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Indicators of Resilience: Mangrove Density and Important Value Index as Measures of Ecosystem Health – A Case Study in Desa Sarang Burung Kolam West Kalimantan

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ABSTRACT

Mangrove ecosystems play a critical role in maintaining coastal resilience, supporting biodiversity, and mitigating the impacts of climate change. This study investigated the health and resilience of mangrove forests in Desa Sarang Burung, West Kalimantan, using two key ecological indicators: mangrove density and the important value index (IVI). Field observations and data analysis reveal that areas with higher mangrove density and strong IVI scores exhibit greater ecosystem stability and biodiversity richness. Four mangrove species were identified: *A. marina*, *A. lanata*, *B. cylindrica*, and *R. apiculata*. *A. marina* had the highest IVI across all sampling stations (150.62–263.55%), followed by *B. cylindrica* (36.45–108.39%), *R. apiculata* (26%), and *A. lanata* (14.96%). This dominance hierarchy was consistent across all growth stages, including saplings and seedlings. These indicators effectively reflect the condition of mangrove ecosystems and provide a practical basis for assessing their ecological integrity. The findings highlight the importance of integrating scientific monitoring with community-based conservation efforts to ensure long-term ecosystem health. This research offers valuable insights for informing sustainable coastal development strategies and enhancing local environmental management practices in vulnerable coastal regions.

INTRODUCTION

Mangrove ecosystems are among the most productive and ecologically valuable habitats worldwide. Globally, approximately 84 mangrove species have been identified, belonging to 16 families and 24 genera. Of these, only 70 species are classified as true mangroves, while the remaining 14 species are considered mangrove associates **(Jun *et al*., 2008)**. Typically found in intertidal zones **(Wang *et al*., 2019; DeYoe *et al*., 2020)**, mangroves play crucial roles in protecting coastlines, stabilizing sediment, providing habitats for various aquatic organisms, and serving as feeding, breeding, and nursery grounds **(Menéndez *et al*., 2020; Gijsman *et al*., 2021; Arceo-Carranza *et al*., 2024)**. Furthermore, mangrove forests are recognized as effective carbon sinks **(Choudhary *et al*., 2024; Sofiana *et al*., 2025)**, for mitigating global climate change.

Despite their ecological importance, mangrove forests in Southeast Asia, including Indonesia, are experiencing significant degradation. The region has the highest deforestation rate in Southeast Asia, primarily driven by aquaculture expansion and coastal land conversion **(Richards & Friess, 2016)**. These changes in land use and land cover (LULC) are caused by complex socio-environmental interactions and can have serious impacts on hydrological patterns, increasing flood risk, disrupting ecological networks, and reducing biodiversity **(Wiarta *et al*., 2025)**.

In Indonesia, West Kalimantan possesses significant potential for mangrove ecosystems since it holds the third-largest mangrove area, estimating around 149,800 ha **(Dharmawan *et al*., 2016; Arifanti *et al*., 2022)**. These mangrove forests are widely distributed along its coastal regions, including Jawai District in Sambas Regency. According to a study by **Yunita *et al*. (2024)**, the total mangrove area in Jawai was reported to be approximately 1,019.212 ha, with about 20.83% of this coverage growing in Desa Sarang Burung Kolam. However, these coastal ecosystems are increasingly threatened by anthropogenic pressures. In West Kalimantan, approximately 30.2% of mangrove areas have been converted into aquaculture ponds and 22.8% have experienced structural fragmentation **(Dharmawan *et al*., 2016; Arifanti *et al*., 2022)**.

Desa Sarang Burung Kolam, located in West Kalimantan, has experienced land cover changes over time, which have also affected its mangrove forest areas. These ecosystems face increasing pressure, resulting in loss of area and ecological stability. However, despite anecdotal evidence of degradation, peer-reviewed studies assessing the current status of mangrove vegetation in this area remain scarce. Critical uncertainties persist concerning (1) the spatiotemporal patterns of mangrove loss, (2) present-day vegetation structure and species composition, (3) landscape fragmentation, and (4) primary socioeconomic drivers triggering land use transitions **(Dharmawan *et al*., 2016; Arifanti *et al*., 2022; Wiarta *et al*., 2025)**.

Moreover, a significant hurdle in mangrove conservation at Desa Sarang Burung Kolam is the absence of crucial baseline ecological data. Without this foundational information, it's incredibly difficult to accurately assess the extent of mangrove degradation or to develop effective, data-driven conservation strategies based on indicators like mangrove density and important value index (IVI). Filling this critical data gap is paramount; it's essential for truly understanding the ecological dynamics of these vital mangrove forests and for guiding future science-based restoration and management efforts aimed at bolstering their resilience. Therefore, this study aimed to precisely evaluate the vegetation patterns and species composition of mangroves, specifically focusing on their density and important value index, within the coastal area of Desa Sarang Burung Kolam, West Kalimantan, Indonesia. This will serve as a crucial step in assessing the ecosystem health of this valuable area.

MATERIALS AND METHODS

1. Study area

This research was carried out from May to June 2025 in the mangrove forest of Desa Sarang Burung Kolam, Sambas Regency, West Kalimantan, Indonesia (Figs. 1, 2). Data collection was conducted at three stations as representatives of the study sites (Table 1).

Table 1. Sampling site and type of data collection

Site Code	Coordinate		Type of Data Collection
1	1° 24' 37.26''N	109° 2' 13.69''E	Species, density, DBH, salinity, temperature, pH, and fraction of sediment
2	1° 24' 45.12''N	109° 2' 14.83''E	
3	1° 25' 18.11''N	109° 2' 10.45''E	

Fig. 1. Mangrove condition at the study site (A) Station I, (B) Station II, (C) Station III

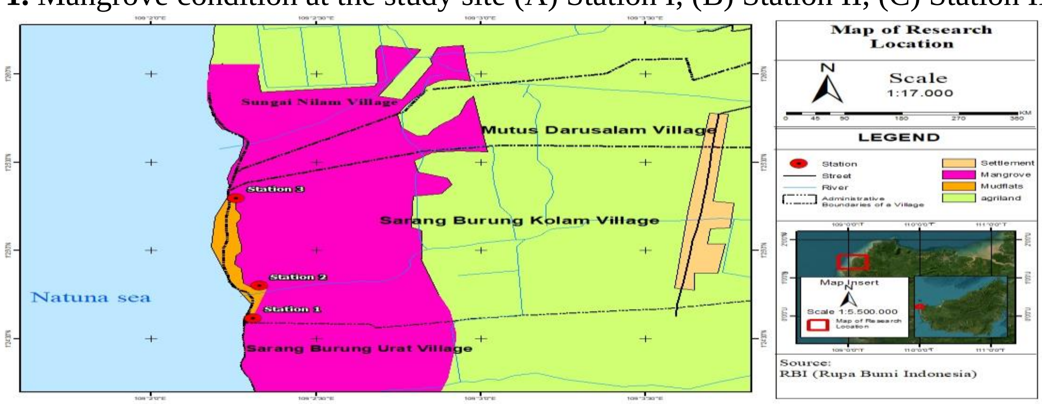

Fig. 2. Mangrove sampling location in Desa Sarang Burung Kolam, West Kalimantan

2. Sampling area design and plots establishment

Data collection on the composition, structure, and zonation of mangrove vegetation consisted of mangrove species, number of individuals of each species, and diameter at breast height (DBH). This collection was done using the transect method with quadratic plots measuring 10x10 m^2 for the tree level, 5x5 m^2 for the sapling strata, and 1x1 m^2 for the seedling stage **(Rahman *et al*., 2020)**. Based on the measurements, the mangrove area extended about 1,300m from the seaward toward the land. The sampling design for each station consisted of five plots placed along a line transect from the sea to the landward side, with an interval of 300m between plots (Fig. 3). Mangrove identification refers to several text books, such as Guide to the Introduction of Mangroves in Indonesia **(Noor *et al*., 2006)**, Guide Australia's Mangroves: The Authoritative Guide to Australia's Mangrove Plants **(Duke, 2006)**, Mangrove Guidebook for Southeast Asia **(Giesen *et al*., 2007)**, and Field Guide to Mangrove Identification and Community Structure Analysis **(Lebata-Ramos, 2013)**. On-site measurements of water quality (salinity, temperature, pH) were conducted at each location. Additionally, sediment samples were collected from these sites.

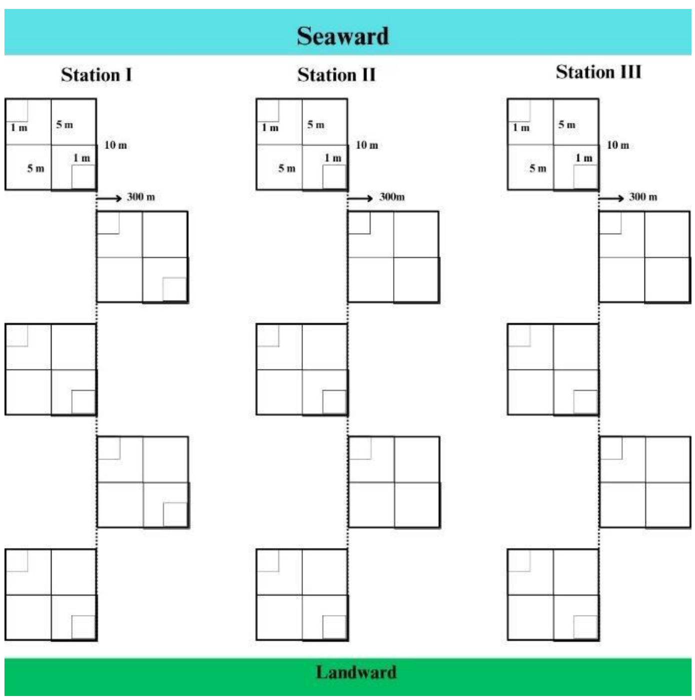

Fig. 3. Illustration of quadratic plots for collecting mangrove vegetation data at tree, sapling, and seedling levels

3. Measurement of environmental parameters

The environmental parameters measured included salinity, pH, and substrate type. Measurements were conducted in triplicate at each station. Salinity and pH were measured *in situ* using a Water Quality Checker AZ86031 instrument. Substrate samples were collected using a stainless-steel shovel at a depth of approximately 30cm from the soil surface. Samples were placed in pre-labeled polyethylene bags and were transported to the Laboratory of Chemistry and Soil Fertility, Faculty of Agriculture, Universitas Tanjungpura for further analysis. Soil texture was analyzed using the hydrometer method to determine the proportion of sand, silt, and clay fractions.

4. Data analysis

Data analysis of mangrove vegetation and community structure was conducted by calculating species density (D_i) and relative density (RD_i), frequency (F_i) and relative frequency (RF_i), dominance (C_i) and relative dominance (RC_i), importance value index (IVI), and diversity index (H'). Species density describes the number of individuals in a unit area **(Bengen *et al*., 2022)**, expressed as:

$$D_i = \frac{n_i}{A} \quad (1)$$

Where, D_i is density of species-i (ind/ha), n_i is number of individuals of species-i (ind), and A is sampling area (ha). Relative density expresses the percentage of individuals of a given species compared to the total number of individuals of all species, calculated using formula **(Bengen *et al*., 2022)**:

$$RD_i = \frac{n_i}{N} \, x \, 100\% \quad (2)$$

Table 2. Mangrove density criteria

Category		Density (ind/ha)
Good	Very dense	Density >1500
	Medium density	Density >1000-1500
Damaged	Low density	Density ≤1000

Source: **The Ministry of Environment and Forestry (2004)**

Species frequency (F_i) is the probability of finding species-i in the observed plot, calculated following the formula by **Bengen *et al*. (2022)**:

$$F_i = \frac{p_i}{\Sigma p} \quad (3)$$

Where F_i is the frequency of species-i, p_i is the number of plots in which species-i is found, and Σp is the total number of plots observed. While, relative frequency (RF_i) is the ratio between the frequency of species-i (F_i) and the total frequency for all species (ΣF), following this formula **Bengen *et al*. (2022)**:

$$RF_i = \frac{F_i}{\Sigma F} \, x \, 100\% \quad (4)$$

Mangrove species dominance is a measure of the degree to which a mangrove species dominates or controls an area compared to other mangrove species. The calculation of the species dominance was done using **Bengen *et al*. (2022)** formula:

$$C_i = \frac{\Sigma\, BA}{A} \text{ .... (5)}$$

Where, BA (basal area) = $\frac{1}{4}\pi \; x \; d^2$, π (3.14) is a constant, d is is the mangrove diameter, and A is sampling area. Relative dominance (RC_i) is the ratio between the area covered by species-i (C_i) and the total area covered by all species (ΣC).

$$RC_i = \frac{C_i}{\Sigma C} \; x \; 100\% \text{ .... (6)}$$

The importance value index (IVI) provides an overview of the influence or role of a particular species of mangrove in the community. For the tree stage, the IVI is obtained by totalling the relative density, relative frequency, and relative dominance, resulting in a value ranging from 0 to 300%. For the sapling and seedling levels, the IVI is calculated by combining only the relative density and relative frequency, with values ranging from 0 to 200% **(Bengen *et al*., 2022)**.

$$IVI = RD_i + RF_i + RC_i \text{ .... (7)}$$
$$IVI = RD_i + RF_i \text{ .... (8)}$$

RESULTS AND DISCUSSIONS

1. Mangrove species composition

According to species identification, four mangrove species were recorded in Desa Sarang Burung Kolam, namely *Avicennia marina*, *Avicennia lanata*, *Bruguiera cylindrica*, and *Rhizophora apiculata*, belonging two families and three genera. Both families consist of two species, respectively. At the study site, the species *A. marina* and *B. cylindrica* exhibited the most widespread distribution, with both species found at all sampling stations (Table 2).

Table 2. Mangrove species composition in Desa Sarang Burung Kolam

Family	Genus	Species	Local Name	Station			Conservation Status
				I	II	III	
Acanthaceae	*Avicennia*	*A. marina* (Forssk.) Vierh	Api-api putih	+	+	+	LC
	Avicennia	*A. lanata* Ridl	Api-api hitam	-	+	-	VU
Rhizophoraceae	*Bruguiera*	*B. cylindrica* (L.) Blume	Berus	+	+	+	LC
	Rhizophora	*R. apiculata* Blume	Bakau	-	+	-	LC

LC: Least Contern, **VU**: Vulnerable, (+) present, (-) absent

Specifically, we identified *A. lanata* alongside three other mangrove species in the study area. According to the International Union for Conservation of Nature (IUCN) Red List, *A. lanata* is classified as Vulnerable (VU), indicating a risk of extinction in the wild. The other three species, however, are listed as Least Concern (LC), reflecting their relatively stable populations and lower risk of extinction. This composition aligns with the findings of **Diba *et al.* (2022)**, who reported the same four species in Desa Sungai Nilam, located in the Jawai Subdistrict of Sambas Regency. *B. cylindrica* was also recorded at all sampling sites, but its presence was limited to plots situated closer to the land and near riverine inflows. This distribution pattern aligns with **Noor *et al*. (2006)**, who noted that Bruguiera species are typically found in the middle zones of mangrove ecosystems, behind the fringe zones dominated by *Avicennia*. Similar findings were reported by **Irpan *et al*. (2017)** in coastal areas of Kubu Raya Regency, where *A. marina* was dominant in the front zone, while *B. cylindrica* was more frequently found inland. This inland preference is likely associated with lower salinity levels and reduced tidal exposure, which are more suitable for *Bruguiera*. **Darwati *et al*. (2022)** reported that *Bruguiera* species generally grow at salinity levels below 25‰.

The other two species, *A. lanata* and *R. apiculata*, were only found at station II. This distribution is closely related to habitat preferences. According to **Noor *et al*. (2006)**, *A. lanata* typically grows on muddy substrates, along riverbanks, or in relatively drier mangrove zones. Station II, located near a river flow, provides such conditions, making it a suitable habitat for the establishment and growth of *A. lanata*. The presence of *R. apiculata* at this station may also be attributed to favorable environmental factors such as moderate salinity and nutrient availability. **Ferdiansyah and Ali (2024)** reported that mangrove biodiversity tends to be higher in riverine areas compared to coastal zones. This is largely due to the influence of freshwater inflows, which lower the salinity and enrich the substrate with organic matter. In addition, river currents transport nutrients and sediments that enhance soil fertility, thereby supporting the growth and diversity of mangrove species in these areas. Previous studies have also reported the presence and dominance of *A. marina* in the coastal areas of West Kalimantan, such as Sambas **(Dekky *et al*., 2016; Diba *et al*., 2022; Rafdinal *et al*., 2022)**, Mempawah **(Marini *et al*., 2018; Rumalean *et al*., 2019; Zuswiryati *et al*., 2022)**, Singkawang **(Nursofiati *et al*., 2020; Astuti *et al*., 2021)**, Sungai Kakap **(Muhardianshah *et al*., 2021)**, and Kayong Utara **(Raynaldo *et al*., 2023)**.

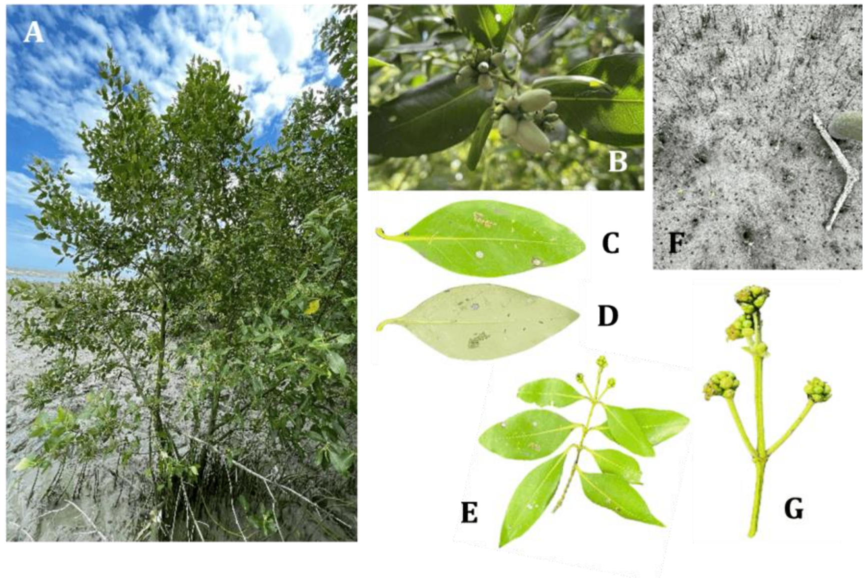

Fig. 4. Morphological characteristics of *Avicennia marina* showing: (A) Growth form; (B) Fruits; (C) Leaf margin (adaxial surface); (D) Leaf abaxial surface (yellowish); (E) Leaf arrangement (opposite); (F) Roots (pencil-like pneumatophores); (G) Inflorescence (raceme)

At the study site, *A. marina* (Fig. 4) was found to be small to medium trees. In addition, seedlings level were also found at all sampling stations. The bark color was green to gray with a smooth or slightly scaly surface. This species has an extensive lateral root system, equipped with pencil-shaped respiratory roots (pneumatophores) which grow vertically with a height of 15- 20cm. The leaves are thick, 6– 8cm long, elliptical or obovate-lanceolate with a pointed tip; the upper surface is glossy covered with glandular dots, and gray or silvery-white on the bottom. The flowers are clustered with white or golden-yellow in color; the fruits are oval in shape, light green, oval-shaped; the surface is covered with fine hairs, and the size is approximately 2cm. There are only five individuals of the species *A. lanata* (Fig. 5), mainly found in areas close to rivers. This species has a horizontal root system shaped like a pencil. The leaves are elliptical with rounded tips, the underside of the leaves is yellowish-white and covered with fine hairs. The flowers appear in clusters at the end of the panicle, and the fruit is heart-shaped with a short beak and a slightly yellowish-green color.

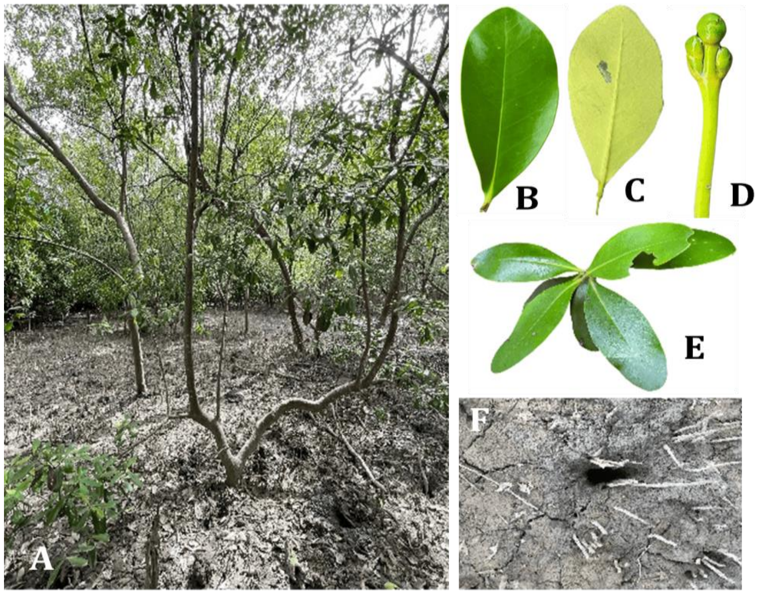

Fig. 5. Morphological characteristics of *A. lanata* showing: (A) Growth form; (B) Leaf margin (adaxial surface); (C) Leaf abaxial surface; (D) Inflorescence bud; (E) Leaf arrangement (opposite); (F) Pneumatophores roots

Fig. 6. Morphological characteristics of *Bruguiera cylindrica* exhibiting: (A) Growth form with leaf arrangement (whorly opposite); (B) Roots (knee roots); (C) Leaf margin (abaxial surface); (D) Leaf adaxial surface; (E) Inflorescence (raceme); (F) Propagule

Bruguiera cylindrica (Fig. 6) has knee roots or buttresses, gray bark with a relatively smooth surface and a number of small lenticels. The leaves are opposite, with a bright green upper surface and a slightly yellowish green underside. The flowers are clustered and appear at the end of the inflorescence, with yellowish petals and a tube-like base. The propagules are elongated cylindrical in shape, green in color, with the base attached to the flower petals. They measure between 8- 14cm in length and have a diameter of approximately 5- 8mm. The species *R. apiculata* (Fig. 7) grows with a distinctive root system and sometimes has aerial roots emerging from the branches. The bark is dark gray. The leaves are leathery and narrowly elliptical with pointed tips, arranged oppositely. The flower heads are yellowish, and the fruits "propagule" are elongated spherical.

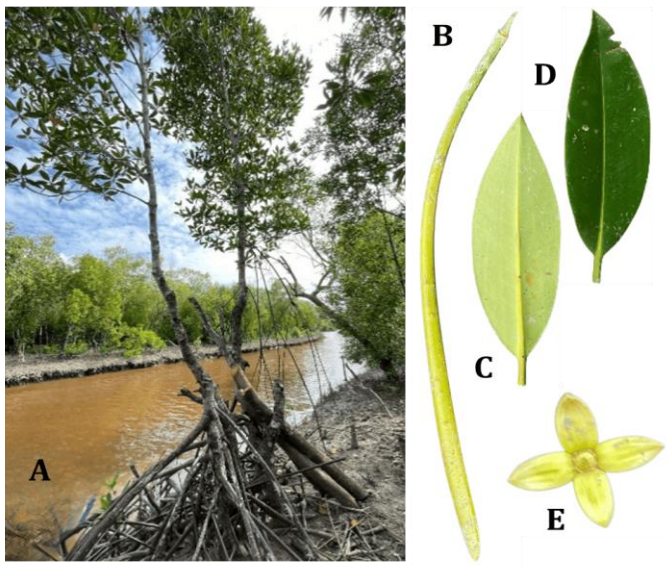

Fig. 7. Morphological characteristics of *Rhizophora apiculata* elucidating: (A) Growth form with leaf arrangement (opposite); (B) Propagule; (C) Leaf margin (abaxial surface); (D) Leaf adaxial surface; (E) Inflorescence

2. Mangrove density

The density and relative density of mangrove species in Desa Sarang Burung Kolam varied across stations and growth stages. At the tree level, densities ranged from 20– 620ind/ ha which falls within the low density category based on the classification by the **Ministry of Environment and Forestry (2004)**. In contrast, sapling densities were more variable, ranging from 80– 6320ind/ ha, representing low to high density conditions. On the other hand, the seedlings layer exhibited high densities (7000– 30000ind/ ha), indicating active regeneration across several sites.

At station I, *A. marina* exhibited the highest tree density (360ind/ ha), accounting for 94.74%, while *B. cylindrica* contributed only 5.26% (20ind/ ha) of the community. A similar trend was observed in the sapling (6320ind/ ha, 68.69%) and seedling (30000ind/ ha, 61.22%) stages, indicating the dominance of *A. marina* at this station. In contrast, station II showed a more balanced distribution among four species. *A. marina* also showed high densities, particularly in the tree (620ind/ ha) and saplings (2680ind/ ha) stages, while its contribution decreased in the seedlings strata (13000ind/ ha). On the other side, *B. cylindrica* was the second most abundant species at this station, *A. lanata* was present in trees and saplings but absent from seedlings, and *R. apiculata* contributed only a small amount to the community at all three stages. In station III, *A. marina* was exclusively dominant in saplings and seedlings, while *B. cylindrica* was only found in trees and saplings layers but was absent in the seedling stage. These results indicate that *A. marina* dominates most stages across all stations, with *B. cylindrica* and *R. apiculata* contributing notably in certain areas, while *A. lanata* appears to be restricted and less abundant, particularly in early growth stages.

The dominance of *A. marina* at all growth levels (trees, saplings, and seedlings) in the study area can be attributed to its status as a native and pioneer species, demonstrating a strong ability to adapt to the environmental conditions of Desa Sarang Burung Kolam. This species is highly tolerant of high salinity levels and can thrive in areas frequently affected by tidal forces **(Sabri *et al*., 2018)**. Furthermore, the minimal exploitation of *A. marina* by local communities results in low levels of disturbance, promoting its widespread growth in the region. Its role as a pioneer species **(Thatoi *et al*., 2016)** enables it to quickly colonize newly available or disturbed intertidal zones, where many other species struggle to survive. Additionally, its propagules disperse widely and establish effectively, facilitating natural regeneration **(Van der Stocken *et al*., 2019)**. Combined with its efficient life cycle and rapid growth from seedlings to mature trees, these factors collectively contribute to the widespread dominance of *A. marina* at all growth levels in Desa Sarang Burung Kolam.

Table 3. Density (D_i), relative density (RD_i), frequency (Fi), relative frequency (RFi), dominance (C_i), relative dominance (RC_i), and importance value index (IVI) of mangrove species in the tree level

Station	**Species**	**D_i (ind/ha)**	**RD_i (%)**	**Fi**	**RFi (%)**	**C_i (m^2/ha)**	**RC_i (%)**	**IVI (%)**
I	*A. marina*	360	94.74	0.80	80	488.87	99.97	274.70
	B. cylindrica	20	5.26	0.20	20	0.17	0.03	25.30
	TOTAL	**380**	**100**	**1.00**	**100**	**489.04**	**100**	**300**
II	*A. marina*	620	79.49	0.8	44.44	10.11	84.53	208.46
	B. cylindrica	100	12.82	0.4	22.22	1.28	10.70	45.75
	A. lanata	20	2.56	0.2	11.11	0.20	1.65	15.33
	R. apiculata	40	5.13	0.4	22.22	0.37	3.12	30.46
	TOTAL	**780**	**100**	**1.80**	**100**	**11.96**	**100**	**300**

III	*A. marina*	220	84.62	0.6	75	3.23	87.78	247.39
	B. cylindrica	40	15.38	0.2	25	0.45	12.22	52.61
	TOTAL	**260**	**100**	**0.80**	**100**	**3.68**	**100**	**300**

Table 4. Density (Di), relative density (RDi), frequency (Fi), relative frequency (RFi), dominance (Ci), relative dominance (RCi), and importance value index (IVI) of mangrove species in the sapling level

Station	**Species**	**D_i (ind/ha)**	**RD_i (%)**	**Fi**	**RFi (%)**	**C_i (m^2/ha)**	**RC_i (%)**	**IVI (%)**
I	*A. marina*	6320	68.69	1	62.50	12.30	82.07	213.26
	B. cylindrica	2880	31.31	0.6	37.50	2.69	17.93	86.74
	TOTAL	**9200**	**100**	**1,60**	**100**	**14.99**	**100**	**300**
II	*A. marina*	2680	55.83	1	41.67	10.30	53.12	150.62
	B. cylindrica	1880	39.17	0.8	33.33	6.96	35.89	108.39
	A. lanata	160	3.33	0.2	8.33	0.64	3.30	14.96
	R. apiculata	80	1.67	0.4	16.67	1.49	7.69	26.03
	TOTAL	**4800**	**100**	**2,4**	**100**	**19.39**	**100**	**300**
III	*A. marina*	2720	95.77	0.8	80	257.97	87.78	263.55
	B. cylindrica	120	4.23	0.2	20	35.92	12.22	36.45
	TOTAL	**2840**	**100**	**1**	**100**	**293.89**	**100**	**300**

Table 5. Density (Di), relative density (RDi), frequency (Fi), relative frequency (RFi), dominance (Ci), relative dominance (RCi), and importance value index (IVI) of mangrove species in the seedling level

Station	**Species**	**D_i (ind/ha)**	**RD_i (%)**	**Fi**	**RFi (%)**	**IVI (%)**
I	*A. marina*	30000	61.22	0.8	57.14	118.36
	B. cylindrica	19000	38.78	0.6	42.86	81.64
	TOTAL	**49000**	**100**	**1.40**	**100**	**200**
II	*A. marina*	13000	34.21	0.6	42.86	77.07
	B. cylindrica	18000	47.37	0.6	42.86	90.23
	A. lanata	0	0	0	0	0
	R. apiculata	7000	18.42	0.2	14.28	32.70
	TOTAL	**38000**	**100**	**1.40**	**100**	**200**
III	*A. marina*	32000	100	0.8	100	200
	B. cylindrica	0	0	0	0	0
	TOTAL	**32000**	**100**	**0.8**	**100**	**200**

3. Mangrove resilience

Such adaptations significantly enhance *A. marina*'s survival and provide competitive advantage, especially since oxygen levels in mangrove ecosystems are often low. This tolerance to both anaerobic conditions and frequent seawater inundation allows *Avicennia* to flourish throughout various zones of the mangrove ecosystem. Additionally, *Avicennia* species display reproductive adaptations that boost their dispersal potential; their small, lightweight fruits are easily carried by tidal currents and water movement, facilitating wider distribution. The high density of this species further supports its capacity to regenerate and establish colonization across various sediment types **(Haseeba *et al*., 2025)**. As noted by **Triest *et al*. (2021)**, the mangrove regeneration process is significantly influenced by the extent to which propagules can spread and successfully settle in suitable environments for growth. The large number of seedlings observed at the study site also indicates successful propagule formation and development, confirming the strong regenerative potential of this species in this ecosystem.

As depicted in Fig. (8), mangrove species generally exhibit strong reproductive ability, which is crucial for ecosystem resilience (except *A. lanata*). Despite this, a significant bottleneck in recruitment exists: less than 20% of seedlings (e.g., *A. marina* and *B. cylindrica*) successfully transition to the sapling stage, and fewer than 10% ultimately reach tree maturity. Key impediments to seedling survival include predation, soil structure, intense competition for space, and the impacts of water hydrodynamics. This situation is closely linked to the Importance Value Index (IVI), as *A. marina* plays a vital role in the community. Moreover, the high salinity of the environment provides ideal conditions that match the ecological niche of *A. marina*. **Budiadi *et al*. (2022)** found that an optimal salinity level for seedling production is between 5 and 15 ppt. Additionally, sandy soil with higher porosity is recommended as a growth medium for initial development.

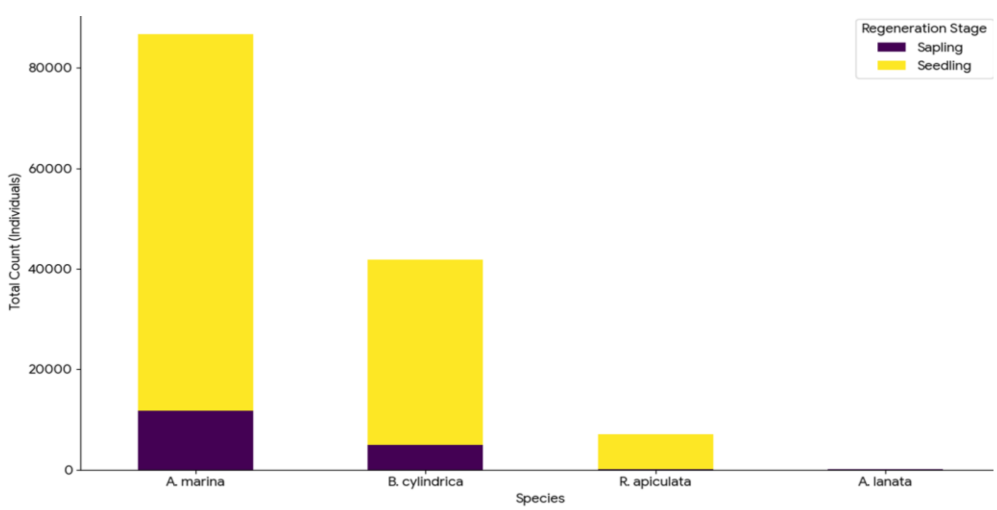

Fig. 8. Mangrove regeneration potential: Species distribution of saplings and seedlings

The second high presence is *B. cylindrica* at the seedling and sapling stages, indicating active natural regeneration within the study area. This pattern can be attributed to the viviparous reproductive strategy **(Aluri & Karyamsetty, 2018)**, in which the propagules develop while still attached to the parent tree. This form of reproduction offers a significant ecological advantage, as the propagules are physiologically mature and capable of immediate establishment upon detachment, thereby enhancing seedling survival in a dynamic environment. From an ecological perspective, *B. cylindrica* is found in the middle to landward zones of mangrove forests in Desa Sarang Burung Kolam. These zones are characterized by less frequent tidal inundation, relatively stable substrates, providing favorable conditions for root development and seedling establishment. The infrequent submergence also reduces physiological stress associated with prolonged anoxic conditions, thereby enhancing the survival and growth of seedlings **(Mangora *et al*., 2014; Piro *et al*., 2023)**. Its ability to colonize a range of sediment types **(Albarico, 2023)** further supports its widespread regeneration. Furthermore, the density of *B. cylindrica* observed at stations I and II may also be attributed to favorable microhabitat conditions, which provide a conducive environment for propagule settlement and early seedling development. These stations likely offer relatively stable substrates, moderate tidal inundation, and sheltered conditions that reduce mechanical disturbance, thus increasing propagule retention and survival. In contrast, station III–particularly in the middle zone–exhibited signs of mangrove degradation, with a high incidence of standing dead trees and sparse canopy cover. Such environmental degradation can reduce propagule anchoring potential, increase exposure to desiccation, and all of which negatively impact seedling establishment and survival **(Asbridge *et al*., 2015)**. The absence of a living canopy can also reduce seed supply and limit the availability of suitable microhabitats for propagule development, further limiting regeneration dynamics in this region.

4. Mangrove zonation

Mangrove zonation is the horizontal distribution pattern of mangrove plants from the shoreline toward the mainland. This zoning is formed due to differences in environmental conditions such as tidal, water salinity, substrate characteristics, and topography which influence the tolerance and adaptation of each mangrove species **(Mughofar *et al*., 2018)**. The mangroves of Sarang burung kolam village are intrinsically linked to Borneo's western coastal mangrove belt, a formation shaped by the continuous flow of thousands of peat swamp rivers emptying into the South China Sea. In this region, these mangrove ecosystems serve as vital coastal habitats, performing critical functions such as coastline protection, biodiversity support, and the provision of essential ecosystem services.

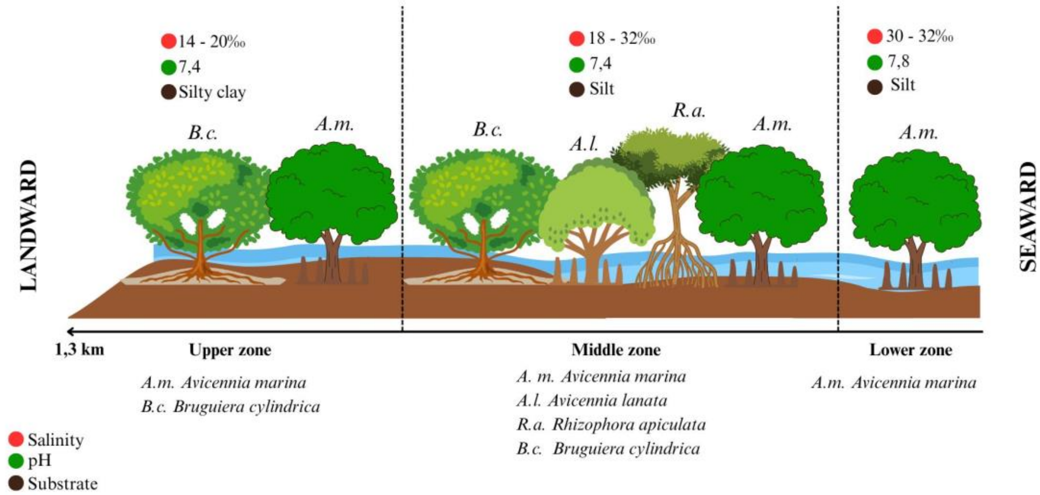

Fig. 9. Mangrove zonation in Desa Sarang Burung Kolam, West Kalimantan

We found that the species composition in this area is typically seaward mangrove zones (Fig. 9), where *Avicennia* sp. dominantly covers the community. The mangrove zonation in Desa Sarang Burung Kolam stretches approximately 1.3 kilometers from the seaward (lower zone) to the landward (upper zone). The seaward zone of a mangrove forest, often called the pioneer or front fringe, is a truly challenging frontier – the very edge closest to the open ocean or estuary mouth. Here, conditions are extreme: relentless high salinity from direct seawater, frequent and powerful tidal surges, unstable, muddy ground, and intense sunlight.

The lower zone is characterized by the exclusive presence of *A. marina*, a pioneer mangrove species well-known for its high tolerance to salinity and frequent tidal inundation. They achieve this through incredible adaptations, like special leaf glands that actively "sweat out" excess salt and clever root systems that act as filters, blocking harmful salt from entering their tissues **(Macnae, 1969; Ball, 1988; Kathiresan & Bingham, 2001)**. This makes *Avicennia* perfectly suited to be among the first to colonize these exposed, constantly inundated mudflats **(Duke, 1991; Kathiresan & Bingham, 2001)**. **Islam *et al*. (2022)** assume, *Avicennia* species are remarkably versatile, capable of thriving across all mangrove zones, from the seaward fringe to the middle and upper reaches, unlike *Bruguiera* species which typically inhabit only the middle and upper zones. This broad distribution underscores the role of *A. marina* as a pioneer species, highly adaptable to diverse environmental conditions. Its prevalence is further supported by key morphological adaptations, notably its lateral roots equipped with pneumatophores that emerge above the soil surface. These pneumatophores contain lenticels, enabling the absorption of atmospheric oxygen **(Kitaya *et al*., 2002)**.

Moving seaward to the middle zone, this transitional area supports greater species diversity, including *A. marina*, *A. lanata*, *R. apiculata*, and *B. cylindrica*. Similar findings were reported by **Kilinau *et al*. (2023)**, who also recorded this species composition in the middle zone. The occurrence of *R. apiculata*, which possesses distinctive stilt roots, indicates its adaptation to soft, unstable sediments and moderate salinity levels. The co-existence of multiple species suggests that this transitional area provides optimal environmental conditions for mangrove growth and natural regeneration. In contrast, the upper zone—closer to the mainland—is dominated by *A. marina* and *B. cylindrica*. *B. cylindrica* is typically found in areas with firmer substrates and reduced tidal influence, indicating its preference for locations less directly affected by seawater intrusion.

CONCLUSION

Four mangrove species were identified, including *A. marina*, *A. lanata*, *B. cylindrica*, and *R. apiculata*. Species of *A. marina* had the highest density and IVI across all sampling stations, followed by *B. cylindrica*. The regeneration analysis further revealed that both species exhibited high numbers of seedlings compared to saplings, indicating strong natural recruitment and the potential for long-term forest persistence. Our study shows that having dense mangrove forests and high importance value index (IVI) scores isn't just good news for scientists, it's a clear sign that the ecosystem is healthy, stable, and full of life. Dense mangrove stands with continuous regeneration are reliable indicators of ecosystem resilience. In Desa Sarang Burung, these findings offer a deeper understanding of how well the mangroves are doing and how important they are in protecting the coastline from erosion and the growing impacts of climate change. More than that, the research highlights how crucial community involvement and continuous monitoring are in keeping these ecosystems resilient. The implications are clear: protecting mangroves isn't just about conserving nature, it's also about securing sustainable livelihoods, supporting biodiversity, and building long-term coastal resilience. This study provides a strong foundation for conservation planning and sustainable coastal development that puts both people and the environment at the center.

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