

## Research Article

# Seedling Diversity Considerably Changes Near Localities in Three Salinity Zones of Sundarbans Mangrove Forest, Bangladesh

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### ABSTRACT

The status of natural seedlings near localities in the Sundarbans Mangrove Forest was assessed through a stratified random sampling method to observe seedling composition and diversity, importance value index, family importance value, and species evenness. A total of 63 sample plots of 3,990 m<sup>2</sup> area were surveyed in three natural and anthropogenic influenced salinity zones of Sundarbans. A total of 16,166 seedlings of 15 species under 12 families were found. Family Euphorbiaceae showed the highest (59.59%) family relative density and Rhizophoraceae presented the highest (20%) family relative diversity Index (FRDI). The maximum family importance value (FIV) showed by Euphorbiaceae (66.26) and the maximum importance value index (IVI) of species has been observed in *Excoecaria agallocha* (114.74). *Excoecaria agallocha* showed the highest relative density (59.6%) and relative abundance (39.87%) where the highest relative frequency (15.27%) was observed by *Heritiera fomes*. The mean stem density and species diversity index in the whole survey area was 2701 stem ha<sup>-1</sup> and 0.0009 correspondingly. The Shannon-Wiener's diversity index was 1.52 where the maximum Shannon-Wiener's diversity index was 2.708. The Simpson's diversity index and Dominance of Simpson index were 0.38 and 0.62 with Simpson's reciprocal index 2.632. The Species evenness index, Menhinick's, and Margalef's indices were 0.561, 0.118, and 1.445 respectively. The Species diversity index of the three salinity zones were 0.0017, 0.0029, and 0.0035 respectively. The Shannon-Wiener's diversity index of Low Salinity Zone (LSZ), Moderate Salinity Zone (MSZ), and Strong Salinity Zone (SSZ) were 0.887, 1.369, and 1.845 correspondingly where LSZ (0.632) showed the highest Simpson's diversity index followed by MSZ (0.394) and SSZ (0.21). The Species evenness index for LSZ, MSZ, and SSZ were 0.346, 0.505, and 0.742 where Menhinick's Index were 0.148, 0.210, and 0.207 respectively. The analysis showed poor diversity indices and the area was dominated by few species with few families. The status is also reduced with increasing salinity.

**Keywords:** diversity, evenness, family, importance value, richness, salinity, seedling

### INTRODUCTION

The flora of the Bangladesh tropical forest is one of the ten global hot spot

zones for biodiversity (Mittermeier et al. 1998) and retains rich biological diversity due to its exceptional geophysical location (Chowdhury 2001; Hossain 2001; Nishat et al. 2002). The forest land and natural forest cover of this country are 1.442 million ha and 1.204 million ha respectively which are managed by the forest department, land ministry, and other individuals (Sobuj & Rahman 2011). Tropical forests are ecologically and economically important for the livelihood of local communities. For the last few decades, the natural forests of the country are rapidly decreasing at an alarming rate by 1- 4% of their current land area (Laurance et al. 1998) due to overpopulation, land use alterations, unsuitable and poor management practices (Khan 2008). The net forest loss in South and Southeast Asia, from 2010 to 2015 was about 25% higher compared to 1990 (Keenan et al. 2015) and Bangladesh is also situated in this zone. Agricultural extension, deforestation, extreme removal of woody and non-woody resources, urbanization, and applying unfitted management tools are the major causes of forest degradation in Bangladesh (Hasan & Alam 2006).

Mangrove forest is one of the most productive vital ecosystems in tropical countries. It provides valuable ecological and economic resources to accelerate sustainable livelihood like nursery grounds, breeding sites for birds, fish, crustaceans, shellfish, reptiles, and mammals with medicinal and aesthetic values (Helal Siddiqui & Islam 2019). It is also a renewable source of wood, accumulation sites for sediments, contaminants, carbon, and nutrients, while also protect against coastal erosion, cyclones, and tsunami (Paolini & Sánchez-Arias 2008; Danielsen et al. 2005; Kathiresan & Rajendran 2005; Badola & Hussain 2005; Alongi 2002; Mazda et al. 1997). Sundarbans mangrove forest is rich in both floral and faunal diversity compared to other mangroves of the world and it is a suitable place for collecting various minor forest products (Islam et al. 2020) and developing tourism (Dey et al. 2020). Prain (1903) and (Seidensticker & Hai 1983) recorded 334 species of plants belonging to 245 genera and 75 families where Field (1995) and Tomlinson (1986) included approximately 16-24 families and 54-75 species respectively. In addition, (Karim 1994) reported 123 plant species belonging to 22 families representing 30 genera, and (Helal Siddiqui 2009) reported about 230 species including non-mangroves. Unfortunately, plant species are decreasing gradually due to climatic change, edaphic factors, and various natural and anthropogenic causes. The diminution of native species is hastening at an alarming rate through the quick loss and degradation of forests in Bangladesh (Rahman et al. 2000; Hossain 2001).

Tree diversity, a portrayal of the natural forest community is fundamental as they offer resources and homes for almost all other forest species (Huston 1994; Richards 1963; Cannon et al. 1998; Hall & Swaine 1976). For understanding the actions and dynamics of forest ecosystems, the knowledge of the floristic arrangement, their quantitative structure, and diversity are vital (Hossain et al. 2015). Effective conservation measures for sustainable management of forests need an appreciation of phytosociological features of tree species diversity (Feroz et al. 2014; Biswas & Misbahuzzaman 2008). Natural regeneration of forest tree species should be enhanced by the appropriate artificial and natural process for defending forest flora and continuing sustainability of yield, goods, and services (Haque & Alam 1988). Potential information for many native tree species is received from various studies that focused on natural regeneration status in different natural forests of Bangladesh (Hossain et al. 2004; Hossain 1999; Hossain et al. 2013; Miah 1999; Motaleb & Hossain 2007; Rahman et al. 2011; Rahaman et al. 2020).

For formulating a conservation strategy of the forest, quantitative information like regeneration, species composition, and distribution is important (Malik et al. 2014; Malik & Bhatt 2016; Sharma et al. 2014). The

range of biodiversity loss in the Sundarbans mangrove forest of Bangladesh is not exactly known due to a very poor database and limited information (Hossain et al. 2004). So, the study of biodiversity is a crucial requisite which is the main objective of this study to effectively protect and manage the existing natural forests for sustainable livelihoods (Hossain et al. 2018; Hossain et al. 2020) for future generations. Some studies were done before in the total area of Sundarbans (Prain 1903; Heining 1892; Helal Siddiqui 2009; Chaffey et al. 1985; Hossain 2003; Rashid et al. 2008; Saiful et al. 2014; Saiful et al. 2015), but this study focused only those areas where various natural and anthropogenic influenced were present. The study was designed to provide quantitative information of the seedling composition, diversity, importance value index, family importance value, species evenness, and compares the diversity indices of three natural and anthropogenic influenced salinity zones in Sundarbans mangrove forest.

## MATERIALS AND METHODS

### Study area

In this study, a total of 21 of 55 compartments were selected randomly which represented the three salinity zones of Sundarbans. The Low Salinity Zone (LSZ) is situated between latitude 22°11'08" and 22°80'00" and longitude 89°04'44" and 89°20'31" and the surveyed compartments were 1, 2, 3, 4, 5, 7, 24, 28 (Figure 1). For the Moderate Salinity Zone (MSZ) the latitude and longitude are between 22°45'13" and 21°15'22" and 89°57'10" and 89°19'59" respectively and the examined compartments were 15, 21, 30, 31, 32, 35, 36, 37, and 38. Also, Strong Salinity Zone (SSZ) are located between latitude 22°11'08" and 22°80'00" and longitude 89°04'44"-89°20'31" and the measured compartments were 46 and 47. All the compartments are located outer part of Sundarbans and near to the localities where natural and anthropogenic influenced are present (Figure 1). The study areas are situated in the warm, humid tropical region. The salinity range of the three zones were <5 ppt for LSZ, 5–10 ppt for MSZ, and >10 ppt for SSZ. The minimum and maximum mean annual temperatures are 21°C and 30 °C, respectively. The mean annual relative humidity differs from 70% to 80% where annual rainfall varies from 1640 mm and 2000 mm (Forest Department 2010).

### Methods

A total of 63 sample plots of 3990 m<sup>2</sup> (21 sample plots of 1330 m<sup>2</sup> area for each salinity zone) area were surveyed followed by a stratified random sampling method in April and May 2019 because most of the phenological behavior (flowering, fruiting, seed dispersal, etc) occurs in April and start to accelerate seed dispersal with seedling recruitment gradually which become more stable gradually to affect seedling diversity. The relative abundance (RA), relative density (RD), relative frequency (RF), and Important Value Index (IVI) were calculated by (Dogra et al. 2009; Nebel et al. 2001; Shukla & Chandal 2000). Family relative density (FRD) and family relative diversity (FRDI) were calculated by following (Rahman et al. 2011). Various diversity and richness indices were scrutinized by following, (Clifford & Stephenson 1975; Kent & Coker 1992; Margalef 1958; Michael 1990; Odum & Barrett 1971; Pielou 1995; Shannon 1948; Simpson 1949; Whittaker 1977). All the empirical data were calculated with the help of Microsoft Excel 2016. The equations were listed below:

- a) Density of a species (D) = (Total no. of individual of a species in all quadrats / Total no. of quadrats studied)
- b) Relative density (RD) (%) = (Total no. of individual of the species / Total no. of individual of all the species) x 100

Map of The Sundarbans Showing Activities of Mangrove Silviculture Division  
Bangladesh Forest Research Institute, Muzgunni, Khulna.

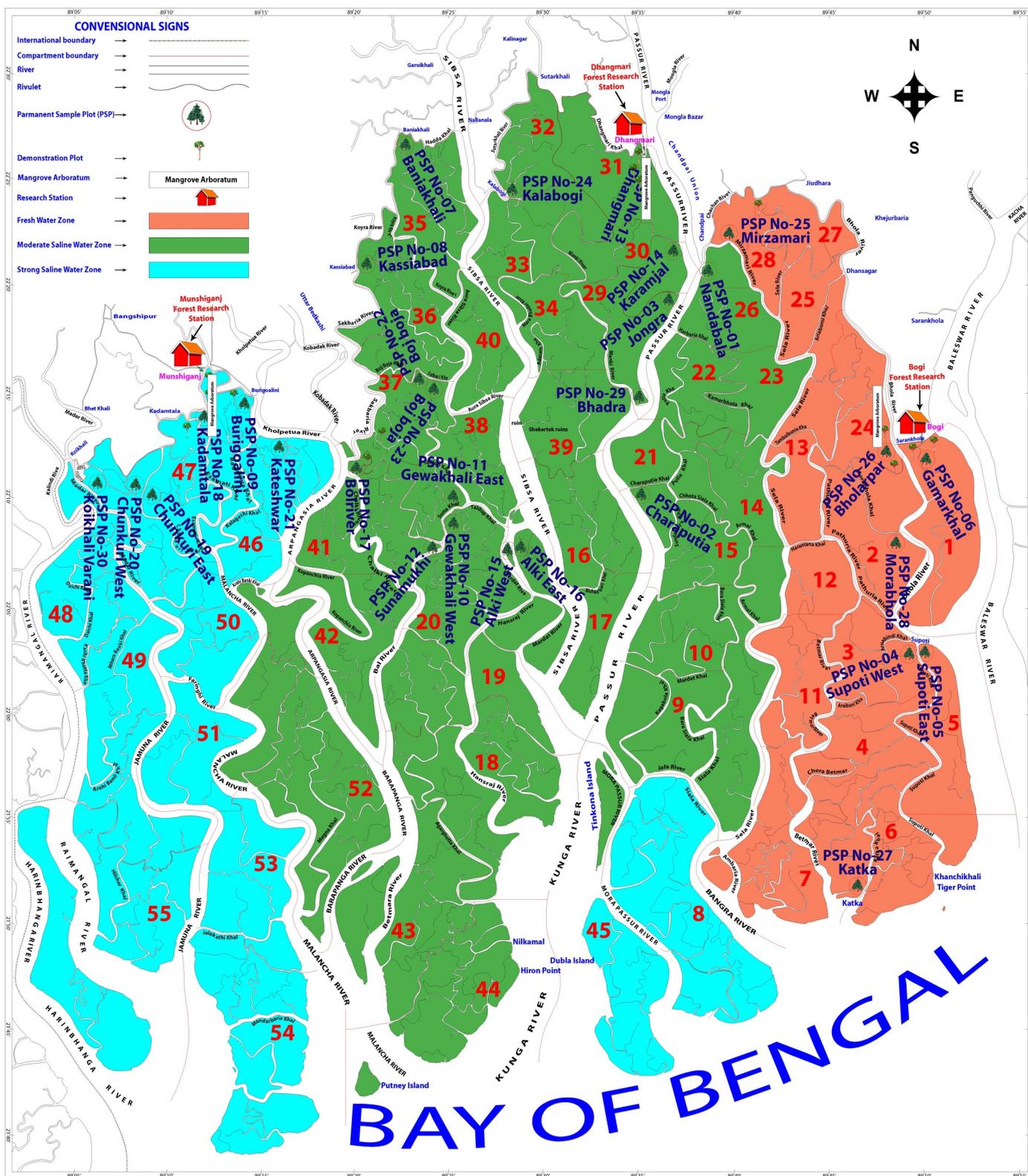


Figure 1. Maps of Sundarbans.

- c) Frequency of a species = (Total no. of individual of quadrats in which the species occurs / Total no. of quadrats studied)
- d) Relative frequency (%) = (Frequency of one species / Total frequency) x 100
- e) Abundance of a species (A) = (Total no. of individual of a species in all the quadrats / Total no. of quadrats in which the species occurred)

- f) Relative Abundance (RA) (%) = (Abundance of one species / Total abundance) x 100
- g) Importance Value Index (IVI) = Relative Density + Relative Frequency + Relative Abundance
- h) Species diversity index ( $Sd_i$ ) =  $S/N$
- i) Margalef's/Species richness index (R) =  $(S-1)/ \ln(N)$
- j) Shannon-Wiener's diversity index (H) =  $- \sum P_i \ln P_i$
- k) Shannon's maximum diversity index ( $H_{max}$ ) =  $\ln(S)$
- l) Simpson's diversity index (D) =  $(\sum P_i)^2$
- m) Dominance of simpson index ( $D'$ ) =  $1-D$
- n) Simpson's reciprocal index ( $D_r$ ) =  $1/D$
- o) Species evenness index (E) =  $H/ \ln(S)$
- p) Menhinick's Index ( $D_{mn}$ ) =  $S/ \sqrt{N}$
- q) Family relative density, FRD (%) =  $(N_f/T_i) \times 100$
- r) Family relative diversity index, FRDI (%) =  $(N_s/T_s) \times 100$
- s) Family importance value (FIV) = FRD + FRDI

Where, S = Total number of species; H = Shannon-Wiener's diversity index;  $N_f$  = No. of individual in a family; N = Total no. of individuals of all the species;  $P_i$  = (Number of individuals of one species / Total number of individuals);  $T_i$  = Total number of individuals;  $N_s$  = No. of species;  $T_s$  = Total number of species.

## RESULTS AND DISCUSSION

### Seedling status

A total of 16,166 seedlings of 15 species under 11 families were found in a 3990m<sup>2</sup> area within three salinity zones of Sundarbans. A total of 7723 seedlings of 13 species under 9 families were found in the Low Salinity Zone (LSZ) where *Aegiceras corniculatum* and *Sonneratia apetala* was not found. Besides, 5075 seedlings of 15 species under 11 families were found in the Moderate Salinity Zone (MSZ). In addition, a total of 3368 seedlings of 12 species under 9 families were found in the Strong Salinity Zone (SSZ) where *Cynometra ramiflora*, *Rhizophora mucronata*, and *Sonneratia apetala* was not found in the Strong Salinity Zone (SSZ).

About 59% were represented by one family (Euphorbiaceae) and about 26% by two families (Rhizophoraceae and Sterculiaceae). Maximum of three species were found in family Rhizophoraceae and two species in Arecaceae and Meliaceae where other families had one species (Table 1). Family Euphorbiaceae showed the highest (59.59%) family relative density followed

**Table 1.** Family composition, number of species, number of seedlings under each Family, Family relative density (FRD), Familyrelative diversity Index (FRDI), and Family importance value (FIV) index of the seedling in Sundarbans.

Family	No of Species	No of Seedling	FRD (%)	FRDI (%)	FIV
Euphorbiaceae	1	9634	59.59	6.67	66.26
Rhizophoraceae	3	2565	15.87	20	35.87
Sterculiaceae	1	1677	10.37	6.67	17.04
Meliaceae	2	460	2.86	13.32	16.17
Arecaceae	2	151	0.93	13.32	14.27
Avicenniaceae	1	519	3.21	6.67	9.88
Myrsinaceae	1	495	3.06	6.67	9.73
Fabaceae	1	289	1.79	6.67	8.45
Acanthaceae	1	224	1.39	6.67	8.05
Pteridaceae	1	149	0.92	6.67	7.59
Lythraceae	1	3	0.019	6.67	6.69
<b>Total</b>	<b>15</b>	<b>16166</b>	<b>100</b>	<b>100</b>	<b>200</b>

by Rhizophoraceae (15.87%), Sterculiaceae (10.37%), Avicenniaceae (3.21%), and Myrsinaceae (3.06%) (Table 1). Family Rhizophoraceae presented the highest (20%) family relative diversity Index (FRDI) followed by Arecaceae (13.32%), Meliaceae (13.32%) and 6.67% showed by other families. Maximum (66.26) family importance value (FIV) showed by Euphorbiaceae followed by Rhizophoraceae (35.87), Sterculiaceae (17.04), Meliaceae (16.17), Arecaceae (14.27), and Avicenniaceae (9.88) (Table 1).

### Quantitative characters of Seedling

Among 15 species, one species *Excoecaria agallocha* embodied 59% and a total of 85% was embodied by four species (*Excoecaria agallocha* 59.60%; *Heritiera fomes* 10.37%; *Ceriops decandra* 8.70% and *Bruguiera sexangula* 6.85%) (Table 2). The Highest (15.273%) relative frequency (RF) were exposed by *Excoecaria agallocha* trailed by *Heritiera fomes* (16.36%), *Ceriops decandra* (11.64%), and *Xylocarpus mekongensis* (10.182%) (Table 2). Again *Excoecaria agallocha* showed the highest (39.87%) relative abundance (RA) followed by *Aegiceras corniculatum* (12.29%), *Bruguiera sexangula* (7.70%), *Ceriops decandra* (7.64%), and *Heritiera fomes* (6.48%) (Table 2). The maximum importance value index (IVI) has been observed in *Excoecaria agallocha* (114.74) trailed by *Heritiera fomes* (33.22), *Ceriops decandra* (27.98), *Bruguiera sexangula* (23.64) and *Aegiceras corniculatum* (17.90) (Table 2). It was found that most of the species were least concert list of IUCN conservation status where *Ceriops decandra* and *Phoenix paludosa* were near threatened and *Heritiera fomes* was listed endangered.

### Biological diversity indices for seedling

The mean stem density and species diversity index in the whole survey area was 2701 stem ha<sup>-1</sup> and 0.0009 correspondingly (Table 3). The Shannon-Wiener's diversity index was 1.52 where the maximum Shannon-Wiener's diversity index was 2.708. The Simpson's diversity index and Dominance of simpson index were 0.38 and 0.62 with Simpson's reciprocal index 2.632 (Table 3). The Species evenness index/Pielou evenness index, Menhinick's Index, and Margalef's/Species richness index were 0.561, 0.118, and 1.445 respectively. The values of Shannon-Wiener's, Menhinick's, and Margalef's indices were specified inadequate plant diversity. The Simpson's index revealed that the species were not uniformly distributed and dominated by 3 or 4 tree species (Table 3).

**Table 2.** Relative Density (RD), Relative Frequency (RF), Relative Abundance (RA), Importance Value Index (IVI), and IUCN (CS) conservation status of the seedling in Sundarbans.

Scientific name	Local name	Family	NoS	RD (%)	RF (%)	RA (%)	IVI	IUCN CS
<i>Excoecaria agallocha</i>	Gewa	Euphorbiaceae	9634	59.60	15.27	39.87	114.7	LC
<i>Heritiera fomes</i>	Sundri	Sterculiaceae	1677	10.37	16.36	6.48	33.22	EN
<i>Ceriops decandra</i>	Goran	Rhizophoraceae	1407	8.70	11.64	7.64	27.98	NT
<i>Bruguiera sexangula</i>	kakra	Rhizophoraceae	1107	6.85	9.09	7.70	23.64	LC
<i>Aegiceras corniculatum</i>	Khalshi	Myrsinaceae	495	3.06	2.55	12.29	17.90	LC
<i>Avicennia officinalis</i>	Baen	Avicenniaceae	519	3.21	6.55	5.01	14.77	LC
<i>Xylocarpus mekongensis</i>	Passur	Meliaceae	296	1.83	10.182	1.84	13.85	LC
<i>Cynometra ramiflora</i>	Singra	Fabaceae	289	1.79	5.82	3.14	10.75	LC
<i>Amoora cucullata</i>	Amur	Meliaceae	164	1.01	7.64	1.36	10.01	DD
<i>Acanthus ilicifolius</i>	Hargoza	Acanthaceae	224	1.39	4.00	3.54	8.93	LC
<i>Acrostichum aureum</i>	Tigerfurn	Pteridaceae	149	0.92	1.82	5.18	7.92	LC
<i>Phoenix paludosa</i>	Hantal	Arecaceae	92	0.57	4.36	1.33	6.27	NT
<i>Nypa fruticans</i>	Golpata	Arecaceae	59	0.36	3.27	1.14	4.78	LC
<i>Rhizophora mucronata</i>	Jhana	Rhizophoraceae	51	0.32	1.09	2.96	4.36	LC
<i>Sonneratia apetala</i>	Keora	Lythraceae	3	0.019	0.36	0.52	0.91	LC
Total			16,166	100	100	100	300	

**Table 3.** Different biological diversity indices for seedlings in Sundarbans.

Parameter	Total
Total Area (m <sup>2</sup> )	3990
Mean Density (stem ha <sup>-1</sup> )	2701
Species diversity index	0.0009
Shannon-Wiener's diversity index	1.52
Shannon's maximum diversity index	2.708
Simpson's diversity index	0.38
Dominance of simpson index	0.62
Simpson's reciprocal index	2.632
Species evenness index/Pielou evenness index	0.561
Menhinick's Index	0.118
Margalef's/Species richness index	1.445

**Biological diversity indices of three salinity zones**

The total number of seedlings and mean density for Low Salinity Zone (LSZ), Moderate Salinity Zone (MSZ), and Strong Salinity Zone (SSZ) were 7723 and 4466 stem ha<sup>-1</sup>, 5075 and 2543 stem ha<sup>-1</sup> and 3368 and 2110 stem ha<sup>-1</sup> separately (Table 4). The Species diversity index of the three salinity zones were 0.0017, 0.0029, and 0.0035 respectively. The Shannon-Wiener's diversity index of LSZ, MSZ, and SSZ were 0.887, 1.369, and 1.845 with Shannon's maximum diversity index were 2.565, 2.708, and 2.485 correspondingly (Table 4). LSZ (0.632) showed the highest Simpson's diversity index followed by MSZ (0.394) and SSZ (0.21). The Dominance of Simpson's index and Simpson's reciprocal index were LSZ (0.368 and 1.582), MSZ (0.606 and 2.538), and SSZ (0.79 and 4.762) separately. The Species evenness index/Pielou evenness index for LSZ, MSZ, and SSZ were 0.346, 0.505 and 0.742 where Menhinick's Index were 0.148, 0.210, and 0.207 respectively (Table 4). The Margalef's/Species richness index for LSZ, MSZ, and SSZ were 1.452, 1.758, and 1.477 correspondingly. The mean density explored a higher number of individuals but diversity indices indicated lower diversity in all three salinity areas near localities. That's mean the forest was converted and dominated by only three or four species.

**Table 4.** Different biological diversity indices for three salinity zones of Sundarbans.

Parameter	LSZ	MSZ	SSZ
Total Area (m <sup>2</sup> )	1330	1330	1330
Compartment No	1,2,3,4,5,7,24,28	15,21,30,31,32,35,36,37,38	46, 47
Total Number of Seedlings	7723	5075	3368
Mean Density (stem ha <sup>-1</sup> )	4466	2543	2110
Species diversity index	0.0017	0.0029	0.0035
Shannon-Wiener's diversity index	0.887	1.369	1.845
Shannon's maximum diversity index	2.565	2.708	2.485
Simpson's diversity index	0.632	0.394	0.21
Dominance of simpson index	0.368	0.606	0.79
Simpson's reciprocal index	1.582	2.538	4.762
Species evenness index	0.346	0.505	0.742
Menhinick's Index	0.148	0.210	0.207
Margalef's/Species richness index	1.452	1.758	1.477

## Discussion

Sundarbans has very rich floristic diversity compared to other mangrove forests of the world where half of the total number of mangrove species found in the world occurs in the Sundarbans (Bangladesh and Indian Sundarbans) (Patil 1962). But this study revealed the poor forest condition of Sundarbans Mangrove Forest (SMF) and about 59% comprised of one species (*Excoecaria agallocha*) where about 85% comprised of four species (*Excoecaria agallocha*, *Heritiera fomes*, *Ceriops decandra*, and *Bruguiera sexangula*). *Excoecaria agallocha* was increased in a highly disturbed area of Sundarbans because its leaves were poisonous and not suitable for grazing. A total of 15 species were found which was higher than the mangrove swamp forest in southern Nigeria (Asuk et al. 2018) and lower than Puerto Princesa Bay (Dangan-Galon et al. 2016) and some other studies carried out in whole Sundarbans (Hossain 2003, Rashid et al. 2008, Saiful et al. 2014, Saiful et al. 2015). The SMF was predominated by Euphorbiaceae and Rhizophoraceae and the dominance of Rhizophoraceae was also found by (Asuk et al. 2018; Igu et al. 2017; Ogar & Asuk 2015). The total number of species found in this study was lesser than other forests of Bangladesh (Hossen et al. 2021; Malaker et al. 2010; Motaleb & Hossain 2011; Rahaman et al. 2020). This poor forest condition may be the effect of natural and anthropogenic disturbance whereas most of the people are dependent on Sundarbans for their livelihood directly or indirectly (Islam 2019). They entered these areas for collecting fuel, fodder, fruits, golpata, and so on through legal permission of the authorities but they are doing this hamper in their subconscious mind or intentionally. Islam et al. (2020) stated that most of the villagers adjacent to Sundarbans collect fish, honey, golpata, fuel wood, hogla, prawn, hantal, crab, nall, keora fruit, malia, goran stick, shrimp fry, and medicinal plants from Sundarbans but only 31.11% respondents had equipment facilities. Besides this, the government has declared officially the Sundarbans as a pirate-free area in 2018 which improved the destination's image perception to tourists (Haque et al. 2016) which affects diversity negatively. Besides, *Sonneratia apetala* was found only Moderate Salinity Zone (MSZ) because of high palatability and collection of *Sonneratia apetala* seeds for making pickles, it was declined drastically.

The average mean density was 2701 stem ha<sup>-1</sup> where a maximum of 4466 stem ha<sup>-1</sup> for LSZ and a minimum of 2110 stem ha<sup>-1</sup> for SSZ. The same rich density was found in Puerto Princesa Bay, Palawan Island, Philippines (Dangan-Galon et al. 2016). The density of SMF was higher than other forest parts of Bangladesh (Motaleb & Hossain 2011; Rahaman et al. 2020).

The Shannon-Wiener's diversity index (1.52), Simpson's diversity index (0.38), Margalef's value (1.445), and Species evenness index (0.561) were lower than Akpabuyo mangrove and the mangrove swamp forest in southern Nigeria (Olowokudejo & Oyebanji 2016; Asuk et al. 2018). But the Simpson's diversity index (0.38) in this study was higher than (Dey & Akther 2020; Hossen et al. 2019; Hossen et al. 2021) which indicated the lower diversity in SMF than other parts of Bangladesh. The values of Menhinick's (0.118) and Margalef's (1.445) indices designated the limited plant diversity in SMF.

The species richness of this study advocated that many plant species represented by few families may lead to the extinction of many of the species in SMF. The opposite result was found by (Olowokudejo & Oyebanji 2016) in southeastern Nigeria. Species evenness index (0.561) was lower than natural sal forest (0.8) (Rahaman et al. 2020), South Eastern Bangladesh (0.613) (Dey & Akther 2020), Himchari National Park (HNP) (0.853) (Hossen et al. 2019) that indicated the less equitable distribution of understory vegetation in SMF.

In this analysis, it was found that the number of seedlings and mean density gradually decreased with the increase of salinity. The highest number (7723 stem) and mean density (4466 stem ha<sup>-1</sup>) were found in LSZ in the same area of 1330 m<sup>2</sup> followed by MSZ (5075 stem, 2543 stem ha<sup>-1</sup>) and SSZ (3368 stem, 2110 stem ha<sup>-1</sup>). The Shannon-Wiener's diversity index (0.887, 1.369, and 1.845) was steadily increased and Simpson's diversity index (0.632, 0.394, and 0.21) was gradually decreased from LSZ to MSZ and SSZ. Simpson's diversity index indicated that the diversity was higher in SSZ than in the other two zones. The highest species evenness was found in SSZ (0.742) where LSZ showed the lowest (0.346). The Menhinick's Index and Margalef's/Species richness index of all three zones indicated the lower diversity but the value was various with the location. It may be the effect of salinity in water and soil, inundation type, time and duration, grazing, erosion, etc. that is observed during field data collection. But the suggested hypothesis of Ball (1998) was the opposite of this observation; he denied the effect of salinity (water and soil) on diversity declination. All these variables may affect the germination and survival rate of species. Further research needs to identify the degree of effect of these factors in SMF.

It was found that most of the species were on the least concerned list of IUCN conservation status where *Ceriops decandra* and *Phoenix paludosa* were near threatened and *Heritiera fomes* was listed endangered. It indicated that this area only consisted of abundant least concern species like *Excoecaria agallocha*, *Bruguiera sexangula*, *Aegiceras corniculatum*, *Avicennia officinalis*, and *Xylocarpus mekongensis*. Anthropogenic factors, grazing, tourism, increased number of water vehicles, and excessive extraction of food, fodder, and fuel wood with various natural calamities may affect the diversity and richness of species. Helal Siddiqui and Islam (2019) were recommended that the sustainable enrichment plantation will be carried out which showed satisfactory growth and survivability to improve the species richness of these areas. This study had many limitations like differences in methods of study, the intensity of sampling, area covered, habitat types, and plot size used which may affect species richness obtained by other studies (Hossain 2003, Rashid et al. 2008, Saiful et al. 2014, Saiful et al. 2015).

## CONCLUSION

The natural regeneration status of forests is very vital for the sustainable management of forests and forest resources. Bangladesh is still lucky to have a high percentage of forest cover in the Sundarbans Reserve Forest (SRF). However, this rich forest is decreasing with time particularly near human habitation to meet the basic needs of fuel, fodder, and small timber where the degree of causes is still unknown. The study will provide quantitative information about the seedling composition which may be very helpful for understanding the Sundarbans Mangrove Forest. The analysis showed poor diversity indices and the forest was dominated by few species with few families. It was recommended that the sustainable enrichment plantation will be carried out to improve the species richness of these areas. The Forest Department is concerned and to lessen this situation has designed co-management committees as well as providing alternative livelihoods to the Sundarbans user groups in cooperation with local NGOs. The study may be supportive and pave the way for advanced research on regeneration potentials of the mangrove species for safeguarding and heightening forests in the future.

## AUTHORS CONTRIBUTION

A.S.M.H.S. and M.N.S.P. conceived the study, A.S.M.H.S., M.N.S.P., M.M.R., M.A.I., and S.M.M.H. participated in field survey, M.N.S.P. analyzed data and wrote the first draft, and all authors revised the manuscript.

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## CONFLICT OF INTEREST

The authors declare no conflicting interests.

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