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RESEARCH ARTICLE

Diversity, distribution and zonation patterns of mangrove species in Sulaman Lake, Tuaran, Sabah

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ABSTRACT

Sulaman Lake is located in Tuaran-Kota Belud, Sabah is an important wetland area that supports rich mangrove ecosystems and provides resources for nearby communities. This study aimed to document and compare the diversity of mangrove species found across four zones which are Sulaman Lake, Sungai Kindu, Kampung Serusop, and Sungai Betutai. A total of 24 mangrove species were identified throughout this floral survey consisting of 12 exclusive and 12 associate mangrove species. Kampung Serusop was noted for having the greatest number of mangrove species found (18 species), followed by Sungai Betutai (19 species), Sungai Kindu (7 species), and Sulaman Lake (5 species). The Rhizophoraceae family was the most dominant and widely distributed particularly *Rhizophora apiculata*, *R. mucronata*, and *Bruguiera gymnorhiza*, which thrive in areas with strong tidal impact. The differences between exclusive and associate species reflected distinct zonation patterns, likely influenced by tidal changes and surrounding habitat features. All recorded species were listed as Least Concern by the IUCN. Overall, the findings highlight Sulaman Lake as a valuable and biodiverse mangrove habitat.

1. INTRODUCTION

Mangrove forests are characterized by special intertidal ecosystems that are essential for preserving shorelines, fisheries, carbon sequestration, and coastal biodiversity. These ecosystems, which are found where land meets the sea, are home to a diverse range of plants and animals that have adapted to live in salty, wet, and anoxic soils. Mangrove forests of Malaysia, especially in the state of Sabah on the island of Borneo, are among the most ecologically significant and biologically varied environments in Southeast Asia (Sabah Forestry Department, 2021).

Mangrove plant species are generally classified into two main groups which are the exclusive and associate mangroves. The associate types are less specialized and can also grow in nearby freshwater or terrestrial habitats, while exclusive mangroves are usually restricted to tidal areas and have evolved special traits such as pneumatophores, salt-excreting leaves, and viviparous propagules. Common examples of exclusive mangroves include species from the genera *Rhizophora*, *Avicennia*, *Bruguiera*, and *Sonneratia* (Duke & Kathiresan, 2022; Spalding et al., 2021; Ferreira et al., 2024).

Numerous environmental conditions, such as salinity gradients, tidal inundation, sediment features, and human disturbances, can affect the variety and abundance of exclusive and associate mangrove species. Despite the acknowledged value of mangrove forests in Sabah, the sustainability and composition of these ecosystems are under threat due to growing pressures from logging, aquaculture, and coastal development (Ghazali et al., 2018). Planning for conservation, restoring ecosystems, and assessing biodiversity all depend on an understanding of the floristic structure of exclusive and associate species.

The purpose of this study is to record and compare the distribution and diversity of associate and exclusive mangrove species across a few chosen Sabah mangrove locations. We provide baseline data to support sustainable management initiatives and advance an improved comprehension of mangrove ecology in the Sulaman Lake by spotting trends in species composition and habitat preferences.

2. MATERIALS AND METHODS

During the three days, from April 17 to April 19, 2025, a survey of mangrove flora was carried out both on land, lake and rivers using four observation routes. Sulaman Lake area, Sungai Kindu, Sungai Betutai, and Sungai Serusop are the four survey sites that were chosen for this study. Since Zones 1, 3, and 4 are the only regions containing rivers and

mangrove forests, they received a lot of attention for this study. Zone 1 contains the locations of Sulaman Lake area and Sungai Kindu, while Zone 3 has Sungai Kampung Serusop and Zone 4 contains Sungai Betutai.

Our group used binoculars upon conducting the survey of the mangrove trees. We will identify the species that are there and note their locations. For documentation purposes, pictures will be taken. Samples will be gathered and examined at the faculty laboratory for species that cannot be recognized on-site. In order to access more remote areas and create a comprehensive dataset that highlights the diversity in these vital habitats, we respectfully need permission to use a boat to navigate the mangrove waterways. The research results will yield a comprehensive inventory of mangrove species and related species, including rare and endangered ones, that might exist in the area.

In the field, the transect survey was done perpendicular to the shoreline reaching from the intertidal zone to the landward margin. This location was chosen to ensure full coverage of the tidal gradient, which has a significant impact on mangrove species zonation (Duke & Kathiresan, 2022). Important details about each individual were recorded, including species identity, DBH, height, and significant physical features. The point at which this threshold was chosen to exclude seedlings and saplings while focusing on mature trees that contribute significantly to biomass and forest structure (Giri et al., 2019). GPS devices had been used to record each individual's coordinates, which facilitated geographical analysis and ensured replicability for future monitoring.

2.1 Flora Survey Approach

A transect survey was used to analyse the composition of mangrove plants in selected mangrove zones. This strategy enabled the study of species zonation patterns and floristic composition changes along tidal and elevation gradients (Spalding et al., 2021). In situ, species were identified using morphological characteristics such as leaf form, bark texture, root type, and reproductive structures. Where species could not be definitely recognised in the field, voucher specimens were gathered for laboratory analysis. GPS devices were utilised to pinpoint the exact locations of notable species. Regional floristic references and taxonomy keys, particularly Tomlinson (1986), were used to aid identification, and local mangrove checklists from the Forest Research Institute Malaysia supplemented this.

Transect-quadrat surveys are widely used in mangrove research because to their capacity for systematic sampling across environmental gradients, including tidal influence, salinity, and sediment composition. In contrary to random sampling, which may neglect zonation patterns, transects systematically document ecological transitions, proving them especially beneficial in varied environments such as Sulaman Lake (Spalding et al., 2021). The same methodologies have been implemented in other areas of Sabah, including Klias Peninsula and Kota Kinabalu Wetlands, where as it gives comparable information for regional biodiversity assessment (Ghazali et al., 2018).

In conclusion, the flora survey methodology utilised in this study combined transect-quadrat sampling with stringent species identification and verification methods. By integrating field-based morphological assessment with herbarium consultation and expert advice, the strategy ensured accurate species documentation over Sulaman Lake and its surrounding mangrove zones. The data generated not only give a full species checklist, but also serve as a platform for analysing biodiversity, species zonation, and biomass distribution. Although the method is resource-intensive, its ability to produce high-quality data makes it essential for ecological study, conservation planning, and long-term monitoring of mangrove ecosystems in Sabah.

2.2 Species Identification

Identifying plant species accurately was a key part of this study, as it helped us understand the overall composition of the mangrove forest. During the fieldwork, we identified each plant species we encountered in the survey plots by looking closely at features like the shape and arrangement of leaves, the type of roots, the texture of the bark, and any visible flowers or fruit. To assist with this process, we referred mainly to The Botany of Mangroves by Tomlinson (1986), which is a widely used reference for mangrove species, and also used local plant checklists published by the Forest Research Institute Malaysia (FRIM, 2020). Not only that, the *Kota Kinabalu Wetlands: Towards Its Ramsar Status* report (Yayasan Sabah & Majlis Bandaraya Kota Kinabalu, 2017) provides a detailed overview of mangrove species commonly found in Sabah, including those documented along the west coast such as *Rhizophora apiculata*, *Avicennia alba*, and *Bruguiera gymnorhiza*. These references helped us distinguish between true mangrove species—those that only grow in tidal zones—and associate species that often grow near mangroves but also exist in other habitats. If we weren't completely sure about a species in the field, we took clear photographs and detailed notes so we could double-check later, either by comparing with herbarium samples or asking local botanical experts. Using multiple resources like this gave us confidence in the accuracy of our species records and made our survey results more reliable.

Morphological features such as leaf shape, venation patterns, bark texture, root structures, and reproductive organs are still the most commonly used indicators for

identifying mangrove species since they are easily visible in the field and are often unique to certain taxonomic. For example, pencil-like pneumatophores distinguish *Avicennia* spp., whereas stilt roots distinguish *Rhizophora* spp. (Duke & Kathiresan, 2022). These characteristics originated as ecological adaptations to the intertidal habitat, making them both dependable and informative when discriminating between exclusive and associate mangroves. The use of morphological features is also less expensive than molecular approaches, which, while exact, need laboratory facilities and funding that may not be available in rapid ecological surveys (Spalding et al., 2021).

However, seasonal conditions can have an impact on field identification accuracy. Particular mangrove species are quicker to differentiate between when they are flowering or fruiting, as reproductive structures provide apparent differentiating traits. For example, the cigar-shaped propagules of *Rhizophora mucronata* and the round fruits of *Sonneratia alba* are easily identifiable during the fruiting season but not at other times of the year. When reproductive organs are absent, researchers must rely more strongly on vegetative qualities such as leaf arrangement and bark characteristics, which can occasionally overlap between species, raising the danger of misidentification (Ferreira et al., 2024). Recognising these seasonal constraints, surveys are best undertaken across numerous seasons to boost confidence in species records.

Cross-verification approaches were used to improve identification reliability. Voucher specimens of unknown individuals were collected and pressed for further comparison with herbarium collections at Universiti Malaysia Sabah and references from the Forest Research Institute Malaysia (FRIM, 2020). The collected samples served as archived documents that taxonomic experts may review if there were any disputes. In addition, digital images of diagnostic features were acquired in situ and then compared to published photographic databases and regional mangrove checklists (Shin et al., 2015). The combined efforts of field identification, herbarium consultation, and expert validation decreases the possibility of errors and assures that the Sulaman Lake species list is comprehensive and accurate.

In addition to herbarium and FRIM resources, regional publications have also been valuable for validating species presence and distribution. For instance, the *Kota Kinabalu Wetlands: Towards Its Ramsar Status* report (Yayasan Sabah & Majlis Bandaraya Kota Kinabalu, 2017) provides a detailed overview of mangrove species commonly found in Sabah, including those documented along the west coast such as *Rhizophora apiculata*, *Avicennia alba*, and *Bruguiera gymnorhiza*. Comparing the field observations with these locally verified records strengthened the accuracy of species identification and ensured consistency with other ecological assessments conducted in nearby wetland systems. This cross-reference with regional data also helped confirm that the species composition observed at Sulaman Lake aligns closely with patterns reported in other coastal mangrove areas of Sabah.

2.3 Comparison of Family and Species Distribution Access Nearby Sites

The study found notable variations in the distribution of mangrove families and species throughout the investigated areas. Kampung Serusop and Sungai Betutai have the highest species richness, with 18 and 19 species, respectively, encompassing both exclusive and associated mangrove types. Kampung Serusop has a higher number of species because it uses both land and marine observation methods, as opposed to other sites that rely only on boat-based surveys. This conclusion is consistent with prior research indicating that thorough survey approaches frequently result in higher biodiversity detection (Yeo et al., 2021). In comparison, the Sulaman Lake area and Sungai Kindu, both in Zone 1, had lower species counts, with only 5 and 7 species each.

A study of mangrove species and family distributions across the four investigated sites which are Kampung Serusop, Sungai Betutai, Sungai Kindu, and the Sulaman Lake area has showed significant variances due to both ecological and methodological issues. Overall, 24 species from 12 families were identified, with Rhizophoraceae, Avicenniaceae and Arecaceae being the most often represented families across sites. These findings show the ecological dominance of distinct mangrove families, as well as site-specific variation in richness and composition caused by habitat heterogeneity and environmental gradients.

Rhizophoraceae emerged as the most widespread and abundant family, with members including *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Bruguiera gymnorhiza*, and *Ceriops tagal*. Members of this family were regularly found at all four sites, demonstrating their resilience to a variety of tidal and sedimentary environments. Their structural characteristics, particularly stilt roots and viviparous propagules, allow them to dominate both the offshore and middle-intertidal zones, where they contribute significantly to coastal stabilisation and sediment accretion (Duke & Kathiresan, 2022). The presence of these species at multiple sites illustrates Rhizophoraceae's resilience and ecological value in preserving mangrove forest structure.

The proportion of exclusive to associate species varied significantly between locations, providing information regarding connectivity between habitats and environmental influence. Kampung Serusop had the most balanced

composition, with 18 species (10 exclusive, 8 associate), which likely reflected its location at the intersection of riverine and terrestrial ecosystems. Sungai Betutai had 19 species (9 exclusive, 10 associate), with an increased proportion of associates, indicating substantial terrestrial influence and stronger ecological connection with surrounding highland systems. Sulaman Lake (3 exclusive, 2 associate) and Sungai Kindu (2 exclusive, 5 associate) had significantly lower richness.

Exclusives dominate at Sulaman Lake, indicating a more tidal-driven habitat, whereas associates dominate at Sungai Kindu, indicating transitional conditions with low tidal flushing. These ratios give significant ecological signals: exclusive-rich sites are essential for preserving basic mangrove processes like sediment trapping and carbon storage, whereas associate-rich sites improve landscape biodiversity and ecological linkages (Spalding et al., 2021).

3. RESULT AND DISCUSSION

A total of 24 mangrove species were identified throughout this floral survey with 12 species being exclusive mangroves, while the remaining 12 species were associated mangroves.

With 18 species (10 exclusive, 8 associate), Kampung Serusop (Zone 3) had the highest species richness. Unlike other sites, which were mostly examined by boat, this site was unique in that it was observed using both terrestrial and marine approaches. The higher species detection was probably caused by the more comprehensive survey strategy, which captured a greater variety of plant types throughout the riverine and forest edge zones. *Bruguiera gymnorhiza*, *Avicennia alba*, *Ceriops tagal*, and *Hoya verticillata* are notable species that are unique to this location; *Hibiscus tiliaceus*, *Ipomoea pes-caprae*, and *Scyphiphorea hydrophyllacea* were also observed as associates.

Sungai Betutai (Zone 4) came next, with 19 species listed, 9 of which were exclusive and 10 of which were associate. Despite having fewer exclusive species than Kampung Serusop, Sungai Betutai had a high diversity of companion species such *Terminalia catappa*, *Wedelia biflora*, and *Morinda citrifolia*.

Sungai Kindu and Sulaman Lake area (both in Zone 1) had lower levels of variety. Sungai Kindu has seven species (2 exclusive, 5 associate), but Sulaman Lake area had only five (3 exclusive, 2 associate). The reduced richness may be attributed to limited accessibility or a narrower habitat range within the sampled locations. Exclusive species such as *Rhizophora apiculata*, *Rhizophora mucronata*, and *Nypa fruticans* were consistently found in both locations, indicating a steady, but less diverse, mangrove presence.

Several species were present in all or the majority of places. *Rhizophora apiculata* and *R. mucronata*, for example, were detected at all four locations, demonstrating their dominance and adaptability in a variety of mangrove settings. These exclusive species are critical components of the forest structure, helping to stabilise the shoreline and retain silt. Meanwhile, associated species like *Pluchea indica* and *Pandanus tectorius* were more limited to specialised microhabitats along the mangrove edge.

The presence of both exclusive and associated mangrove species across the study locations demonstrates the importance of preserving a diverse range of habitat types in the landscape. This diversity not only shows the area's biological richness, but it also supports a diverse range of plant and animal life that rely on various aspects of the mangrove ecosystem.

Despite differences in overall species richness, members of the Rhizophoraceae family, such as *Rhizophora apiculata* and *R. mucronata*, were consistently found throughout all four sites, demonstrating their dominance and resilience in tropical mangrove ecosystems (Duke & Kathiresan, 2022; Alongi 2022). These species are important ecological players in sediment trapping, coastline stabilisation, and carbon storage (Alongi, 2022; Rahman et al., 2021). Differences in species and family distribution between neighbouring sites may represent variations in habitat complexity, environmental gradients, and anthropogenic pressure, all of which are known to influence mangrove biodiversity and structure (Carugati et al., 2018; Nauta et al., 2023).

Zonation is one of the most distinguishing characteristics of mangrove ecosystems, and the findings of this study revealed significant patterns of species distribution along tidal and elevation gradients. *Rhizophora apiculata* and *R. mucronata* were consistently prominent at all examined sites along the seaward boundary. Their structural features, particularly the large prop roots, enable them to become embedded in soft, wet sediments and endure powerful tidal currents. These roots also serve as sediment traps, stabilising the shoreline and providing microhabitats for crabs, molluscs, and juvenile fish (Duke & Kathiresan, 2022; Alongi 2022). The prevalence of *Rhizophora* spp. in this zone demonstrates not just physiological adaptation, but also their ecological relevance as ecosystem engineers.

3.1 Mangrove Status

Table 1 summarises the 24 mangrove species recorded at the four areas, categorizing them as exclusive or associate according to the Mangrove Guidebook for Malaysia (Shin et al., 2015). The IUCN Red List currently lists all recorded species as Least Concern (LC), meaning that their

populations face no forthcoming global threat. Local population trends, however, may fluctuate due to site-specific factors such as land conversion, logging, or water pollution, which are not taken into account in the global assessment.

Table 1: Mangrove status available in the Sulaman Lake.

Mangrove Status (with Red List Assessment based on IUCN)		
	Exclusive	Associates
1.	*Rhizophora apiculata* (Least Concern)	*Hibiscus tiliaceus* (Least Concern)
2.	*Rhizophora mucronata* (Least Concern)	*Oncosperma tigilarium* (Least Concern)
3.	*Rizophora stylosa* (Least Concern)	*Glochidion littorale* (Least Concern)
4.	*Bruguiera gymnorrhiza* (Least Concern)	*Pluchea indica* (Least Concern)
5.	*Avicennia alba* (Least Concern)	*Macaranga gigantea* (Least Concern)
6.	*Nypa fruticans* (Least Concern)	*Syzygium* sp. (Least Concern)
7.	*Sonneratia alba* (Least Concern)	*Scyphiphorea hydrophyllacea* (Least Concern)
8.	*Hoya verticillata* (Least Concern)	*Ipomea pes-caprae* (Least Concern)
9.	*Lumnitzera littorea* (Least Concern)	*Morinda citrifolia* (Least Concern)
10.	*Xylocarpus granatum* (Least Concern)	*Pandanus tectorius* (Least Concern)
11.	*Acrostichum speciosum* (Least Concern)	*Terminalia catappa* (Least Concern)
12.	*Ceriops tagal* (Least Concern)	*Wedelia biflora* (Least Concern)

Among the 12 exclusive mangrove species, dominant species such as *Rhizophora mucronata*, *Rhizophora apiculata*, and *Nypa fruticans* were consistently found across multiple zones. Meanwhile, other exclusive species such as *Bruguiera gymnorrhiza*, *Xylocarpus granatum*, and *Sonneratia alba* were more particular to the site, being available in only one or two locations.

Hibiscus tiliaceus, *Pluchea indica*, *Pandanus tectorius*, and *Macaranga gigantea* are among the 12 associated mangrove species, which are frequently found on the edges of mangrove forests or in transitional zones. Their presence enhances landscape biodiversity and ecological connectedness (Spalding et al., 2021; Ferreira et al., 2024). While not limited to mangrove ecosystems, many associated species continue to serve vital functions in maintaining fauna, stabilising soil, and controlling water movement between habitats.

Moving towards the shore, *Bruguiera gymnorhiza* and *Ceriops tagal* were found in mid-intertidal zones where flooding is less common. These species are classified as transitional mangroves, crossing the heavily swamped seaward margin with more stable landward portions. Their knee roots produce aeration in moderately anoxic soils, allowing them to endure periodic flooding without the instability found in seaward zones. The existence of these species at Sungai Betutai and Kampung Serusop indicates that both sites have relatively undisturbed tidal gradients, allowing for a broad range of zonation from pioneer seaward species to shade-tolerant landward taxa (Spalding et al., 2021).

Terminalia catappa, *Pandanus tectorius*, and *Morinda citrifolia* were limited to the higher intertidal or terrestrial borders, respectively. Their range implies tolerance of less salty conditions and a predilection for solid soils, which are frequently enhanced with freshwater input from upstream catchments. The greater amount of these associations in Sungai Betutai emphasises the area's significance as a transitional environment, with mangroves fluidly connecting to surrounding terrestrial habitats. Such transitional zones are important for landscape-level biodiversity because they support both mangrove specialists and terrestrially compatible flora, improving total species diversity and ecological connectedness (Ferreira et al., 2024).

Understanding zonation is crucial for both ecological theory and conservation management. Species limited to shallow tidal areas, such as *Ceriops tagal*, are especially at risk for habitat loss because minor changes in hydrology or sedimentation can cause a local decline. Generalist species, such as *Rhizophora mucronata*, may survive in a wider range of environments, but their dominance cannot sustain total biodiversity. Preserving natural patterns of zonation ensures that mangrove forests perform a wide range of biological tasks, from sediment stabilisation at the coastal border to habitat connection at land boundaries (Rahman et al., 2021; Nauta et al., 2023).

The zonation patterns seen in Sulaman Lake are consistent with global mangrove trends, in which salinity and tidal flooding are the key drivers of species distribution. Salt-tolerant genera like *Avicennia* and *Rhizophora* often dominate seaward zones, whilst landward edges host species with reduced salt tolerance, such as *Hibiscus tiliaceus* and *Wedelia biflora.* The presence of *Avicennia alba* in various locations in Sulaman Lake suggests that it is a pioneer species capable of colonising freshly produced mudflats, allowing ecological succession and opening the way for other taxa (Ferreira et al., 2024).

The study's findings also highlight the need of neighbourhood engagement in conservation. Mangroves are important to the local settlements near Sulaman Lake because they provide fisheries, fuelwood, and coastal protection. Interactive monitoring and co-management in

these communities can promote sustainability while ensuring that conservation measures are in line with local livelihoods. Controlled harvesting of non-timber items, such as *Nypa fruticans* leaves for roofing, or sustainable crab harvesting in mangrove creeks, can both give income and protect ecosystem health. Raising local awareness of the biological functions of exclusive mangroves, such as carbon storage and shoreline stabilisation, is critical to achieving long-term conservation goals (Rahman et al., 2021).

In conclusion, Sulaman Lake is important for conservation because it serves as a local biodiversity reservoir. With 24 mangrove species, evenly distributed between exclusive and associate species, it is one of Sabah's richest mangrove systems. This diversity helps to increase ecological resilience, enabling the system to endure disturbances like storms, flooding, and sea-level rise. As climate change worsens, preserving healthy and rich in species mangrove ecosystems will become increasingly critical for protecting both wildlife and human communities along Sabah's coasts. Management techniques should consequently prioritise habitat protection, restoration of ecological balance in degraded areas, and monitoring over time of species composition in order to identify disturbances before they become permanent.

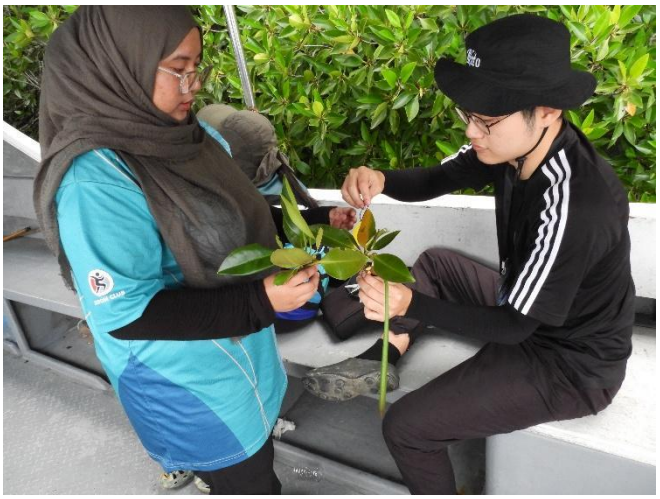

Figure 1: Sample recorded for further identification.

4. CONCLUSION

This work provides important information about the floristic makeup of these ecologically crucial coastal habitats by highlighting the variety and distribution of exclusive and associate mangrove species across a few sites in Sabah. Because of their special physiological adaptations to tidal and saline conditions, exclusive species like *Rhizophora apiculata*, *Avicennia alba*, and *Bruguiera gymnorhiza* are dominant, reflecting their vital role in stabilising coastlines, reducing erosion, and supporting carbon sequestration (Duke & Kathiresan, 2022; Alongi, 2022). Even though they are less specialised, associate mangrove species link mangrove zones with upland and terrestrial systems, provide more habitat and food sources for different faunal groups, and greatly enhance the structural complexity and ecological resilience of the forest (Spalding et al., 2021).

Interpreting zonation patterns and evaluating the health of ecosystems depend on an understanding of the ecological roles and preferred habitats of both exclusive and associate species. In view of growing anthropogenic pressures and climate-related changes, these distinctions are crucial for guiding conservation planning, restoration techniques, and sustainable resource use in Sabah's mangrove ecosystems (Ferreira et al., 2024). Maintaining the biodiversity and environmental services that mangrove forests offer will require ongoing species composition monitoring and documenting.

The primary site throughout this research, Sulaman Lake, is a significant ecological zone in Sabah because of its high mangrove cover, numerous riverine inputs, and function as a breeding and feeding ground for a variety of terrestrial and aquatic species. Because of its biological diversity and advantageous position, it is a top priority for integrated wetland management and conservation. By preserving Sulaman Lake and comparable habitats, Sabah will become more resilient to coastal hazards like habitat loss, erosion, and sea level rise, while also promoting regional biodiversity.

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