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# SPECIES DIVERSITY, CHANGE IN FOREST COVER AND AREA OF THE SUNDARBANS, BANGLADESH

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**Abstract**

The phytosociological analysis, species diversity and types, fidelity, presence, constancy, Sørensen similarity index and changes in forest cover, land and water areas since 1972 were analyzed. Forty six species were recorded both in quadrats and growing outside which belong to 26 families and 41 genera, 19 were distinguished as true mangrove species and the rest were mangrove associates. Leguminosae and Rhizophoraceae were the dominant families represented by 5 spp. each. Three species were found to be invasive, namely *Blumea lacera* (Burm. F.) DC., *Catharanthus roseus* (L.) G. Don., *Wedelia chinensis* (Osbeck) Merr. The maximum importance value index was found in *Heritiera fomes* Buch.-Ham (48.08). The overall species diversity (H) of SMF was found 3.81, species richness (d) was 9.10 and evenness (e) was 0.47. The forest area was 385,237 ha in 2015. The satellite images showed that the forest and water area of SMF decreased gradually till 2015 in comparison to 1972. The bare land of Sundarbans showed a significantly increasing trend till 2015 since 1972.

## Introduction

In the estuary of the River Ganges, in south-west coastal areas of Bangladesh and some part of West Bengal, the Sundarbans Mangrove Forest (SMF) exists. The Sundarbans originally extended about 40 thousand sq. km and forest clearing was initiated by the Turkish Sultans as early as the 13th century for agricultural purposes (Eaton 1991). The forest area reduced to about 20 thousand sq. km when the British started colonizing the subcontinent in 1793, but the agricultural invasion continued and the forest area reduced by a further 20% by the 1930s (Blasco 1977). The British Government declared the SMF as a reserve forest under the Forest Act 1927 to halt further encroachment. The Sundarbans is now restricted to around 10 thousand sq. km, stretching between the Baleshwar River, Bangladesh (about 60%) and the Hooghly River, India (about 40%).

Due to climate change, sea level rise and other anthropogenic factors the destruction has been aggravated and the area of the SMF drastically reduced over the last few centuries. Therefore, the present research work was undertaken to analyse the current state of the structure, composition, pattern of distribution and the diversity of the mangrove species in the three ecological zones of all four Ranges of SMF and to estimate the changes in forest covers and land area by using satellite images.

## Materials and Methods

Ecological exploration to the SMF of Bangladesh was carried out from 6 to 10 April, 2015. The study was conducted in Chandpai, Sarankhola, Satkhira and Khulna Ranges. Fourteen quadrats were taken in the three ecological zones namely, oligohaline, mesohaline and polyhaline of the SMF (Nazrul-Islam 2003). Details of the sampling stations along with the corresponding co-ordinates

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have been furnished in Table 1. To find out the total number of different plant species of overall SMF, the plant species situated outside the studied quadrats were also recorded. A 15 × 15 m plot (quadrat) was established in each location at about 15 - 20 m inland from shore to avoid effects of the nearby flowing rivers (Chen and Twilley 1999) for phytosociological survey. Sampling was done in all the strata i.e. trees, shrubs, herbs and climbers (Table 2). Plants with dbh ≥ 10 cm with height at least 8 - 10 feet and good growing conditions were considered as tree.

Among the 14 quadrats, 8 were established in oligohaline zone and 3 each in mesohaline and polyhaline zones of the forest (Table 1). The chief synthetic character such as important value index (IVI) was measured according to Curtis (Curtis 1959); the types of species (Tomlinson 1986), fidelity, presence and constancy were measured according to Braun-Blanquet (1932). Species diversity (H) of each site was determined by using Shannon-Weaver Index (Shannon and Weaver 1949), species richness index (d) was calculated according to Margalef (1951), and evenness (e) was calculated according to Pielou (1966). Floristic similarities were measured according to Sørensen (1948) similarities index.

**Table 1. Name of the sampling stations in different ecological zones of the Sundarbans mangrove forests along with the co-ordinates and dates of sample collection.**

| Location No. | Name of the areas | Co-ordinate | Ecological zone | Range | Dates of sample collection |
|---|---|---|---|---|---|
| 1 | Mrigamari (Sela river east bank) | 22°21′36.1′′N 89°40′8.7′′E | Oligohaline | Chandpai | 06/04/2015 Quadrat- 01 |
| 2 | Aandarmanik forest office | 22°21′36.1′′N 89°40′11.3′′E | " | " | 06/04/2015 Quadrat-02 |
| 3 | Tambulbunia forest office | 22°12′34′′N 89°41′59.4′′E | " | " | 07/04/2015 Quadrat-03 |
| 4 | Pathuria river west bank | 22°12′33.7′′N 89°42′16′′E | " | " | 07/04/2015 Quadrat-04 |
| 5 | Pathuria river east bank | 22°12′33.7′′N 89°42′16′′E | " | Sarankhola | 07/04/2015 Quadrat-05 |
| 6 | Supati forest office | 22°02′51.6′′N 89°49′41.6′′E | " | " | 07/04/2015 Quadrat-06 |
| 7 | Katka jamtola | 21°51′33.6′′N 89°46′40.2′′E | Mesohaline | " | 08/04/2015 Quadrat-07 |
| 8 | Katka forest office | 21°51′33.6′′N 89°46′40.2′′E | " | " | 08/04/2015 Quadrat-08 |
| 9 | Harbaria forest office | 22°15′55′′N 89°37′5′′E | Oligohaline | Chandpai | 09/04/2015 Quadrat-09 |
| 10 | Burigoalini forest office (Opposite site) | 22°17′50.5′′N 89°19′10.9′′E | Polyhaline | Satkhira | 09/04/2015 Quadrat-10 |
| 11 | Kalagachia forest office | 22°12′53.1′′N 89°14′13.6′′E | " | " | 10/04/2015 Quadrat-11 |
| 12 | Kobadak river west bank | 22°12′53.1′′N 89°14′13.6′′E | " | " | 10/04/2015 Quadrat-12 |
| 13 | Kashitana forest office | 22°13′17.2′′N 89°20′53.4′′E | Mesohaline | Khulna | 10/04/2015 Quadrat-13 |
| 14 | Kalabagir tota | 22°24′33.8′′N 89°27′4.7′′E | Oligohaline | " | 09/04/2015 Quadrat-14 |

Remote sensing and geographical information system have been applied to assess the changes in the forest cover, water bodies and bare areas. Satellite TM data of 1972, 1989, 2001, 2010 and 2015 were downloaded from GLOVIS, USA. Satellite data were geo-referenced using ERDAS IMAGINE/ ARC-GIS software. Then mosaic was done to the necessary frame and sub-set of Sundarbans forest area for the research work. Fifteen classes were made by unsupervised classification tools of ERDAS IMAGINE software. Finally three classes of areas like forest cover, water bodies and bare land were calculated through the software.

**Results and Discussion**

Forty six species was found to be present in the SMF of which 23 were trees, 3 shrubs, 5 herbs and 5 climbers, 2 woody parasites, 3 grasses, 2 palm species and one each of gregarious fern, sedge, prickly screw-pine species. These species belong to 26 families and 41 genera. Leguminosae (5 spp.) and Rhizophoraceae (5 spp.) were the dominant families. Fifteen families were represented by single genus and thus have single species (Table 2). Among 46 species, 32 different plant species were found within the studied quadrats (Table 3) and rest 14 species were found outside the quadrats (Table 2).

The flora of the Sundarbans is rich in comparison to most other mangroves in the world and it contains about 44% of global mangrove species (Alongi 2009). The members of the families Rhizophoraceae and Avicenniaceae generally dominate most of the mangrove forest in the world, while the previous studies indicated that Sundarbans had the greatest abundance of the members of the families Sterculiaceae and Euphorbiaceae (Hussain and Acharya 1994). But in the present study it has been found that Rhizophoraceae and Leguminosae were the dominant. Prain (1903) recorded about 334 plant species, including 35 legumes, 29 grasses, 19 sedges, 18 euphorbia and 50 true mangrove plant species in SMF. Hussain and Acharya (1994) reported 22 families of tree species of which 6 were from Rhizophoraceae, 3 of each from Avicenniaceae and Meliaceae, 2 of each from Combretaceae and Sonneratiaceae from the Sundarbans. Hossain (2003) reported 44 undergrowth species of SMF. Ahmed *et al*. (2011) recorded only 8 tree species growing in quadrats in their study. Although the mangrove forests of the world is conspicuous for the absence of reproducing under-story herbs and shrubs and for the absence of the vine life form (Janzen 1985), in the present study 3 shrubs and 5 herbs growing in the Sundarbans were recorded.

True mangroves and their associates were differentiated according to Tomlinson (1986). Among 46 species, 19 were distinguished as true mangrove species and rest 27 species were mangrove associates (Table 2). Among 27 mangrove associate species found in the present study, 3 were invasive, namely *Blumea lacera* (Burm. F.) DC., *Catharanthus roseus* (L.) G. Don., *Wedelia chinensis* (Osbeck) Merr. (Table 2). It is considered that invasive species can only spread into natural vegetation as result of disturbance (Biswas 2003). Besides, 25 species of mesophytes were also recorded which were mainly planted by the foresters along the different forest offices of the SMF and one xerophyte, namely *Calotropis gigantea* (L.) R. Br. and one sand dune species, namely *Vitex trifolia* L. f. were found to grow naturally west side of Katka forest office. The main mesophytes were *Cocus nucifera* L., *Litchi chinensis* Sonn., *Mangifera indica* L., *Artocarpus heterophyllus* Lam., *Syzygium malaccense* (L.) Merr. & L.M. Perry etc. On the bank of the canals and creeks, *Cryptocoryne ciliata* (Roxb.) Fisher *ex* Wydler were also found to grow. One free-floating fern-allies species, namely *Salvinia molesta* Mitch. was found growing in the drinking water ponds near Tambulbunia and Supoti Forest offices for the first time from SMF which was reported only once from Bangladesh by Hadiuzzaman and Khondker (2005). Banerjee *et al*. (1989) reported 37 obligate mangroves and 32 mangrove associates from the Indian Sundarbans.

**Table 2. List of plants of SMF of Bangladesh found in and outside the quadrats along with the types of species.**

| Sl. no. | Family | Scientific name | Ver. name | Habit | Types |
|---|---|---|---|---|---|
| 1 | Acanthaceae | *Acanthus ilicifolius* L. | Hargoza | Scrambling herb | MA |
| 2 | Apocynaceae | *Catharanthus roseus* (L.) G. Don.* | Nayantara | Herb | INV |
| 3 | Apocynaceae | *Cerbera odollam* Gaertn. | Dhakur | Small tree | MA |
| 4 | Asclcpiadaccae | *Sarcolobus globosus* Wall. | Bowalilota | Climber | MA |
| 5 | Avicenniaceae | *Avicennia marina* (Forssk.) Vierh. | Morchabaen | Small tree | TM |
| 6 | Avicenniaceae | *Avicennia officinalis* L. | Baen | Tree | TM |
| 7 | Celastraceae | *Salacia chinensis* L. | Choytbraai | Small tree | MA |
| 8 | Combretaceae | *Lumnitzera racemosa* Willd. | Kirpa | Small tree | TM |
| 9 | Compositae | *Blumea lacera* (Burm.F.) DC.* | Hash | Aromatic herb | INV |
| 10 | Compositae | *Wedelia chinensis* (Osbeck) Merr.* | Wadella | Herb | INV |
| 11 | Cyperaceae | *Cyperus javanicus* Houtt. | Kusha | Sedge | MA |
| 12 | Euphorbiaceae | *Excoecaria agallocha* L. | Gewa | Tree | TM |
| 13 | Euphorbiaceae | *E. indica* (Willd.) Muell.-Arg. | Batla | Small tree | TM |
| 14 | Euphorbiaceae | *Shirakiopsis indica* (Willd.) Esser.* | Hurmui | Tree | MA |
| 15 | Flagellariaceae | *Flagellaria indica* L. | Flagellaria | Climber | MA |
| 16 | Gramineae | *Imperata cylindrica* (L.) Raeusch. | Chhon | Grass | MA |
| 17 | Gramineae | *Myriostachya wightiana* (Nees *ex* Steud.) Hook.f. | Dhanshi | Grass on accretions | MA |
| 18 | Gramineae | *Phragmites karka* (Retz.) Trin. *ex* Steud. | Nolkhagra | Grass | MA |
| 19 | Leguminosae | *Cynometra ramiflora* L. | Shingra | Shrub | TM |
| 20 | Leguminosae | *Dalbergia spinosa* Roxb. | Chandalota | Shrub | MA |
| 21 | Leguminosae | *Derris trifoliate* Lour. | Kalilota | Climber | MA |
| 22 | Leguminosae | *Mucuna gigantea* (Willd.) DC. | Doyal | Climber | MA |
| 23 | Leguminosae | *Pongamia pinnata* (L.) Pierre. | Karanja | Small tree | MA |
| 24 | Liliaceae | *Crinum asiaticum* L. | Nagapata | Herb | MA |
| 25 | Loranthaceae | *Dendrophthoe pentandra* (L.) Miq. | Porgassa | Woody parasite on trees | MA |
| 26 | Loranthaceae | *Viscum monoicum* Roxb. *ex* DC. | Shamulota | Woody parasite on trees | MA |
| 27 | Malvaceae | *Hibiscus tiliaceus* L. | Bhola | Shrub | MA |
| 28 | Meliaceae | *Aglaia cuculata* (Roxb.) Pellegr. | Amur | Small tree | TM |
| 29 | Meliaceae | *Xylocarpus granatum* Koen | Dhundul | Small tree | TM |
| 30 | Meliaceae | *X. moluccensis* (Lamk.) M. Roem. | Passur | Tree | TM |
| 31 | Myrsinaceae | *Aegiceras corniculata* Blanco. | Khalshi | Small tree | TM |
| 32 | Myrtaceae | *Eugenia fruticosa* Roxb. | Ban jam | Small tree | MA |
| 33 | Palmae | *Nypa fruticans* Wurmb. | Golpata | Palm, under-ground stem | TM |
| 34 | Palmae | *Phoenix paludosa* Roxb. | Hantal | Thorn palm | TM |
| 35 | Pandanaceae | *Pandanus foetidus* Roxb. | Kewakata | Prickly screw-pine | MA |

(Contd.)

| | | | | | |
|---|---|---|---|---|---|
| 36 | Pteridiaceae | *Acrostichum aureum* L. | Tiger fern | Gregarious fern | MA |
| 37 | Rhizophoraceae | *Bruguiera gymnorrhiza* (L.) Lamk. | Kankra | Tree | MA |
| 38 | Rhizophoraceae | *Ceriops decandra* (Griff.) Ding Hou | Goran | Small tree | TM |
| 39 | Rhizophoraceae | *Kandelia candel* (L.) Druce. | Gura | Small tree | TM |
| 40 | Rhizophoraceae | *Rhizophora apiculata* Blume. | Vora | Tree | TM |
| 41 | Rhizophoraceae | *R. mucronata* Poir. | Garjan | Tree with stilt roots | TM |
| 42 | Sonneratiaceae | *Sonneratia apetala* Buch.-Ham. | Keora | Tree | TM |
| 43 | Sonneratiaceae | *S. caseolaris* (L.) Engl. | Choyla | Small tree | TM |
| 44 | Sterculiaceae | *Heritiera fomes* Buch.-Ham. | Sundri | Tree | TM |
| 45 | Tamaricaceae | *Tamarix dioica* Roxb. *ex* Roth | Jhau | Small tree | MA |
| 46 | Tiliaceae | *Brownlowia tersa* (L.) Kosterm. | Lotasundry | Climbing shrub | MA |

(Ver. name = Vernacular name, TM = True mangroves, MA= Mangrove associates, INV= Invasive, * = New found in SMF).

The phytosociological analysis revealed that the maximum IVI in case of overall SMF was found in *H. fomes* (48.08) (Table 3). Importance value index (IVI) is a measure of how dominant a species in a given forest area and overall picture of ecological importance of the species in relation to the community structure (Curtis and McIntosh 1951). The most dominant species was *H. fomes* having highest IVI value and then sequentially *S. apetala* and *E. agallocha* were the other most dominant species in overall SMF. Dominant species were not same within three different ecological zones of SMF. Although *H. fomes* and *S. apetala* were dominant in oligohaline zone, they were not dominant in mesohaline and polyhaline zone. Mesohaline zone was dominated by *E. agallocha, B. gymnorrhiza* and *A. marina.* On the other hand, polyhaline zone was dominated by *A. corniculata* and *C. decandra.* The constancy of *H. fomes, C. decandra, S. apetala* and *Xylocarpus moluccensis* (Lamk.) M. Roem. was 60 - 80% (Class 4) and they were mostly present in studied quadrats in SMF (Table 3). *Hibiscus tiliaceus* L. was the selective species in SMF (Table 3). The constancy of *E. agallocha, Phoenix paludosa* Roxb., *Aglaia cucullata, Avicennia officinalis* L. were 40 - 60% (Table 3). *Nypa fruticans* Wurmb. occurred in SMF preferentially (Table 3). The constancy of *Acanthus illicifolius* L., *Acrostichum aureum* L., *A. corniculata, N. fruticans, Pandanus foetidus* Roxb., and *Phragmitis karka* (Retz.) Trin. Steud. were 20 - 40%. *Acanthus ilicifolius, A. aureum, A. corniculata, A. marina, A. officinalis, Brownlowia tersa* (L.) Kosterm., *C. decandra, E. agallocha, Rhizophora mucronata* Lam., *S. apetala* and *X. moluccensis* were in different plants in SMF (Table 3). *Aglaia cucullata, B. gymnorrhiza, C. roseus, C. odollam, Cyperus javanicus* Houtt., *Derris trifoliate* Lour., *Eugenia fruticosa, L. racemosa, M. gigantea, M. wightiana, P. pinnata, S. indica, Sonneratia caseolaris* (L.) Engl. and *Tamarix dioica* Roxb. *ex* Roth. were the stranger species and were rarely present in 1 - 20% of the sampling units (Table 3). But in some places outside the quadrat specially beside the rivers *P. pinnata* was found to grow profusely. *Cynometra ramniflora, H. fomes, P. foetidus* and *P. paludosa* were the exclusive species of SMF (Table 3). Traditional phytosociology uses the concept of fidelity to recognize character species (Braun-Blanquet 1964), which requires the comparison of constancy values of species among communities. *Hibiscus tiliaceus* and *N. fruticans* are characteristic species of SMF because of having selective and preferential fidelity, respectively based on Braun-Blanquet (1932).

Species richness is the oldest and the simplest concept of species diversity - the number of species in the community or the region (Krebs 1989). Spatial variability in species diversity was observed within the SMF. Shannon-Weaver Index of diversity showed higher values in oligohaline zone (H = 3.47) than in mesohaline (H = 3.11) and polyhaline zone (H = 2.77) (Table 4). The H-value was relatively lower at polyhaline zone. The both highest and lowest H-values were found

in two different of quadrats of mesohaline zone where the lowest H-value (1.05) was found in Katka jamtola (Q-7) and highest H-value (2.93) was found in Katka (Q-8). The overall species diversity (H) of SMF was 3.81 (Table 4) indicating in high diversity in terms of species (Barbour *et al*. 1999).

**Table 3. Synthetic characteristics of plant species of SMF in three ecological zones.**

| Name of species | Important value index (IVI) | | | | Presence | Fidelity | Constancy |
|---|---|---|---|---|---|---|---|
| | Oligohaline | Mesohaline | Polyhaline | Overall | | | |
| *Acanthus ilicifolius* | 4.75 | 7.84 | 16.49 | 16.36 | Seldom | Indifferents | Class2 |
| *Acrostichum aureum* | 9.91 | 20.65 | 15.98 | 11.94 | Seldom | Indifferents | Class 2 |
| *Aegiceras corniculata* | 3.26 | 37.65 | 59.67 | 11.72 | Seldom | Indifferents | Class 2 |
| *Aglaia cucullata* | 13.37 | 4.96 | - | 10.26 | Often | Strangers | Class 3 |
| *Avicennia marina* | 2.41 | 36.24 | - | 13.67 | Rare | Indifferents | Class 1 |
| *Avicennia officinalis* | 8.74 | 5.11 | 11.23 | 8.631 | Often | Indifferents | Class 3 |
| *Brownlowia tersa* | 6.23 | 11.74 | - | 6.871 | Rare | Indifferents | Class 1 |
| *Bruguiera gymnorrhiza* | 1.68 | 37.74 | 18.47 | 14.02 | Rare | Strangers | Class 1 |
| *Catharanthus roseus* | 3.56 | - | - | 1.92 | Rare | Strangers | Class 1 |
| *Cerbera odollam* | 2.17 | - | - | 1.80 | Rare | Strangers | Class 1 |
| *Ceriops decandra* | 20.97 | 17.23 | 59.09 | 19.97 | Mostly | Indifferents | Class 4 |
| *Cynometra ramiflora* | 6.94 | - | - | 2.793 | Rare | Exclusives | Class 1 |
| *Cyperus javanicus* | 6.82 | - | - | 5.22 | Rare | Strangers | Class 1 |
| *Derris trifoliate* | 6.52 | - | - | 1.92 | Rare | Strangers | Class 1 |
| *Eugenia fruticosa* | 3.26 | - | - | 8.924 | Rare | Strangers | Class 1 |
| *Excoecaria agallocha* | 16.77 | 51.87 | 50.13 | 23.24 | Often | Indifferents | Class 3 |
| *Heritiera fomes* | 57.05 | 19.27 | 7.66 | 48.08 | Mostly | Exclusives | Class 4 |
| *Hibiscus tiliaceus* | 6.00 | - | - | 2.793 | Rare | Selectives | Class 1 |
| *Lumnizera racemosa* | 4.13 | - | - | 1.048 | Rare | Strangers | Class 1 |
| *Mucuna gigantea* | 2.87 | - | - | 1.048 | Rare | Strangers | Class 1 |
| *Myriostachya wightiana* | 11.24 | - | - | 1.048 | Rare | Strangers | Class 1 |
| *Nypa fruticans* | 7.15 | - | 10.34 | 7.565 | Seldom | Preferents | Class 2 |
| *Pandanus foetidus* | 8.54 | - | - | 6.251 | Seldom | Exclusives | Class 2 |
| *Phoenix paludosa* | 12.73 | - | - | 10.86 | Often | Exclusives | Class 3 |
| *Phragonites karka* | 7.94 | - | - | 5.794 | Seldom | Exclusives | Class 2 |
| *Pongamia pinnata* | 2.41 | - | - | 1.877 | Rare | Strangers | Class 1 |
| *Rhizophora mucronata* | 3.86 | 4.87 | - | 3.427 | Rare | Indifferents | Class 1 |
| *Shirakiopsis indica* | 2.87 | - | - | 1.255 | Rare | Strangers | Class 1 |
| *Sonneratia apetala* | 43.86 | 25.50 | 10.52 | 35.64 | Mostly | Indifferents | Class 4 |
| *Sonneratia caseolaris* | 4.13 | 5.65 | - | 4.158 | Rare | Strangers | Class 1 |
| *Tamarix dioica* | 2.17 | - | 26.76 | 3.951 | Rare | Strangers | Class 1 |
| *Xylocarpus moluccensis* | 7.15 | 11.70 | 11.92 | 17.11 | Mostly | Indifferents | Class 4 |

IVI, Curtis (1959), fidelity, presences and constancy, Braun-Blanquet (1932), - = Not found.

Species richness (d) were higher in oligohaline zone (d = 10.02) than in mesohaline (d = 6.27) and polyhaline zone (d = 4.37) (Table 4). The d-value was relatively lower at polyhaline zone. The species richness (d) of SMF was 9.10 indicating its peculiarity than any other communities. The lowest d-value was found in Kashitana (1.93) and hightest d-value was found in Aandarmanik (5.99) (Table 4). The overall value of species diversity for the mangroves of Lothian Island, India

was 2.26 (Joshi and Ghose 2014) and species diversity (2.74) was reported by Nazrul-Islam (1995) for Bangladesh Sundarbans. The present study showed that SMF have higher species diversity.

**Table 4. Summary of the species diversity (H), species richness (d), evenness (e) of plant species of overall SMF.**

| Location no. | Area name | H | d | e |
|---|---|---|---|---|
| 1 | Mrigamari (Sela river east bank) | 2.80 | 4.37 | 0.48 |
| 2 | Aandarmanik forest office | 2.36 | 5.99 | 0.40 |
| 3 | Tambulbunia forest office | 2.65 | 5.81 | 0.55 |
| 4 | Pathuria river west bank | 2.52 | 3.88 | 0.42 |
| 5 | Pathuria river east bank | 1.91 | 2.79 | 0.38 |
| 6 | Supati forest office | 1.20 | 2.71 | 0.20 |
| 9 | Harbaria forest office | 2.78 | 4.74 | 0.52 |
| 14 | Kalabagirtota | 2.56 | 3.79 | 0.45 |
| Oligohaline zone | | 3.47 | 10.02 | 0.52 |
| 7 | Katka jamtola | 1.05 | 2.21 | 0.02 |
| 8 | Katka forest office | 2.93 | 4.04 | 0.57 |
| 13 | Kashitana forest office | 2.10 | 1.93 | 0.35 |
| Mesohaline zone | | 3.11 | 6.27 | 0.47 |
| 10 | Burigoalini forest office (Opposite site) | 1.99 | 3.32 | 0.35 |
| 11 | Kalagachia forest office | 1.94 | 2.52 | 0.42 |
| 12 | Kobadak river west bank | 2.24 | 3.01 | 0.41 |
| Polyhaline zone | | 2.77 | 4.37 | 0.43 |
| Overall SMF | | 3.81 | 9.10 | 0.47 |

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Since heterogeneity contains two separate ideas - species richness and evenness it was only natural to try to measure the evenness component separately (Krebs 1989). Evenness (e) showed higher values in oligohaline zone (e = 0.52) than in mesohaline zone (e = 0.47) and polyhaline zone (e = 0.43). The e-value was relatively lower at polyhaline zone. The overall e-value of SMF was 0.47 (Table 4). The lowest e-value (0.02) was found in Kotka jamtola, and highest e-value (0.57) was found in Kotka forest office nearby area (Table 4). The overall evenness of SMF was 0.47. Joshi and Ghose (2014) have found the overall value of evenness for the mangroves of Lothian Island to be 0.52. Slightly higher evenness (0.82) was reported by Nazrul-Islam (1995) for the mangroves of the Bangladesh Sundarbans.

A good number of stocking rates (plants of dbh ≥ 10 cm with height at least 8 - 10 feet) of different major mangrove species of SMF was found. *Heritiera fomes* has growing stocks of 3433 ind./ha and 652 ind./ha in oligo-, and mesohaline zones, respectively. Although no *H. fomes* was found to grow within the quadrats of polyhaline zone, there were some plants growing in different places of this zone showing very stunted growth (10 - 15 feet only). The overall stocking rate of this plant in SMF was 2012 ind./ha. *S. apetala* and *A. cuculata* showed same distribution pattern as *H. fomes* with overall stocking rate of 1565 and 270 ind./ha, respectively. The growing stock of *C. decandra* were 925, 534, 2207 and 1117 ind./ha in oligo-, meso-, polyhaline zones and overall SMF, respectively. The number of individuals per ha of *E. agallocha* in oligo-, meso-, polyhaline zones and overall SMF were 634, 274, 1822 and 1340 ind./ha, respectively. The number of individuals per ha of *A. corniculata* in oligo-, meso-, polyhaline zones and overall SMF varied from

634, 274, 1822 and 1340 ind./ha, respectively. Chaffey *et al.* (1985) showed a decrease in growing stock of plants (plants with 15 cm dbh) with 180 per ha by 1983 in comparison to 296 per ha in 1959 (FORESTAL 1960). Bangladesh forest department recorded a stock of 144 i.e. a further reduction by 48.65% in 1996 (Aziz and Paul 2015) who reported that (using "Table curve 2D" program) total number of plants would be reduced to 109 per ha in 2020 and number of *H. fomes* and *E. agallocha* will be 80 and 7. Ahmed *et al.* (2011) have shown the reduction of *H. fomes* by 28.75% area coverage but an increase in *E. agallocha* by 6.7% i.e. 1016 ha between 1989 and 2010 in only two Ranges. The present study does not agree with the findings of Aziz and Paul (2015) and showed a great variation where the number of *E. agallocha* per ha showed a sharp increase. However, it is in agreement with the findings of Ahmed *et al*. (2011) who have reported an increase of area coverage of this plant by 6.7%. The increase in the number might be due to the ban on collection of timber of this plant as it was done previously for the raw materials of Khulna News Paper Mills.

The floristic similarities between the 14 locations were examined based on the species presence/absence data using the Sørensen similarity index ($C_s$) (Table 5). According to Sørensen (1948), $C_s$ value indicates similarity in floristic composition between two locations. When $C_s$ value is greater than 0.5, it is considered that high similarity in floristic composition present between the locations. The highest $C_s$ value (0.833) was found between Pathuria river west bank (L-4) and Pathuria river east bank (L-5) of oligohaline zone of SMF (Table 5). The lowest $C_s$ was observed between Pathuria river banks (L-4, 5) of oligohaline zone and Kashitana (L-13) of mesohaline zone of SMF (Table 5). In spite of establishing in different ecological zones the following locations showed higher $C_s$ value between them: Aandarmanik and Katka 8 ($C_s$ = 0.666), Pathuria river east bank and Katka jamtola ($C_s$ = 0.666) and Katka jamtola location and Burigoalini ($C_s$ = 0.714).

**Table 5. Sørensen similarity index ($C_s$) of the 14 locations of SMF.**

| Location no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 0.625 | | | | | | | | | | | | |
| 3 | 0.222 | 0.500 | | | | | | | | | | | |
| 4 | 0.266 | 0.769 | 0.533 | | | | | | | | | | |
| 5 | 0.400 | 0.615 | 0.533 | 0.833 | | | | | | | | | |
| 6 | 0.375 | 0.285 | 0.250 | 0.307 | 0.461 | | | | | | | | |
| 7 | 0.400 | 0.615 | 0.533 | 0.500 | 0.666 | 0.307 | | | | | | | |
| 8 | 0.521 | 0.666 | 0.588 | 0.428 | 0.571 | 0.533 | 0.428 | | | | | | |
| 9 | 0.631 | 0.705 | 0.315 | 0.500 | 0.500 | 0.235 | 0.500 | 0.555 | | | | | |
| 10 | 0.352 | 0.533 | 0.470 | 0.428 | 0.428 | 0.266 | 0.714 | 0.500 | 0.444 | | | | |
| 11 | 0.266 | 0.307 | 0.266 | 0.166 | 0.166 | 0.307 | 0.333 | 0.285 | 0.125 | 0.470 | | | |
| 12 | 0.222 | 0.250 | 0.333 | 0.133 | 0.307 | 0.250 | 0.307 | 0.352 | 0.526 | 0.533 | 0.400 | | |
| 13 | 0.266 | 0.307 | 0.133 | 0 | 0 | 0.153 | 0.333 | 0.428 | 0.250 | 0.545 | 0.333 | 0.400 | |
| 14 | 0.352 | 0.307 | 0.250 | 0.428 | 0.266 | 0.333 | 0.285 | 0.125 | 0.470 | 0235 | 0.500 | 0.428 | 0.461 |

The SMF showed a fluctuation in land area covers. In 1972, the forest area of Sundarbans occupied 398,278 ha (Table 6). But it had been increased 1.52% in 1989 covering 404,351 ha (Table 6). There had been decreasing tendency of the forest area since then. In 2015, Sundarbans covered 385,237 ha forest area, which was 3.27% less than that of 1972 (Table 6). The forest area of Sundarbans occupied 398,278 ha in 1972 and 392,398 ha in 2010. There had been a decreasing tendency of the forest area since 1972, which reduced to 385, 237 ha in 2015 i.e. 3.27% less than that of 1972. This reduction might be due to natural calamities such as Cyclone of 1991, Sidr (2007)

and Aila (2009), and soil erosion which have destructed the mangroves of Bangladesh during this period. Giri *et al.* (2014) have shown that the forest lands had an overall increase of 1.4% during 1970s to 2000s but a decrease of 2.5% between 1900s and 2000s. Ahmed *et al.* (2011) reported an overall reduction of total areas of the two Ranges (Chandpai and Khulna) by 3.6% (1598 ha) of Bangladesh SMF. The water area of Sundarbans which was 224,109 ha in 1972 (Table 6) decreased gradually in comparison to 1972. The bare land of Sundarbans showed a significantly increase trend till 2015 since 1972. But it decreased in 2010 having 9,100 ha than 2001. Sundarbans had 17,312 ha land area in 2015, which increased greatly 12655.67 % than 1972.

**Table 6. Changes of forest cover (ha), water area and bare land from 1972 to 2015 of SMF, determined by GIS technique (unsupervised classification of Satellite TM data).**

| Serial No. | Year | Forest area (ha) | % area increased or decreased (since 1972) | Water area (ha) | % area increased or decreased (since 1972) | Bare area (ha) | % area increased or decreased (since 1972) |
|---|---|---|---|---|---|---|---|
| 1. | 1972 | 3,98,278 | - | 2,24,109 | - | 135.72 | - |
| 2. | 1989 | 4,04,351 | 1.52% | 2,15,000 | –4.06% | 2,676.15 | 1871.82% |
| 3. | 2001 | 3,87,555 | –2.69% | 2,29,234 | –2.29% | 13,521.10 | 9862.49% |
| 4. | 2010 | 3,92,398 | –1.48% | 2,20,530 | –1.60% | 9,100.00 | 6604.98% |
| 5. | 2015 | 3,85,237 | –3.27% | 2,19,201 | –2.19% | 17,312.00 | 12655.67% |

The present study provides an update of the state of plant diversity and changes in forest cover and area and is likely to contribute in assessing the different anthropogenic impacts. Therefore, the SMF being World Heritage deserves special attention particularly from the Government of the People's Republics of Bangladesh for its conservation.

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