan estuary, Medan City, is significantly lower compared to other locations. For example, mangrove density in Mursala Island ranges from 1,367 to 3,233 individuals/ha, and in Tapian Nauli Bay, Central Tapanuli Regency, it ranges from 2,425 to 3,820 individuals/ha [10]. The average mangrove density in the Nias Islands is 4,360 individuals/ha [11], and it is even higher in Sembilan Island, Langkat Regency, reaching 5,935 individuals/ha [20]. However, the mangrove density in the Belawan estuary is still higher than that in Bali Beach, with a density of 1,233–1,400 individuals/ha [16], and Labu Beach, which has an average density of 1,217 individuals/ha [18]. The highest relative frequency of mangroves, specifically *N. fruticans* and *E. agallocha*, was observed at stations 22, 25, 26, and 28, each with a relative frequency of 100%. The frequency value of mangroves is influenced by the number of occurrences of a species within each quadrant. The more quadrants in which a mangrove species is found, the higher its frequency of occurrence.

Mangrove density across growth stages (seedlings, saplings, and trees) exhibited clear spatial variation along the Belawan Estuary, reflecting the established zonation from seaward to landward areas. In the seaward stations, relatively high tree and sapling densities were recorded, consistent with the dominance of Avicennia marina and A. lanata. These species are well adapted to high salinity, strong tidal inundation, and unstable muddy substrates. Their pneumatophore (pencil-root) system enhances oxygen uptake in anoxic sediments, supporting stable stand development under frequent tidal flooding. The middle estuarine section showed comparatively higher densities of seedlings and saplings, indicating active natural regeneration. This zone likely represents optimal ecological conditions, characterized by moderate salinity, balanced freshwater–seawater mixing, and relatively stable sediment deposition. Such transitional environments often promote higher species coexistence and recruitment success, resulting in structurally complex mangrove stands. In contrast, the landward stations, strongly influenced by freshwater input, were structurally dominated by *Nypa*

fruticans. Although tree density remained notable, seedling and sapling densities were generally more variable, suggesting that regeneration in this zone is closely linked to hydrological dynamics and periodic flooding intensity rather than tidal frequency alone. Overall, the density distribution across growth stages confirms the estuarine zonation pattern in the Belawan system, demonstrating a gradual shift from salt-tolerant Avicenniaceae in the seaward zone to freshwater-influenced assemblages dominated by *Nypa fruticans* in the inner estuary [3], [13].

A

B

C
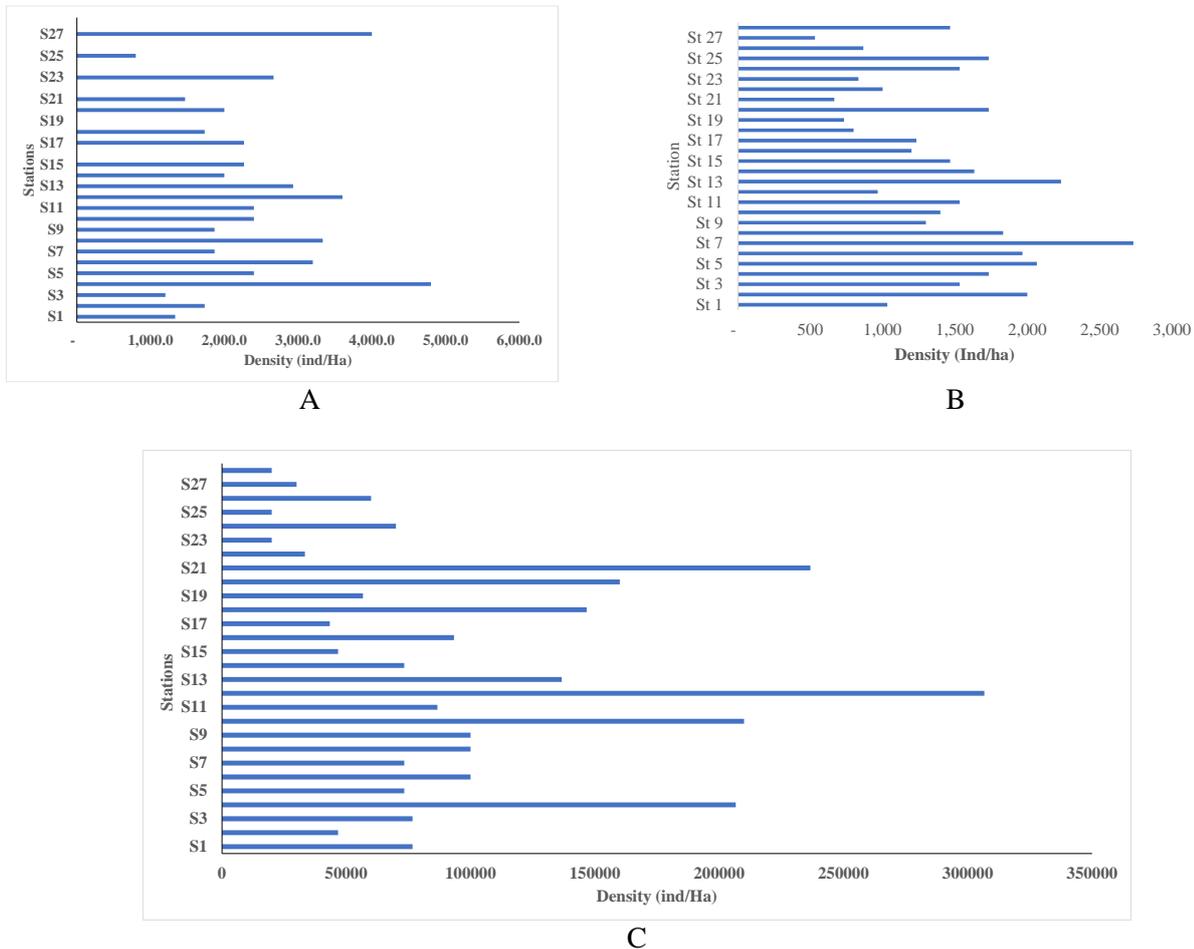
Figure 3. Spatial variation in mangrove density (ind ha⁻¹) at different growth stages in the Belawan Estuary: (A) saplings, (B) trees, and (C) seedlings. Density values vary among stations (S1–S28), reflecting differences in zonation, tidal influence, and freshwater input along the estuarine gradient.

3.4. Mangrove Coverage

Mangrove coverage in the Belawan estuary ranges from 0.86 to 11.86 cm²/ha. The highest mangrove coverage was recorded at Station 25 for *N. fruticans* with a value of 11.86 cm²/ha, while the lowest was at Station 6 for *X. granatum*, with a value of 0.86 cm²/ha (Figure 2). The mangrove coverage in the Belawan estuary, Medan City, is lower compared to Sembilan Island (Langkat Regency), which ranges from 25.22 to 58.10 cm²/ha [20], and the Nias Islands, which range from 0.08 to 31.62 cm²/ha [9]. However, it is higher than in Tapian Nauli Bay, which ranges from 1.39 to 3.07 m²/ha, and Mursala Island, which ranges from 0.25 to 3.32 m²/ha [10]. The variability in mangrove coverage is influenced by species type, tree age, and environmental conditions. Large, dense trees with abundant branches and leaves provide greater coverage by "shading" the surrounding area. However, even older trees may exhibit stunted growth if environmental conditions are unfavourable [2], [3], [9], [10], [20].
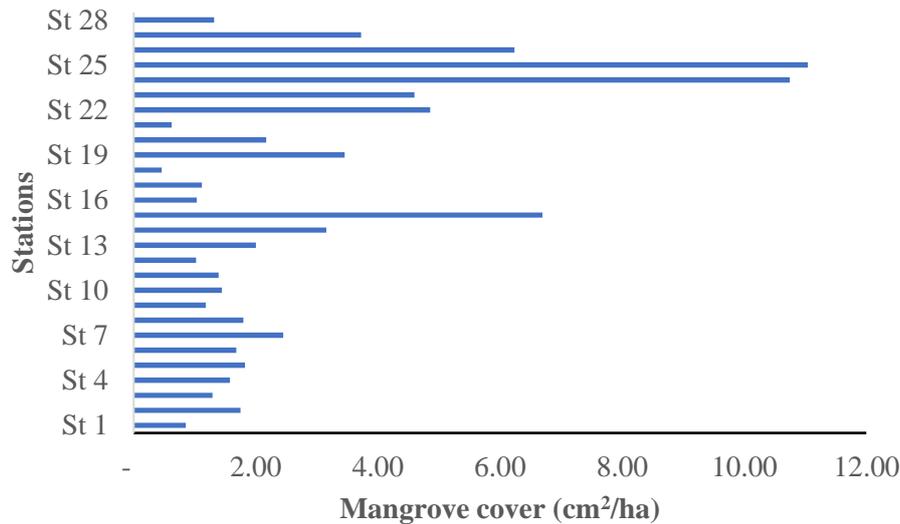
Figure 4. Mangrove Cover (trees) in Belawan estuary

3.5. Diversity and Importance Value Index of Mangrove Communities

The mangrove diversity in the Belawan estuary is relatively low, ranging from 0.04 to 1.95 (Figure 4). The highest diversity was observed at Station 8 (value 1.95), while the lowest was at Station 24 (0.04). The high diversity at Station 8 is attributed to the number of species and the high and evenly distributed tree density at the site. This aligns with the findings of Muhtadi et al. [9], who reported that high diversity in a location is associated with a greater number of species and a more even tree density. In general, the front or river mouth sections of the estuary exhibit higher diversity compared to the back sections. This is evident in the dominance of *Nypa fruticans* in the back sections of the Belawan estuary, where only one or two individual *Buta-buta* (*Excoecaria agallocha*) or *Pedada* (*Sonneratia* spp.) trees are occasionally found within the *Nypa* community. This pattern highlights the significant influence of river discharge from the Belawan River on the mangrove community. As noted by Surbakti et al. [23], the presence of freshwater acts as a "control" for mangrove community structure.

Despite the low mangrove diversity, the front sections of the Belawan estuary demonstrate high evenness (0.80–0.97) and low dominance (0.17–0.31). Conversely, the back sections of the Belawan estuary exhibit high dominance (0.62–0.92) and low evenness (0.06–0.48). This indicates that *Nypa fruticans* is highly dominant and plays a significant role in the mangrove community in the back sections of the estuary. This is further supported by the Importance Value Index of *Nypa fruticans*, which is the highest among mangrove communities in the back sections of the Belawan estuary. In contrast, the front sections of the Belawan estuary are dominated by *Avicennia* species. This pattern reflects the zonation within mangrove communities, where specific species grow according to substrate type and inundation frequency [9], [10], [20]. Thus, *Nypa fruticans* and *Avicennia* spp. are the dominant species, playing critical roles in the mangrove communities of the Belawan estuary. Suitable habitats and stable water conditions are key factors influencing the Importance Value of mangrove species [3], [13].These findings differ from the mangrove communities in the Nias Islands, Tapian Nauli Bay, and Bali Beach, Batubara, where *Rhizophora* species are the dominant and influential components of the mangrove ecosystems [9], [10], [16].

Rhizophora species are often dominant and structurally influential in mangrove ecosystems due to a combination of physiological tolerance, reproductive strategy, and ecosystem engineering capacity [3], [4], [13], [26]. First, high salinity tolerance and tidal adaptability allow Rhizophora spp. to thrive in frequently inundated intertidal zones. Their salt-exclusion mechanism at the root level enables them to survive in saline environments while maintaining internal osmotic balance. Second, their distinctive stilt (prop) root system provides strong mechanical stability in soft, unconsolidated sediments. These roots reduce erosion, trap suspended sediments, and enhance substrate accretion, gradually stabilizing coastlines. This sediment-trapping capacity often facilitates land building and creates suitable microhabitats for other mangrove species. Third, Rhizophora exhibits viviparous reproduction, where propagules germinate while still attached to the parent tree. The elongated propagules can disperse over long distances via tides and currents, increasing colonization success and allowing rapid establishment in newly formed mudflats
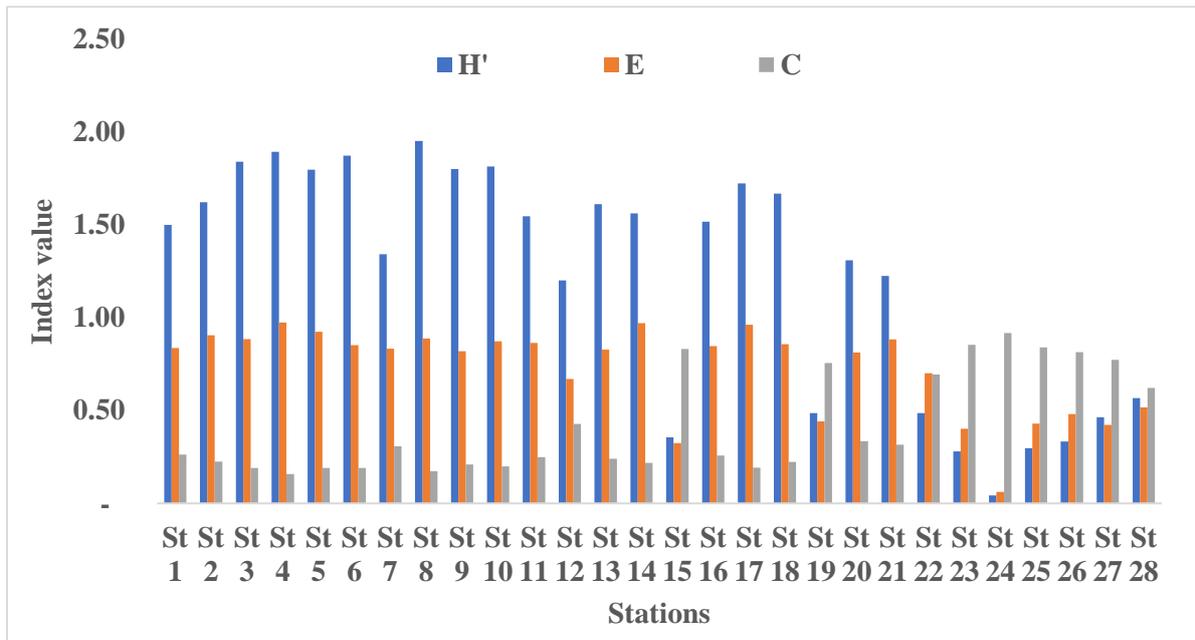
Figure 5. Species diversity (H′), evenness (E), and dominance (C) indices of mangrove communities across sampling stations in the Belawan Estuary.

3.7. Mangrove Status

Based on national criteria [14], the mangrove ecosystem in the Belawan Estuary is generally classified as moderate to good. However, two locations, namely Stations 21 and 27, fall into the damaged category. This is attributed to the cutting of mangrove trees by some local residents living in the area. Therefore, although the overall mangrove status in Belawan is considered good, it is "highly threatened" by both human activities and government policies. According to the new spatial plan for Medan city [27], parts of the mangrove areas are designated for the development of industrial zones in North Medan. This contrasts with the previous spatial plan, where all mangrove areas in Belawan were classified as protected forests, offering them a higher level of safety due to their conservation status.

According to the latest report from the Ministry of Environment and Forestry in 2023 Indonesia's mangrove ecosystem was classified as good, covering 92.78% of its total area. In North Sumatra, the mangroves were reported to be in good condition, reaching 73.93%. This indicates an improvement in mangrove health both in North Sumatra and Indonesia as a whole, compared to the previous report in 2012, where only 55.77% of mangroves in North Sumatra were in good condition [28]. This is a positive development and must be consistently maintained and enhanced to ensure the sustainability of coastal ecosystems.

Although the mangroves in the Belawan estuary are considered to be in good and natural condition, human activities continue to pose a threat to their preservation. The primary threat to mangrove degradation is deforestation, although it is occurring on a relatively small scale. Looking ahead, the main threat is the change in the status of Belawan's mangroves, as the new spatial plan has shifted land use for industrial development [27]. Previously, under the old spatial plan, all mangrove areas in Belawan were designated as protected forests [29]. This change will likely lead to the conversion of mangrove areas into land for industrial, residential, and other activities, which could significantly impact the mangrove ecosystem.

4. Conclusion

Mangroves in the Belawan Estuary exhibit relatively high species richness and clear zonation patterns driven by salinity and hydrological gradients. While the ecosystem is currently in moderate to good condition, increasing urban and industrial expansion poses significant threats. Strengthening conservation-based spatial planning is essential to maintain ecological integrity and long-term sustainability.

5. Acknowledgement

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6. Conflict of Interest

The author declares no conflict of interest in this research and publication.

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