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Vegetation structure, species diversity of mangrove plants from a specific area of the Indian Sundarbans

[a]Alokesh Das, [a]Bholanath Mondal* and Palash Mondal

[a]Department of Plant Pathology, Palli Siksha Bhavana (Institute of Agriculture),Visva Bharati, Sriniketan – 731 236,West Bengal, India

[b]Department of Agricultural Entomology, Palli Siksha Bhavana (Institute of Agriculture),Visva Bharati, Sriniketan – 731 236,West Bengal, India

***Corresponding Email: bholanath.ppvb@gmail.com**

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Abstract

Vegetation structures of different locations of mangrove forests in the Indian part of the Sundarbans are studied in this research article. Sundarbans are home to the most extensive mangrove ecosystem in India. In 1989, the Sundarbans Wildlife Sanctuaries were included on the list of UNESCO's World Heritage Sites. The Indian side of the Sundarbans received the famous status of "Wetlands of International Importance" in the Ramsar Convention on Wetlands in 2019. The primary objective of this study was to establish the species make-up of different locations. According to the findings of the study, there are 39 different mangrove plant species that belong to 23 different families. The Avicenniaceae family is the most predominant, while members of the Euphorbiaceae, Acanthaceae, Chenopodiaceae, and Rhizophoraceae families have higher densities. Besides, small shrub species of different families are found around the ecotonic zone. The study also revealed that among the 39 species, 21 are considered true mangroves, 14 are mangrove associates, and the remaining 4 taxa are considered other categories such as angiospermic plant parasites. A few numbers of *Ceriops decandra, Aegialitis rotundifolia*, and *Phoenix paludosa*, which were declared as near-threatened species by IUCN, are recorded. At the same time, *Heritiera fomes* and *Nypa fruticans* are found to be endangered for Sundarbans. The reduction of species diversity of mangroves in the Sundarbans is due to the dramatic shift in climate accompanying the rise of saline water level. Overexploitation of natural resources, increasing pollution trends along with some human activities like residential and commercial development, and expansion of agricultural and allied aspects are also aggravating the situation. If the Sundarbans are not adequately protected against the consequences of climate change, many more species will become extinct. For this reason, a participatory strategy is required to safeguard the Sundarbans.

Key words: Mangrove species, species diversity, Indian Sundarbans, species density, abundance

Introduction

Mangroves are unique and vital salt-tolerant groups of plants at the interface between land and sea in tropical and subtropical regions (Alappatt, 2008; Parida and Jha, 2010;). These are productive ecosystems on coastlines covering 140,000 sq km worldwide. Mangrove forests are in different parts of the world, especially the Florida Everglades, USA, the Amazon River Delta, Brazil, the Indo-Pacific Region, Mesoamerican Reef, Central America, the Red Sea Region, West Africa, and East Africa. Southeast Asia and Sundarbans (Abdel-Hamid et al., 2018). In India, the costs cover 4921 sq km, which accounts for nearly 3 percent of Worlds mangrove cover. The Sundarbans are located in the delta region of the Ganges, Brahmaputra, and Meghna rivers (Mondal and Das, 2023). The Sundarbans mangrove forest spans parts of India and Bangladesh. It's the largest contiguous mangrove forest in the world and is famous for its Bengal tigers (Ishtiaque et al., 2016). Mangrove species were classified into two groups: (1) True mangroves - those that are entirely devoted to the mangrove environment; and (2) Mangrove associates - those that are not found in mangrove habitats but may prefer the mangrove regions' peripheries (Mandal and Bar, 2018). The term "Mangrove associate" was used to describe the plants that grow along the tidal edge of mangrove environments. These plants include herbaceous, sub-woody, and climber species (Vyas, 2012; Das, 2021). Tomlinson (1986, 2016) used very strict criteria to identify true mangroves from mangrove associates (Tomlinson and Cox, 2000). According to his standards, true mangroves possess all or most of the following– (1) they are obligate inhabitants of the mangrove ecosystem and cannot be found elsewhere, (2) they have a significant role in the structure of the mangrove community, (3) they are morphologically adapted to their environment (e.g., having aerial roots and vivipary of the embryo), (4) they can grow in sea water because their bodies can get rid of salt (like excretion) that lets them survive in salty environments, and (5) they have different taxonomies from their relatives on land, at least at the generic level.

Mangrove associates are differentiated by their incapacity to be a prominent component of this vegetation type. Such plants grow form pure stands and are usually found on the outside of the environment (Ong and Gong, 2013). These species are linked with mangrove forests or coastal ecosystems spread by sea currents. Among the 69 intertidal plant species documented in Indian Sundarbans, 30 are true mangroves, 20 are mangrove associates, and 12 are back mangroves (Chakraborty, 2011). Significantly, the Indian Sundarbans alone encompass 30 true mangrove

species, constituting a substantial portion of the 48 reported true mangrove species in the World Tropics (40 true mangrove) (Mondal et al., 2014; Mandal et al., 2019). The dwindling population of mangrove species is attributed to persistent deforestation by wood cutting, poaching, anthropogenic effect and various other factors (Islam et al., 2018). Certain mangrove species, such as Sundari (*Heritiera fomes*), Genwa (*Excoecaria agallocha*), Golpata (Nypa fruticans), Kalo Bain (*Avicennia alba*), Ban Lebu (*Atalantia corea*), and Lata Harguza (*Acanthus vulubilis*), have already been designated as 'threatened' (Naskar and Bakshi, 1995; Mandal et al., 2010; Mondal et al., 2014). Notably, the species *Nypa fruticans* is exclusive to the Sundarbans of West Bengal and is particularly sensitive to high salinity (Selvam et al., 2004; Mandal et al., 2010). The Indian Sundarbans, comprising 62% of the total area coverage and showcasing 90% of floral diversity among all mangrove forests in India, stands out as the largest. A comparative study by Rodriguez et al. (2012) delved into the morphology and anatomy of select mangrove species, exploring their adaptation to the saline habitat in the Indian Sundarbans.

The mangroves are vanishing for several reasons, including natural calamities and facing disasters like cyclones, floods, tsunamis, droughts, etc., every year. Excessive dependence on humans has destroyed the mangrove forests (Andharia, 2020). As a consequence, there may be a risk of mangrove plant destruction. However, the global demand for mangrove plants for their ecological and economic value is increasing (Carugati et al., 2018). The Sundarbans play a crucial role in protecting the coastal areas of West Bengal from the erosive force of the Bay of Bengal. It also acts as a buffer against storm surges and helps mitigate cyclone impacts (Sánchez-Triana et al., 2018).

The present research examines the arrangement of vegetation, the variety of mangrove plant species, their distribution, abundance, uniformity, and ecological roles in the ecosystem. Alongside revising the species inventory of mangroves in the Indian Sundarbans within the current context, the study considers the morphological features that enable them to adapt to the tidal saline conditions in this deltaic region.

Material and Methods

Study area

The Indian Sundarbans encompasses the world's largest delta region, formed by the confluence of three major rivers, including the Ganges, Brahmaputra, and Meghna. The present study was conducted in the selected area in the Indian Sundarban region of the 24-Parganas district of West Bengal (21°31′00″ N - 22°30′00″ N, 88°10′00″ E - 89°51′00″ E) during 2021,2022 and 2023 (Figure 1). The sampling area included Basanti, Gosaba, and Kultali blocks in the north-central part. The Indian Sundarbans are located on the southern fringe of West Bengal, spreading over a significant portion of the districts of North 24-Parganas and South 24-Parganas. The selected regions exhibit rich biodiversity in terms of halophytic plants. The surface characteristics of these areas are very diverse due to their landscape behavior.

Vegetation sampling

We conducted a random sampling of the area by deploying 60 quadrats, each measuring 10m x 10m, from March 2020 to February 2022, covering all seasons. Within each quadrat, we identified all trees with a diameter at breast height (dbh) of ≥1cm, recording their numbers and dbh using a slide caliper. In cases where dbh measurement was not feasible, the girth at breast height (gbh) was measured using a meter tape. Shrubs, climbers, and tree saplings (<1cm dbh, height >30 cm) were sampled in four 2.5m x 2.5m quadrats, while herbs, including tree seedlings (<1cm dbh, height <30 cm), were sampled in four 1m x 1m quadrats nested within each 10m x 10m quadrat. Plant specimens were collected, and unidentified species were identified by consulting the regional mangrove flora (Ganguli et al., 2016).

Data Analysis

For each quadrat sample, identified plant species were individually counted morphological parameters such as Frequency [$\text{Frequency} = \frac{\text{Number of quadrates of occurrence of a species x 100}}{\text{Number of quadrates of studied}}$], Abundance, Density [$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrates studied}}$], basal area, and ImportanceValue Index (IVI) [IVI = Relative frequency + Relative density + Relative Dominance] were calculated (Sharma and Raina,2018). Relative density, relative diversity, and relative dominance of a family, species dispersion was assessed as the ratio of abundance to frequency (A/F) (Kumar et al., 2020).

Various diversity indices, including Shannon-Wiener index [H' = $-\sum_{i=1}^{s} Pi \ln Pi$], Simpson's index [D== $\frac{1}{\sum_{i=1}^{s}(Pi)^2}$)], Pielou's Index for species evenness [J = $\frac{H'}{Log\ S}$] and Margalef's index of species richness [R = $\frac{(S-1)}{\log N}$] were calculated (Shannon and Weaver, 1949; Simpson, 1949; Pielou, 1966; Margalef, 1968). Frequency, density, basal cover, abundance, and Importance Value Index (IVI) of the species were computed following Misra (1968) and Muller-Dombois and Ellenberg (1974). Where, s=total no of species, pi= ni/N, ni= total no of individual of "i" species, N= total no of individual of all species, ln= natural log. Where, s=total no of species, pi= ni/N, ni= total no of individual of "I th" species, N= total no of individual of all species, ln= natural log.

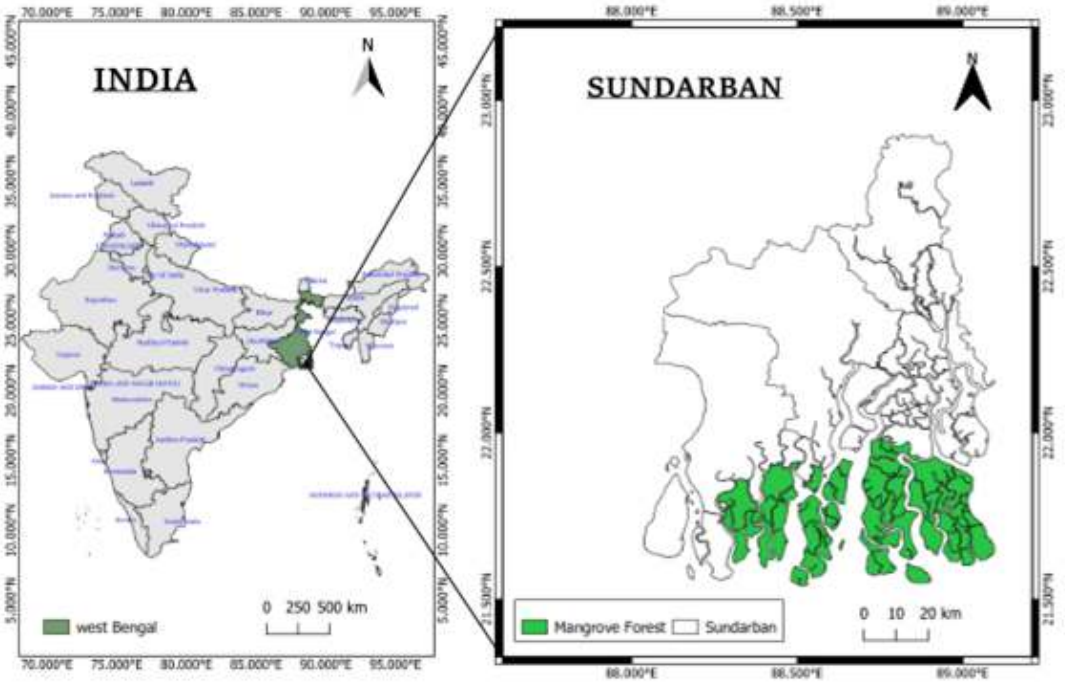

Figure 1: Location map of the study area

Results

A total 39 species species were isolated from the specific area representing 29 gerena and 23 families. Of this 39 species there are 21 true mangrove species containing 10 families and 14 genus. Beside true mangrove species there are 14 mangrove associate species belonging 11 families and 12 genera. Other plants are 4 angiospermic plant parasite belonging 2 families and 2 genus. Among the true mangrove tree constitute 90.47% (19 species) shrub and herb constitute 9.53% (2 species), noclimber found as true mangrove. Among mangrove associate tree constitute 21.42 % (3 species), shrub 14.28% (2 species) and other mangrove associate plants are herbs 64.28% (9 species) with that 4 plants are climber. There are 4 angiosperm plant parasitic plants in the selected area belonging 2 families and two genus.

The study revealed that *Heritiera fomes*, an endangered species, occasionally showed a distribution, and *Sonneratia griffithii*, a "critically endangered" plant according to the IUCN Red List, was determined to be a rare plant in the Indian Sundarbans. Nonetheless, the study found that three "near threatened" species—*Ceriops decandra, Aegialitis rotundifolia,* and *Phoenix paludosa*—had a shared distribution in the Indian Sundarbans (Table 1). Because different species have different growth forms, adding other features like cover and basal area to these numbers is important. This is especially true for woody species, because the basal area—visible when leaves and stems are chopped at the ground surface—indicates the actual ground area covered by the stems.

The occurrence of *Sonneratia griffithii*, *Heritiera fomes*, *Ceriops tagal*, and *Ceriops decandra* is characterized by significantly lower frequencies at 2.78, 6.94, 8.33, and 11.11, respectively. Conversely, *Avicennia officinalis*, *Avicennia marina*, *Excoecaria agallocha*, and *Avicennia alba* exhibit the highest frequencies at 51.39, 55.56, 56.94, and 62.50, respectively. Notably, mangrove associate plants such as *Suaeda nudiflora*, *Heliotropium curassavicum*, and *Ipomoea pes-capre* also demonstrate predominant frequencies. Total density remains low in *Sonneratia griffithii*, *Viscum orientate*, *Viscum monoicum*, *Dendrophthoe falcate*, *Ceriops tagal*, *Hoya parasitica*, and *Ceriops decandra*, ranging from 0.17 to 1.33. Conversely, *Acanthus ilicifolius*, Salicornia brachiata, Suaeda nudiflora, Avicennia officinalis, Avicennia marina, Avicennia alba, and *Excoecaria agallocha* exhibit the highest densities, ranging from 22.26 to 27.15. *Excoecaria agallocha* boasts the highest total densities, followed by *Avicennia alba* and *Avicennia marina*.

Sonneratia apetala, *Avicennia marina*, *Lumnitzera racemosa*, *Sonneratia griffithii*, *Avicennia alba*, and *Avicennia officinalis* contribute predominantly to the basal area, with values of 3.90, 4.12, 4.47, 5.09, 6.02, and 6.59 m^2 ha^{-1}, respectively. In terms of the Importance Value Index (IVI), *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia marina*, *Avicennia officinalis*, and *Avicennia alba* are noteworthy, with IVI values of 10.73, 13.76, 16.16, 17.67, and 19.27, respectively.

A greater Shannon index signifies a more favorable environment characterized by a higher number of species or a more even distribution of individuals across species within a quadrat. In the selected region of the Indian Sundarbans, the Shannon diversity index and Simpson dominance index were 3.369 and 0.9585, respectively. Additionally, elevated Pielou's evenness index values (0.7452) indicate an even distribution of mangrove species across the study area.

The Brillouin Index, registering at 3.36, gauges the diversity of species by considering both abundance and evenness. A higher Brillouin Index implies a more diverse ecosystem. The Menhinick Index, recorded at 0.322, evaluates species richness relative to the total number of individuals, with a higher value indicating increased species richness and a greater variety of species. The Margalef Index of species richness (R) at 3.961 denotes species richness in the ecosystem, considering both the total number of species and their abundance. Equitability, with a value of 0.9197, measures the evenness of species distribution in the community, with a higher index suggesting a more balanced distribution of species abundance. The Fisher Alpha Index, with a value of 4.868, estimates diversity based on the number of rare species. A higher Fisher alpha Index signifies increased diversity, particularly regarding rare species. The Berger-Parker Index, at 0.07585, indicates the dominance of the most abundant species, with a lower index suggesting a more evenly distributed community. The Chao-1 Index, registering at 39, estimates the total number of species in the community, including those that may not have been observed. This index is particularly valuable for predicting species richness in a given ecosystem. Collectively, these indices provide a comprehensive assessment of biodiversity, richness, evenness, dominance patterns, and species distribution in the studied area.

Table 1: Species composition of Mangroves from selected areas of Indian Sundarbans

	Species	Family	Type	Mangrove	**Frequency (%)**	**Density**	**Abundance**	**Basal area (m2 ha-^{1})**	**IVI**
1.	*Avicennia marina*	Acanthaceae	T	M	55.56	14.08	25.35	4.127389	16.16551
2.	*Avicennia alba*	Acanthaceae	T	M	62.50	15.25	24.40	6.026274	19.2774
3.	*Avicennia officinalis*	Acanthaceae	T	M	51.39	12.92	25.14	6.593153	17.67348
4.	*Acanthus ilicifolius*	Acanthaceae	S/H	M	43.06	9.58	22.26	0.000796	8.681066
5.	*Acanthus volubilis*	Acanthaceae	H	M	23.61	5.96	25.24	0.000796	5.107238
6.	*Phoenix paludosa*	Acecaceae	T	M	29.17	4.83	16.57	2.771497	7.833757
7.	*Nypa fruticans*	Acecaceae	S	M	15.28	2.88	18.82	2.152866	4.975381
8.	*Lumnitzera racemosa*	Combretaceae	T	M	16.67	2.21	13.25	4.478503	7.097708
9.	*Excoecaria agallocha*	Euphorbiaceae	T	M	56.94	15.46	27.15	0.920382	13.76735
10.	*Xylocarpus mekongensis*	Meliaceae	T	M	19.44	3.29	16.93	1.472134	4.881195
11.	*Aegiceras corniculatum*	Myrsinaceae	T	M	25.00	5.96	23.83	0.975318	6.208956
12.	*Aegialitis rotundifolia*	Plumbagnaceae	T	M	25.00	4.88	19.50	1.149682	5.853185
13.	*Rhizophora mucronata*	Rhizophoraceae	T	M	20.83	3.71	17.80	2.321656	6.06415
14.	*Rhizophora apiculata*	Rhizophoraceae	T	M	18.06	2.38	13.15	1.089968	3.925489
15.	*Bruguiera cylindrica*	Rhizophoraceae	T	M	26.39	3.83	14.53	0.815287	5.132513
16.	*Ceriops tagal*	Rhizophoraceae	T	M	8.33	1.08	13.00	1.472134	2.770012
17.	*Ceriops decandra*	Rhizophoraceae	T	M	11.11	1.33	12.00	1.210987	2.888811

18.	*Bruguiera gymnorhiza*	Rhizophoraceae	T	M	38.89	7.67	19.71	1.089968	8.446253
19.	*Sonneratia apetala*	Sonneratiaceae	T	M	37.50	6.88	18.33	3.901274	10.73779
20.	*Sonneratia griffithii*	Sonneratiaceae	T	M	2.78	0.17	6.00	5.095541	5.429225
21.	*Heritiera formes*	Steculiaraceae	T	M	6.94	1.46	21.00	1.149682	2.505959
22.	*Sesuvium portulacastrum*	Aizoaceae	H	A	25.00	3.33	13.33	0.001791	3.946285
23.	*Suaeda nudiflora*	Amarathaceae	H	A	43.06	10.58	24.58	0.000796	9.171719
24.	*Salicornia brachiata*	Amarathaceae	H	A	40.28	9.67	24.00	0.000796	8.468284
25.	*Sarcolobus carinatus*	Asclepiadaceae	C*	A	26.39	3.54	13.42	0.000796	4.176799
26.	*Dolischandrone spathaceae*	Bignoniaceae	T	A	13.89	1.75	12.60	0.624204	2.765811
27.	*Heliotropium curassavicum*	Chenopodiaceae	H	A	43.06	8.38	19.45	0.001791	8.093276
28.	*Ipomoea pes-capre*	Convolvulaceae	C*	A	43.06	7.29	16.94	0.001791	7.558464
29.	*Derris scandens*	Fabaceae	C*	A	22.22	2.83	12.75	0.001791	3.444018
30.	*Derris tripholia*	Fabaceae	C*	A	19.44	3.04	15.64	0.001791	3.290114
31.	*Acrostichum aureum*	Pteridaceae	H	A	31.94	5.29	16.57	0.019904	5.567483
32.	*Atalantia correa*	Rutaceae	S	A	38.89	6.92	17.79	0.11465	7.104222
33.	*Tamarix dioiica*	Tamaricaceae	T	A	34.72	4.04	11.64	2.07086	7.259379
34.	*Tamarix gallica*	Tamaricaceae	T	A	15.28	1.50	9.82	1.612261	3.758383
35.	*Clerodendrum inerme*	Lamiaceae	S	A	37.50	6.00	16.00	0.06449	6.474257
36.	*Viscum orientate*	Loranthaceae	C	PP	12.50	0.71	5.67	0.000796	1.50447
37.	*Viscum monoicum*	Loranthaceae	C	PP	11.11	0.88	7.88	0.000796	1.45941
38.	*Dendrophthoe falcata*	Loranthaceae	C	PP	11.11	1.00	9.00	0.001791	1.519282
39.	*Hoya parasitica*	Asclepiadaceae	C	PP	18.06	1.25	6.92	0.002301	2.284807

T=Tree, S=Shrub, H=Herb, M=True Mangrove, A= Mangrove associate, PP=Plant parasite

Table 2: Diversity Indices and Plant Taxa Metrics Summary

	Number of Plant
Taxa	39
Individuals	14673
Simpson index (D)	0.9585
Shannon - Wiener Index (H')	3.369
Pielou's Index for species evenness (J)	0.7452
Brillouin Index	3.36
Menhinick Index	0.322
Margalef Index of species richness (R)	3.961
Equitability_J	0.9197
Fisher alpha Index	4.868
Berger-Parker Index	0.07585
Chao-1 Index	39

Discussion

The study in the specified area revealed a diverse composition of plant species, with 39 species identified, representing 29 genera and 23 families. Among these, 21 were identified as true mangrove species, spanning 10 families and 14 genera, which agrees with the reports of Chakraborty (2011) and Ghosh et al., 2015. Additionally, 14 mangrove associate species from 11 families and 12 genera were identified, along with four angiospermic plant parasites belonging to two families and two genera (Barik and Chowdhury, 2014). The study also highlighted the presence of four angiospermic plant parasites in the area. The investigation revealed noteworthy findings related to the distribution and status of certain species (Ghosh et al., 2012). For instance, *Heritiera fomes*, classified as an endangered species, was sporadically distributed, and *Sonneratia griffithii*, listed as "critically endangered" on the IUCN Red List, was identified as a rare plant in the Indian Sundarbans. Conversely, three "near threatened" species—*Ceriops decandra*, Aegialitis rotundifolia, and *Phoenix paludosa*—were found to have a shared distribution in the region (Ragavan et al., 2016; Vyas, 2012). Furthermore, the study delved into the ecological

dynamics of the identified species, considering factors such as frequency, density, basal area, and importance value. The frequency analysis revealed significant variations among different species, with *Avicennia alba, Avicennia marina, Excoecaria agallocha*, and *Avicennia officinalis* exhibiting the highest frequencies. Total density varied across species, with *Excoecaria agallocha* having the highest density, followed by *Avicennia alba* and *Avicennia marina* (Chowdhury et al., 2019; Sreelekshmi et al., 2020). The basal area, an essential indicator of the ground area covered by plant stems, was predominantly contributed by *Sonneratia apetala, Avicennia marina, Lumnitzera racemosa, Sonneratia griffithii, Avicennia alba, and Avicennia officinalis*. The Importance Value Index (IVI) emphasized the ecological significance of certain species, with *Sonneratia apetala, Excoecaria agallocha, Avicennia marina, Avicennia officinalis,* and *Avicennia alba* being particularly noteworthy (Mandal et al., 2019; Sreelekshmi et al., 2020). The assessment of biodiversity using indices such as the Shannon diversity index, Simpson dominance index, Brillouin Index, Menhinick Index, Margalef Index, Equitability, Fisher Alpha Index, Berger-Parker Index, and Chao-1 Index provided a comprehensive understanding of the ecological dynamics, species richness, evenness, and dominance patterns in the studied area (Paingankar et al., 2018).

Conclusion

The assessment of this study reveals a diverse composition of 39 plant species in the Indian Sundarbans, comprising 21 true mangrove species, 14 mangrove associates, and four angiospermic plant parasites. Noteworthy findings include sporadic occurrences of the endangered Heritiera fomes and the rarity of the critically endangered *Sonneratia griffithii*. Ecological dynamics, including frequency, density, basal area, and Importance Value Index (IVI), highlight the significance of specific species. Utilizing various indices, such as Shannon diversity and Fisher Alpha, provides a comprehensive understanding of species richness, evenness, and dominance. This research contributes valuable insights for future ecological studies and conservation efforts in the region. In conclusion, this research contributes valuable insights into the studied region's plant diversity, distribution, and environmental dynamics, offering a foundation for further ecological studies and conservation efforts in the Indian Sundarbans.

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