Journal of Plant Development Sciences
Meerut, India

REVIEW ARTICLE

FLORAL RESOURCES OF THE SUNDARBAN BIOSPHERE RESERVE, WEST BENGAL, INDIA AND ITS SOCIO - ECOLOGICAL IMPORTANCE

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Received-02.10.2023, Revised-16.10.2023, Accepted-28.10.2023

Abstract: The Sundarban Biosphere Reserve is one of the renowned mangrove forests and a UNESCO heritage site, situated the in the Bay of Bengal. It is also recognised as the world's largest contiguous mangrove forest and habitat for the iconic Royal Bengal Tiger. Spreading in *ca* 4200 sq km, the Indian Sundarbans is endowed with 102 islands, of which 54 are known for human habitation. Due to the unique deltoid nature, the region is very rich in biodiversity. The marine flora of the Sundarban Biosphere Reserve mainly includes mangroves and mangrove associates, seaweeds (marine macro algae), seagrasses and the phytoplanktons. The present comprehensive study reveals 32 taxa of true mangroves, 47 taxa of mangroves associates, 28 taxa of seaweeds, 6 taxa of seagrasses and 77 taxa of Phytoplantons. This rich floristic diversity of this Biosphere Reserve plays an important role in the sustainability of the marine ecosystems, carbon sequestration, climate change mitigation, and influences the socio-economic aspects of the region. Therefore, the present review study highlights the floristic resources of the Sundarban Biosphere Reserve and its importance in the ecological and socio-economical perspectives.

Keywords: Carbon sequestration, Floral resources, Mangroves, Socio-ecological, Sundarban, UNESCO Heritage

INTRODUCTION

The Sundarban Biosphere Reserve is one of the world's renowned mangrove sites. Because of the unique ecosystem and excellent support to the biodiversity, Sundarban was declared as UNESCO heritage site in the year 1987 and as Biosphere Reserve in the year 1989. Further, it was included in the global network of Biosphere Reserve under MAB program in 2001. The Sundarban mangrove forest is spreading in *ca* 10,200 sq km of area, of which *ca* 4200 sq km falls in India (Fig. 1) while *ca* 6000 sq km is in Bangladesh. It is the world's largest delta, formed by the rivers Ganges, Brahmaputra, Meghna and many other river tributaries, and situated on the lower end of the Ganges in the Bay of Bengal (Satpati *et al.*, 2012). The Indian Sundarban is endowed with 102 deltaic islands, of which 54 are reclaimed for human habitation (Chakraborty, 2011). More recently, considering the unique importance of the Sundarban, the government of India designated in 2019 as 27th site as a *Wetland of International Importance* (https://www.ramsar.org; Karthigeyan and Mao, 2022).

The conservation of biodiversity is a matter of global concern and therefore, its proper exploration and documentation in all the habitats are prerequisite for effective conservation. *The life below water* has been included as one of the components under the Sustainable Development Goals (SDG) of the United Nations. Therefore, extensive survey, explorations and documentation of the marine flora of the country is prerequisite for proper conservation and sustainable utilization of these marine resources towards *Blue Economy* for posterity.

The marine flora constitutes one of the important components of the marine biodiversity and plays an important role in the sustainability of the marine ecosystems. The marine flora are taxonomically very diverse and consist of mainly four different group of plants *viz.* mangroves, seagrasses (marine angiosperms), seaweeds (marine macro algae), and microalgae including phytoplanktons. The mangroves are the salt tolerant plants (halophytes), adapted to survive in coastal swamps. The seagrasses are the marine angiosperms, belonging to the monocots and are successfully adapted to survive in the marine habitats. The seaweeds are the marine macro algae and exclusively found in marine habitats. Its plant body is called *thallus*, which is usually differentiated into three parts namely holdfast, stipe and frond. The microalgae and phytoplantons are the microscopic and primitive plants and can survive in all aquatic habitats including fresh as well as marine water bodies.

The perusal of literature reveals that several sporadic reports and information are available on the floral resources of the Indian Sundarbans. As the Mangroves are the prime floral components in the Sundarban, it has been well explored and

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documented by many workers (Mukherjee and Mukherjee, 1978; Chaudhuri and Chaudhury, 1994; Mandal and Naskar, 2008; Chakraborty, 2011; Barik and Chowdhury, 2014; Karthigeyan and Mao, 2022). Similarly, there are several reports on the seagrasses of the West Bengal coast (Mahapatro *et al*., 2014; Thangaradjoua and Bhatt, 2018; Thirumalaiselvan *et al*., 2020). The seaweed resources of the Sundarban Biosphere Reserve have also been well explored and documented by many researchers (Naskar and Santra, 1985; Santra and Pal, 1988; Pal *et al*., 1988; Chattopadhyay and Pal, 1995; Pal, 2000; Naskar *et al*., 2000; Mukhopadhyay and Pal, 2002; Sen and Naskar, 2003; Saptati *et al*., 2012, 2013; Sengupta and Pal, 2016; Yadav and Majumdar, 2020; Yadav *et al*., 2020; Yadav, 2022). Likewise, the microalgae and phytoplantons of the region have also been reported by many researchers (Santra and Pal, 1988; Pal *et al*., 1988; Santra *et al*., 1991; Naskar *et al*., 2000; Sen *et al*., 2003; Choudhury and Bhadury, 2014; Basu *et al*., 2022). These reports and information on the floristic resources of the Sundarban are intermittent and sporadic. Therefore, an attempt has been made here to provide a comprehensive report on the floral resources of the Indian Sundarban Biosphere Reserve, with highlights on the ecological and socio - economic perspectives of these resources in the region.

Field explorations in the Sundarban Biosphere Reserve

The present study is mainly based on the field exploration in the Sundarban Biosphere Reserve and comprehensive study of the relevant literature. The field explorations were conducted during the years 2020 to 2021 in different locations of the study area. During the field visit, the vegetation patterns, habit, habitats, nature of the locality, GPS (using GARMIN 12 channel XL) etc. were recorded and photographed using digital camera (Nikon COOLPIX L120). The fresh samples of algal specimens (seaweeds) were collected from various habitats and parts of the mangrove like pneumatophores, barks, branches and decayed wooden pieces. The collected samples were carefully washed and preserved in dry forms (herbarium specimens) as well as wet form, following the standard herbarium techniques (Dhargalkar and Kavlekar, 2004) and deposited at the Botanical Survey of India, Central National Herbarium (CAL), Howrah.

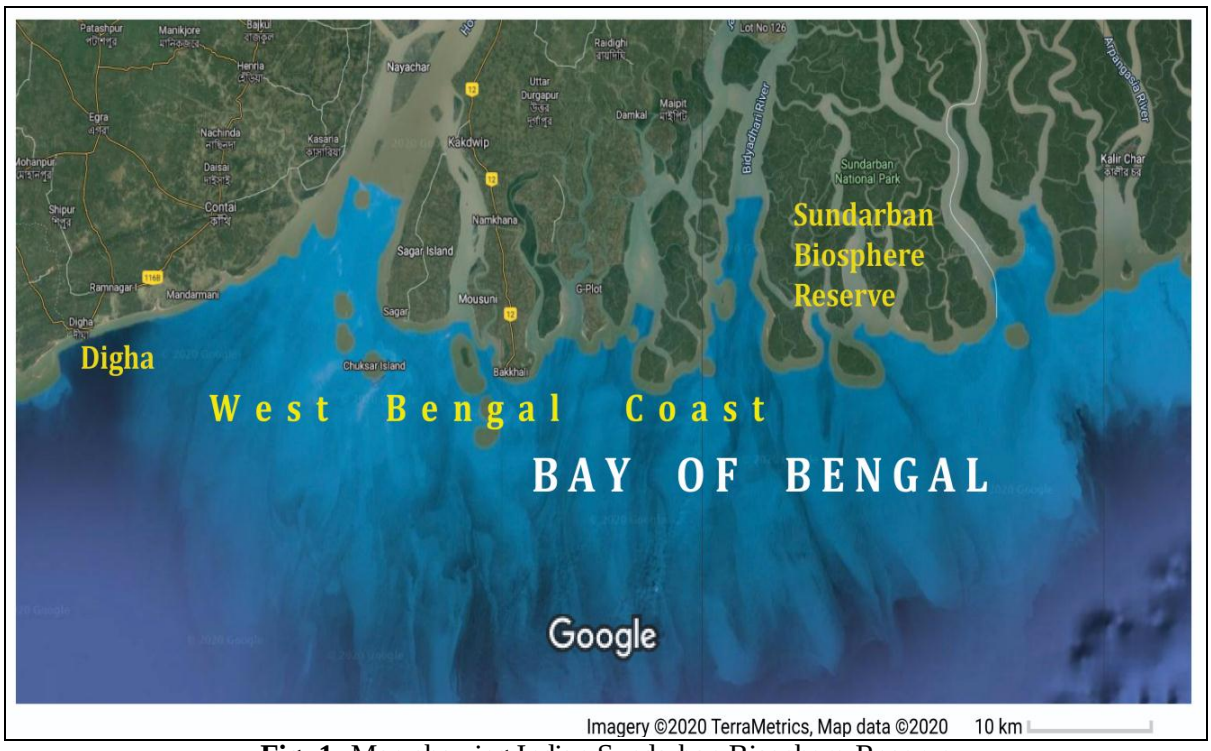

Fig. 1. Map showing Indian Sundarban Biosphere Reserve

DISCUSSION

The Sundarban Biosphere reserve is the world's largest contiguous Mangroves site, and also a UNESCO heritage site. The study revealed that the Indian Sundarban is endowed with rich floral diversity. The marine flora of the Sundarban mainly includes mangroves, seaweeds (marine macro algae), seagrasses (marine angiosperms), phytoplanktons and microbes. Therefore, based on the field explorations and study of the relevant literature, a comprehensive list of the floral resources of the Sundraban Biosphere Reserve has been prepared, which is enumerated as below:

Mangroves and Mangrove Associates

(a) Mangroves

The mangroves are the most dominant, and prime components of the flora of the Sundarban Biosphere Reserve. The name '*Sundarban'* is also derived from the name of a mangrove tree *Heritiera fomes* Buch.-Ham (Sterculiaceae), which is locally called as '*Sundari'*. The mangroves of the region have attracted many botanists and researchers for a long time. Therefore, several studies have been carried out by various researchers for the study and documentation of the mangroves of the region (Roxburgh, 1814; Clarke, 1896; Prain, 1903, Mukherjee and Mukherjee, 1978; Naskar, 1983; Chaudhuri and Chaudhury, 1994; Mandal and Naskar, 2008; Chakraborty, 2011; Debnath *et al*., 2013; Barik and Chowdhury, 2014; Maity *et al*., 2020). Debnath *et al*. (2013) reported 964 taxa of angiosperms including mangroves and mangrove associates. The most recent studies by the Botanical Survey of India revealed 32 taxa of true mangroves under 22 genera and 15 families from the Sundarban Biosphere Reserve, West Bengal as shown in Table 1a, and 42 taxa of true mangroves from India (Karthigeyan and Mao, 2022).

Table 1a: List of the True Mangroves in the Sundarban Biosphere Reserve

Sl. No.	Name of the taxa	Family
1.	*Acanthus ilicifolius* L.	Acanthaceae
2.	*Acanthus volubilis* Nees	Acanthaceae
3.	*Nypa fruticans* Wurmb.	Arecaceae
4.	*Phoenix paludosa* Roxb.	Arecaceae
5.	*Avicennia alba* Blume	Avicenniaaceae
6.	*Avicennia marina* (Forssk.) Vierh.	Avicenniaaceae
7.	*Avicennia officinalis* L.	Avicenniaaceae
8.	*Dolichandrone spathacea* Sch.	Bignoniaceae
9.	*Lumnitzera racemosa* Willd.	Combretaceae
10.	*Excoecaria agallocha* L.	Euphorbiaceae
11.	*Shirakiopsis indica* (Willd.) Esser	Euphorbiaceae
12.	*Cynometra iripa* Kostel.	Fabaceae
13.	*Brownlowia lanceolata* Kost.	Malvaceae
14.	*Heritiera fomes* Buch.-Ham.	Malvaceae
15.	*Aglaia cucullata* (Roxb.) Pellegrin.	Meliaceae
16.	*Xylocarpus granatum* J.Koenig	Meliaceae
17.	*Xylocarpus moluccensis* (Lam.) M.Roem.	Meliaceae
18.	*Aegiceras corniculatum* (L.) Blanco	Myrsinaceae
19.	*Aegialitis rotundifolia* Roxb.	Plumbaginaceae
20.	*Acrostichum aureum* L.	Pteridaceae
21.	*Bruguiera cylindrica* (L.) Blume	Rhizophoraceae
22.	*Bruguiera gymnorrhiza* (L.) Lam.	Rhizophoraceae
23.	*Bruguiera parviflora* Wight & Arn ex Groff.	Rhizophoraceae
24.	*Bruguiera sexangula* (Lour.) Poir	Rhizophoraceae
25.	*Ceriops decandra* (Griff.) Ding Hou	Rhizophoraceae
26.	*Ceriops tagal* (Perr.) Robin.	Rhizophoraceae
27.	*Kandelia candel* (L.) Druce	Rhizophoraceae
28.	*Rhizophora apiculata* Blume	Rhizophoraceae
29.	*Rhizophora mucronata* Poir.	Rhizophoraceae
30.	*Scyphiphora hydrophyllacea C.F.* Gaertn.	Rubiaceae
31.	*Sonneratia apetala* Buch. Ham.	Sonneratiaceae
32.	*Sonneratia caseolaris* (L.) Engler	Sonneratiaceae

(b) Mangroves associates

The mangrove associates are those plants that usually grow in association with the mangroves. It plays an important role in the stability of the mangroves ecosystems. About 68 mangroves associates have been reported from all over the Indian coastlines (Karthigeyan and Mao, 2022). There are many reports on the diversity of mangroves associates in the Sundarban region (Naskar and Guhabakshi, 1987; Naskar, 1993; Ghosh *et al*., 2002; Mandal and Naskar, 2008; Chakraborty, 2011; Karthigeyan and Mao, 2022). The perusal of relevant literature

revealed a comprehensive list of about 47 taxa of mangroves associates under 41 genera and 22 families from the Sundarban Biosphere Reserve of West Bengal, as shown in table 1b.

Table 1b: List of the Mangroves associates in the Sundarban Biosphere Reserve

Sl. No.	Name of the taxa	Family
1.	*Aeluropus lagopoides* (L.) Trin. ex Thwaites	Poaceae
2.	*Barringtonia acutangula* (L.) Gaertn.	Lecythidaceae
3.	*Barringtonia racemosa* (L.) Spreng.	Lecythidaceae
4.	*Caesalpinia bonduc* (L.) Roxb.	Fabaceae
5.	*Caesalpinia crista* L.	Fabaceae
6.	*Calophyllum inophyllum* L.	Clusiaceae
7.	*Cassytha filiformis* L.	Lauraceae
8.	*Casuarina equisetifolia* L.	Casuarinaceae
9.	*Cerbera odollam* Gaertn.	Apocynaceae
10.	*Clerodendrum inerme* (L.) Gaertn.	Verbenaceae
11.	*Clerodendrum neriifolium* var. *macrocarpum* Wall. ex C.B.Clarke	Verbenaceae
12.	*Cryptocoryne ciliata* (Roxb.) Fisch. ex Schott	Araceae
13.	*Cynometra ramiflora* L.	Fabaceae
14.	*Dalbergia spinosa* Roxb.	Fabaceae
15.	*Derris scandens* Benth.	Fabaceae
16.	*Derris trifoliata* L.	Fabaceae
17.	*Dodonaea viscosa* Jacq.	Sapindaceae
18.	*Finlaysonia obovata* Wall.	Cyperaceae
19.	*Heliotrophium curassavicum* L.	Boraginaceae
20.	*Hibiscus tiliaceous* L.	Malvaceae
21.	*Hoya parasitica* (Roxb.) Wall. ex Wight	Asclepiadaceae
22.	*Ipomoea pes-caprae* (L.) R. Br.	Convolvulaceae
23.	*Launaea sarmentosa* (Willd.) Sch. Bip. ex Kuntze	Asteraceae
24.	*Manilkara hexandra* (Roxb.) Dubard	Sapotaceae
25.	*Myriostachya wightiana* (Nees ex Steud.) Hook.f.	Poaceae
26.	*Pandanus odorifer* (Forssk.) Kuntze	Pandanaceae
27.	*Pentatropis capensis* (L.f.) Bullock	Asclepiadaceae
28.	*Phragmites karka* (Retz.) Trin. ex Steud.	Poaceae
29.	*Phyla nodiflora* (L.) Greene	Verbenaceae
30.	*Porteresia coarctata* (Roxb.) Tateoka	Poaceae
31.	*Premna corymbosa* Rottler	Verbenaceae
32.	*Ruppia maritima* L.	Potamogetonaceae
33.	*Saccharum spontaneum* L.	Poaceae
34.	*Salacia chinensis* L.	Celastraceae
35.	*Salicornia brachiata* Roxb.	Chenopodiaceae
36.	*Sarcolobus carinatus* Wall.	Asclepiadaceae
37.	*Sarcolobus globosus* Wall.	Asclepiadaceae
38.	*Scirpus littoralis* Sch.	Cyperaceae
39.	*Sesuvium portulacastrum* (L.) L.	Aizoaceae
40.	*Solanum trilobatum* L.	Solanaceae
41.	*Spinifex littoreus* (Burm.f.) Merr.	Poaceae
42.	*Suaeda maritima* (L.) Dumort.	Chenopodiaceae
43.	*Suaeda nudiflora* (Willd.) Moq.	Chenopodiaceae
44.	*Thespesia populneoides* (Roxb.) Kostel.	Malvaceae
45.	*Trianthema portulacastrum* L.	Aizoaceae
46.	*Trianthema triquetra* Rott. & Willd.	Aizoaceae
47.	*Vigna marina* (Burm.) Merr.	Fabaceae

Seaweeds (Marine macro algae)

Seaweeds are the marine macro algae and grow exclusively in the marine and estuarine habitats. India, with a coastline of about 7,500 km long coastline, is endowed with diverse forms of coastal habitats and support more than 865 taxa of seaweeds, comprising of 212 taxa of chlorophyceae, 211 taxa of phaeophyceae and 442 taxa of Rhodophyceae (Rao and Gupta, 2015). Seaweeds are mostly lithophilic in nature and grow luxuriantly on rocky habitats. However, in the Sundarban Biosphere reserve, the rocky habitats are almost negligible, rather it is full of shallow land, muds and deltaic nature. Therefore, in such a changed habitat in the Sundarban, seaweeds

are adapted to grow on the mangroves forest floor, trunks and pneumatophores as epiphytes and also to some extend on the scattered rocky substrata (Yadav *et al*., 2020). The seaweed resources of the Indian Sundarban region have been studies and published by several researchers (Naskar and Santra, 1985; Santra and Pal, 1988; Pal *et al*., 1988; Chattopadhyay and Pal, 1995; Pal, 2000; Naskar *et al*., 2000; Mukhopadhyay and Pal, 2002; Sen and Naskar, 2003; Sen *et al*., 2003; Saptati *et al*., 2012, 2013; Sengupta and Pal, 2016; Sinha *et al*., 2016; Yadav and Majumdar, 2020; Yadav *et al*., 2020; Yadav, 2022). The recent field explorations and study of the relevant literature revealed 28 taxa of seaweeds under 13 genera, 9 families and 8 orders. These include 20 taxa of Chlorophyceae and 8 taxa of Rhodophyceae. Chlorophyceae is dominant with 71% diversity, followed by Rhodophyceae with 29% diversity. The updated list of the seaweeds recorded from the Sundarban Biosphere Reserve is provided in table 2.

Table 2: List of the seaweeds (marine macro algae) in the Sundarban Biosphere Reserve (Yadav, 2022).

Sl. No.	Name of the taxa	Family
1.	*Ulva clathrata* (Roth) C. Agardh	Ulvaceae
2.	*Ulva compressa* L.	Ulvaceae
3.	*Ulva flexuosa* Wulfen	Ulvaceae
4.	*Ulva intestinalis* L.	Ulvaceae
5.	*Ulva lactuca* L.	Ulvaceae
6.	*Ulva linza* L.	Ulvaceae
7.	*Ulva linza* L. var. *bicornuta* H.V. Joshi & V. Krishnam.	Ulvaceae
8.	*Ulva prolifera* O.F. Muell.	Ulvaceae
9.	*Chaetomorpha aerea* (Dillwyn) Kuetz.	Cladophoraceae
10.	*Chaetomorpha gracilis* Kuetz.	Cladophoraceae
11.	*Chaetomorpha tortuosa* (Dillwyn) Kleen	Cladophoraceae
12.	*Cladophora glomerata* (L.) Kuetz.	Cladophoraceae
13.	*Rhizoclonium crassipellitum* West & G.S.West	Cladophoraceae
14.	*Rhizoclonium fontanum* Kuetz.	Cladophoraceae
15.	*Rhizoclonium hieroglyphicum* (G. Agardh) Kuetz.	Cladophoraceae
16.	*Rhizoclonium pachydermum* Kjellm.	Cladophoraceae
17.	*Rhizoclonium riparium* (Roth) Harv.	Cladophoraceae
18.	*Rhizoclonium antillarum* Kuetz.	Cladophoraceae
19.	*Pseudorhizoclonium africanum* (Kuetz.) Boedeker	Cladophoraceae
20.	*Codium geppiorum* O.C.Schmidt	Codiaceae
21.	*Gelidium pusillum* (Stackh.) Le Jolis	Gelidiaceae
22.	*Gracilaria gracilis* (Stackh.) Steentoft, L.M.Irvine & Farnham	Gracilariaceae
23.	*Catenella caespitosa* (With.) L. Irvine	Caulacanthaceae
24.	*Catenella nipae* Zanardini	Caulacanthaceae
25.	*Ceramium manorense* P.Anand	Ceramiaceae
26.	*Bostrychia simpliciuscula* Harv. ex J.Agardh	Rhodomelaceae
27.	*Polysiphonia mollis* Hook.f. & Harv.	Rhodomelaceae
28.	*Compsopogon caeruleus* (Balb. ex C. Agardh) Mont.	Compsopogonaceae

Seagrasses

The Seagrasses are the angiosperms which are ecologically adapted to grow and survive in the marine and estuarine environments. Unlike seaweeds, seagrasses produce flowers, fruits and seeds, and also possess true roots which make them capable of extracting minerals and other nutrients from the substrata. It is an important component of the marine flora and plays an important role in the stability of the marine ecosystems, stabilizing the sea bottom, serving as breeding ground for the fishes, maintaining oxygen level and serving as bioindicator of the health of the marine habitats. Besides, seagrasses are the favourite diet of Dugongs (*Dugong dugon*), an IUCN Vulnerable (VU) herbivorous marine mammal, also known as *sea cows*, and plays an important role in its conservation strategies (Marsh *et al*., 1999, 2002; Sivakumar and Nair, 2013). Therefore, considering its importance in the marine ecosystems, seagrasses are also popularly known as *Biological sentinels, ecological engineers* (Thangaradjoua and Bhatt, 2018) and also the *lungs of the sea*, as one square meter of the seagrass beds can produce 10 litres of Oxygen through photosynthesis every day (Reynolds, https://ocean.si.edu/).

In India, so far 16 taxa of seagrasses have been documented from various coastal localities

(Thangaradjoua and Bhatt, 2018; Thirumalaiselvan *et al*., 2020). From the West Bengal coast, so far 6 taxa of the seagrasses, belonging to two genera *Halodule* and *Halophila* under the families Cymodoceaceae and Hydrocharitaceae respectively have been reported (Mahapatro *et al*., 2014; Thangaradjoua and Bhatt, 2018). The study also reveals 2 taxa of seagrasses namely *Halophila decipiens* Ostenf. and *Halodule uninervis* (Forssk.) Boiss. from the Sundarban forests of the Bangladesh (Islam and Aziz, 1980). The list of the seagrasses reported form the West Bengal coast is given in table 3.

Table 3: List of the seagrasses in the Sundarban Biosphere Reserve (Mahapatro *et al*., 2014; Thangaradjoua and Bhatt, 2018).

Sl. No.	Name of the taxa	Family
1.	*Halodule pinifolia* (Miki) Hartog	Cymodoceaceae
2.	*Halodule uninervis* (Forssk.) Boiss.	Cymodoceaceae
3.	*Halodule wrightii* Asch.	Cymodoceaceae
4.	*Halophila beccarii* Asch.	Hydrocharitaceae
5.	*Halophila ovalis* (R.Br.) Hook.f.	Hydrocharitaceae
6.	*Halophila ovata* Gaudich.	Hydrocharitaceae

Phytoplanktons and Microalgae

The phytoplanktons and microalgae constitute one of the important components of the marine flora. They are very fragile and microscopic in nature and play very crucial role in the marine ecosystems. There are many reports by various researchers (Santra and Pal, 1988; Pal *et al*., 1988; Santra *et al*., 1991; Naskar *et al*., 2000; Sen *et al*., 2003; Choudhury and Bhadury, 2014; Basu *et al*.,2022) on the Phytoplanktons and microalgae of the Sundarban region. Mitra *et al*. (2012) reported 47 taxa of phytoplankton from 12 selected localities in the region and suggested that cell volumes of certain phytoplanktons can be used as indicator of aquatic salinity. Satpati *et al*. (2013) reported 32 taxa of green microalgae from the Sundarbans mangroves and studied its morphotaxonony. Choudhury and Bhadury (2014) also studied the cell biovolume estimation of 19 selected genera of the phytoplankton from the Sundarban regions. Sinha *et al*. (2021) reported 77 taxa of Phytoplantons under 66 genera under 11 families from the Bhetkimari canal in the Indian Sundarbans. The report also indicated the dominance of diatoms with diversity of 25 taxa, mainly from Pennales.

Table 4: List of the Phytoplanktons in the Sundarban Biosphere Reserve (Sinha *et al*., 2021).

Sl. No.	Name of the taxa	Family
1.	*Oscillatoria*	Cyanophyceae
2.	*Dolichospermum*	Cyanophyceae
3.	*Lyngbya*	Cyanophyceae
4.	*Chroococcus*	Cyanophyceae
5.	*Merismopedia*	Cyanophyceae
6.	*Spirulina*	Cyanophyceae
7.	*Phormidium*	Cyanophyceae
8.	*Calothrix*	Cyanophyceae
9.	*Nostoc*	Cyanophyceae
10.	*Coelosphaerium*	Cyanophyceae
11.	*Ulothrix*	Chlorophyceae
12.	*Chlorella*	Chlorophyceae
13.	*Oedogonium*	Chlorophyceae
14.	*Microspora*	Chlorophyceae
15.	*Tetraedron*	Chlorophyceae
16.	*Ankistrodesmus*	Chlorophyceae
17.	*Schroederia indica*	Chlorophyceae
18.	*Monoraphidium*	Chlorophyceae
19.	*Scenedesmus quadricauda*	Chlorophyceae
20.	*Selenastrum*	Chlorophyceae
21.	*Chlamydomona*	Chlorophyceae
22.	*Raphidiopsis*	Chlorophyceae
23.	*Planktosphaeria*	Chlorophyceae
24.	*Eudorina*	Chlorophyceae
25.	*Coelastrum*	Chlorophyceae
26.	*Oocystis*	Trebouxiophyceae
27.	*Actinastrum*	Trebouxiophyceae
28.	*Closteriopsis*	Trebouxiophyceae
29.	*Crucigenia*	Trebouxiophyceae
30.	*Closterium*	Conjugatophyceae
31.	*Spirogyra*	Conjugatophyceae
32.	*Fragilaria*	Bacillariophyceae
33.	*Amphora*	Bacillariophyceae
34.	*Amphipleura*	Bacillariophyceae
35.	*Pinnularia*	Bacillariophyceae
36.	*Mastogloia*	Bacillariophyceae
37.	*Cymbella*	Bacillariophyceae
38.	*Synedra ulna*	Bacillariophyceae

39.	*Synedra acus*	Bacillariophyceae
40.	*Cylindrotheca closterium*	Bacillariophyceae
41.	*Epithemia*	Bacillariophyceae
42.	*Hantzschia*	Bacillariophyceae
43.	*Navicula* sp.	Bacillariophyceae
44.	*Navicula rhyncocephala*	Bacillariophyceae
45.	*Navicula gracilis*	Bacillariophyceae
46.	*Navicula angusta*	Bacillariophyceae
47.	*Gyrosigma*	Bacillariophyceae
48.	*Nitzschia* sp.	Bacillariophyceae
49.	*Nitzschia palea*	Bacillariophyceae
50.	*Nitzschia reversa*	Bacillariophyceae
51.	*Nitzschia obtusa*	Bacillariophyceae
52.	*Nitzschia sigmoidea*	Bacillariophyceae
53.	*Nitzschia intermedia*	Bacillariophyceae
54.	*Tetracyclus*	Bacillariophyceae
55.	*Tabellaria*	Bacillariophyceae
56.	*Surirella*	Bacillariophyceae
57.	*Asterionella*	Bacillariophyceae
58.	*Gomphonema angustum*	Bacillariophyceae
59.	*Gomphonema truncatum*	Bacillariophyceae
60.	*Cyclotella*	Mediophyceae
61.	*Leptocylindrus*	Mediophyceae
62.	*Melosira*	Coscinodiscophyceae
63.	*Trieris mobiliensis*	Coscinodiscophyceae
64.	*Planktioniella*	Coscinodiscophyceae
65.	*Lauderia*	Coscinodiscophyceae
66.	*Skeletonema*	Coscinodiscophyceae
67.	*Aulacoseira*	Coscinodiscophyceae
68.	*Coscinodiscus*	Coscinodiscophyceae
69.	*Thalassiosira*	Coscinodiscophyceae
70.	*Thalassionema nitzschioides*	Coscinodiscophyceae
71.	*Centritractus*	Xanthophyceae
72.	*Tribonema*	Xanthophyceae
73.	*Synura*	Synurophyceae
74.	*Trachelomonas*	Euglenophyceae
75.	*Euglena*	Euglenophyceae
76.	*Phacus*	Euglenophyceae
77.	*Ceratium*	Dinophyceae

ECOLOGICAL SERVICES BY THE MARINE FLORA IN THE SUNDARBAN BIOSPHERE RESERVE

The marine ecosystems are the integral part of our biodiversity and provide many services to the human beings, particularly in the food security, fodder, and raw materials for many industries, building materials for coral and sand, and protection against various natural dangers such as coastal erosion and floods. The Indian Sundarban Biosphere Reserve is very rich in floral and faunal biodiversity (Fig. 2 and Fig. 3). Verma *et al*. (2017) and Saha and Taron (2023), estimated that Indian Sundarbans provides different ecosystem services with an economic value estimated at USD 10,285.90 million in 2014 (USD 13,764.85 million) at 2019 prices. According to the Millennium Ecosystem Assessment (MEA), the marine and coastal ecosystems produce four types of ecosystem services (https://ocean-climate.org/) that include 1. Provisioning services (fisheries, building materials), 2. Supporting services (maintenance of life-cycle for both fauna and local, element and nutrient cycling), 3. Regulating services (carbon sequestration and storage, erosion prevention, waste-water treatment, moderation of extreme events etc.) and 4. Cultural services (tourism, recreational, aesthetic, and spiritual benefits). In USA, the total value of the services produced by marine and coastal ecosystems is valued at USD$ 29.5 trillion per year in 2015 (https://ocean-climate.org/). Therefore, the ecological services bestowed by the marine flora are excellent and may be discussed broadly as below:

Food chain and sustainability of marine ecosystems: The phytoplanktons, microalgae, seaweeds and seagrasses serve as primary producer in the food chain and play a very crucial role in the sustainability of the marine ecosystems. Besides, it serves as food and breeding ground for the marine fauna like fishes, crabs, molluscs etc. The seagrasses, popularly known as the *lungs of the sea*, are the favourite diet of Dugongs (*Dugong dugon*), which has been assessed as an IUCN Vulnerable (VU) herbivorous marine mammal (Sivakumar and Nair, 2013). In addition, marine flora produces Oxygen through photosynthesis and maintains DO level in the aquatic ecosystems, which is very essential for the survival of the aquatic fauna. Therefore, it plays an exceptional role in the aquatic ecosystems.

Carbon Sequestration: The Ocean is considered as one of the major carbon sink on the Earth. It absorbs very enormous quantity of the atmospheric carbons in various forms. The mangroves, seagrasses, seaweeds and phytoplantons are the key bio components to absorb and store the atmospheric carbons. Mangroves has the capacity to constitute rich soil carbon content up to several metres depth (Donato *et al*., 2011) and also a high belowground

carbon content in their root system, as compared to other tropical forests (Lovelock, 2008). Therefore, mangroves have high rates of carbon sequestration in both above- and below-ground live biomass (Alongi, 2012). The marine flora such as phytoplankton, seaweed and seagrass are excellent carbon sequestering agents than their terrestrial counterparts (Zou, 2005; Kaladharan *et al*., 2009). Kathiresan *et al*. (2021) and Sivaraj *et al*. (2023) studies the carbon sequestration in planted mangrove stands of *Avicennia marina* in the Indian coast. Kaladharan *et al*. (2009) reported Carbon sequestration analysis by 5 marine algae in the lab condition, in which the green alga *Ulva lactuca* registered 100 % utilization of CO_2 towards carbon fixation. The monetary evaluation of the carbon sequestration by the Sundarnban is excellent. It is estimates that the Sundarbans have soaked in 4,150,000,000 tonnes of carbon dioxide, valued at around $79 billion in the international market (Paul, 2012; Mahadevia and Vikas, 2012). Bera *et al*. (2022) studied the quantification of carbon sequestration by the Mangroves of the Sundarban for ecosystem service values (ESVs) for the period of 45 years (1975 - 2020) and reported that the total static carbon storage was 48.87, 46.65 and 43.33 Tg for the year 1975, 2000 and 2020 respectively. Therefore, the marine flora have significant role in carbon sequestration.

Climate change mitigation: The marine ecosystems play important role in the climate change mitigation by storing greenhouse gases and carbon. The sea is highly influenced by the climate change. The marine flora act as *blue carbon sinks* and play very crucial role in climate change mitigation, sequestering 2.67 times more carbon than afforestation and over 10 times more than grasslands and agriculture (https://www.ceew.in/).Besides, the marine flora, particularly mangroves resist the wind speed, wave turbulence and act as a speed breaker in the context of cyclones and coastal protection. The mangroves of the Sundarbans act as first line of defence for the state of West Bengal from the violent storms that periodically arise in the Bay of Bengal and also as a natural shield and buffer zone for the metro city of Kolkata from the impact of super cyclones like *Amphan* which is considered as one of the sternest cyclone to hit West Bengal in the last 100 years and caused damage in about 1,600 sq km area in the Sunderbans (Sen, 2020). The Sundarban mangroves play a key role in protecting the city of Kolkata from the greatest danger, which is likely to come from higher tides and more intense storms ravaging the urban greens, as witnessed in *Amphan* (Sen, 2020; Biswas and Sen, 2020). As sea levels rise and storm patterns shift in the Bay of Bengal, scientists project increases in extreme water levels near Kolkata (Mitchell *et al*., 2006). Sardar and Samadder (2023) studied the long term ecological vulnerability assessment in the Indian Sundarban and hypothesises that mangrove ecosystems are highly adaptive and respond to the changing environment by various natural resilience strategies at the ecosystem level. Therefore, marine flora in the Sundarbans have very crucial role in the climate change mitigation.

Socio-economic importance: Globally, around 1.6 billion people worldwide are thought to depend on forests for their livelihoods (World Bank, 2004).The Sundarban Biosphere Reserve has high impact on the socio economic aspects of the state. It provides sustainable livelihoods for millions of people living in its vicinity and acts as a biological shelter to protect the people from storms, cyclones, tidal surges, sea water seepage and intrusion. The surroundings of the Sundarban mangroves, both in India and Bangladesh, are some of the most densely populated areas in the world (Ghosh *et al*., 2015). Abdullah *et al*. (2016) reported that approximately 3.5 million people live in the immediate proximity to the Bangladesh Sundarbans forest, and depend largely on forest resources in various ways, particularly the lower and middle income households. The Indian Sundarban provides livelihood for large numbers of people living in the vicinity of the areas and working as wood-cutters, fisherman, honey gatherers, leaves and grass gatherers. More than half of the population, living in the vicinity of the area depend heavily on the goods and services that the Sundarban forests provide (Banerjee, 1964; Iftekhar, 2008; Ghosh *et al*., 2015). In addition, apiculture is prevalent within the Indian Sundarban and provides honey and wax. Around 2000 people are engaged in beekeeping, producing about 90% of the total natural honey production in India (Spalding *et al*., 2010). About 1100 villages are located in the vicinity of the Sundarbans region, of which about 62 are situated on the peripheries of the forest, and majority of the local population here depends on forest products such as fuel wood as biomass (https://www.wwfindia.org). In addition, mangrove plants provide tannins for leather production and a wide array of medicinal uses. Whilst crabs, molluscs, shrimps and fish are caught in the ocean and the brackish waters surrounding the mangrove forests, the mangrove proper is the most important source for shrimp larvae supplying the aquacultures. The surroundings of the Sundarban mangroves, both in India and Bangladesh, are some of the most densely populated areas in the world (Ghosh *et al*. 2015). Besides, mangroves also provide tannins which is of industrial uses. Therefore, Sundarban Biosphere Reserve has great socio-economic importance in the region.

CHALLENGES FOR CONSERVATION

There are many challenges including Natural and Anthropogenic factors, which affect the biodiversity of the Sundarban Biosphere Reserve. The natural

factors primarily include cyclones, Tsunamies, earthquakes, floods, coastal erosion, rise in the sea level, coastal landscapes, temperature, coastal habitats, temperature, salinity of the seawater and many other issues due to climate change. Whilst, the anthropogenic factors mainly include the human pressure, uncontrolled fishing, and many other activities that influence the Sundarban area. Due to the climate change, the relative mean sea-level in Sagar island of the Indian Sundarban and adjoining areas of the Bay of Bengal is rising at the rate of 12 mm per year, as compared to the global average of 2 mm per year, and has also caused submergence of the considerable landmass (https://www.wwfindia.org). Raha *et al*. (2014) studied the nine southern-most islands of Indian Sundarban estuary, for the period of 14 years from 1999 to 2013, through time-series analysis of satellite imageries and revealed that few islands were undergoing gradual erosion, while continuous emergence of few more new islands through deposition of silt load. They further reported that other factors like destruction of mangrove vegetation, sediment deposition, natural subsidence and lack of fresh water flow can have more impact on the dynamics of Sundarban islands than the single factor of sea level rise. In addition, the *post - Tsunami* study carried out by Sen (2020) revealed that there is substantial dieback of *Sundari* trees (*Heritiera fomes* Buch.-Ham) due to the outbreak of the top-dying disease, locally known as *'agamora'*. Besides, the two major factors that affect the biodiversity of the Sunderban is the salinization and sedimentation due to the extensive floods that occur in the eastern parts of India during the monsoon, and secondly the sea level rise due to the global climate change (Gopal and Chauhan, 2006).

Historically, during the British colonial era, large tracts of the Indian Sundarbans were cleared, drained and reclaimed for cultivation and the remaining parts have been under various protection regimes since the 1970s, primarily to protect the remaining population of Bengal tigers (Ghosh *et al*., 2015). Because of the dense population pressure in the region, the encroachment in the area for various purposes such as agriculture, extraction of forest resources continues that leads to the pressure on the ecosystem and brought threshold of its carrying capacity (Ghosh, 2012). There are many instances of cause of conflict with the refugees who intended to settle in the periphery of the protected area (Jalais, 2005). In addition, the presence of highly invasive alien species, viz. *Prosopis juliflora* at the sand dune and nearby area of the plantation site of 'Buraburir Tot' also poses threat to the local biodiversity of the Sundarban. Therefore, it needs proper management to contain the rapid spread of such invasive species (Karthigeyan and Bhattacharjee, 2020). Hence, there are many factors which affect the ecosystems of the Sudarbans and its biodiversity.

CONSERVATION MEASURES AND FUTURE PERSPECTIVES

There are many conservation measures that are being adopted for the conservation of biodiversity of the Sundarban Biosphere Reserve. These include proper monitoring and survey of the mangroves forest, sustainable tourism and fishing, awareness among the local inhabitants, mangroves restoration and plantation activities in the areas. Incentive design is also one of the most significant factors behind active community participation and long-term sustainability of participatory forest management. The concept of the Joint Forest Management (JFM) or community based participatory forest management has already been introduced in the Sundarbans Reserve Forest since 1991 (Dasgupta and Shaw, 2016; Saha and Taron, 2023). Besides, in order to protect habitat of the national animal - tigers, the Government of India declared Sundarbans as Tiger Reserve in the year 1973. The mangroves restoration activities in the Sundarban through community participation offers the promise of reaping multiple environmental benefits while simultaneously helping local communities augment their livelihoods through generating incomes from ecosystem services. The incomes generated through carbon credits by restoration activities must be shared within the local communities for better livelihood options in order to ensure long-term involvement of the community (Ranjan, 2010). In addition to the government measures, several NGOs are also involved in restoration activities in the Sundarbans. Recently, a restoration project "*Restoration of Mangroves in Sundarbans through Afforestation, Integrated Mangrove-Shrimp Farming, Income Generation and Community Participation (2017-2020)*" was undertaken by the 'Nature Environment and Wildlife Society' (NEWS), an NGO with objectives to stabilize the mangrove ecosystems effectively and to improve the livelihood of the local coastal population through mangrove afforestation. The afforestation process at two selected sites of Sundarbans namely *Buraburir Tot* and *Lakshmipur intertidal mangrove habitat* in Kakdwip, was monitored and evaluated by the Scientists of Botanical Survey of India (BSI), Ministry of Environment, Forest and Climate Change, Government of India and reported very positive response in strengthening the natural regeneration and afforestation programme (Karthigeyan and Bhattacharjee, 2020).

Fig. 2. Sundarban Biosphere Reserves: A. Panoramic view of Mangroves forests in Sundarban; **B.** Exposed mangroves during low tide near Dobanki camp (*Inset*: a Deer grazing in the forest)

Fig. 3. Mangroves associated vegetation in Sundarban Biosphere Reserves: A. *Salicornia brachiata* Roxb. – an important mangrove associate; **B.** Mixed vegetation of seaweeds with dominant growth of *Ulva lactuca* forming thick biomass at Amlamethi; **C.** Red algae *Catenella caespitosa* (With.) L. Irvine and *C. nipae* Zanardini growing as epiphytes on a young mangrove; **D.** Mangrove pneumatophores supporting as substrata for green alga *Chaetomorpha aerea* (Dillwyn) Kuetz.

Fig. 4. Sustainable livelihood activities in the Sundarban B.R.: A. Influx of tourists towards Dobanki Camp - an important tourist destination; **B.** Selling of forest produces by local people at Jharkhali (*Inset*: fruits and seeds of *Sterculia foetida* L. – Sterculiaceae -Kathbadam).

Considering the immense importance of the natural resources in the Sundarban areas, the Government of India has initiated many schemes notably National Coastal Mission Programme on '*Conservation and Management of Mangroves and Coral Reefs*', MISTI (*Mangrove Initiative for Shoreline Habitats & Tangible Incomes*), PMMSY (*Pradhan Mantri Matsya Sampada Yojana), Sagar Parikrama* etc. which are being implemented to conserve the marine biodiversity with the vision to promote sustainable utilization of these marine resources as part of the *Blue Economy* and improve the livelihood of the local people (Fig. 4). Further, it is also pertinent to mention that the mangrove beds of the Sundarban support 11 economically important seaweeds (Fig. 3, B-D) in good biomass (Yadav, 2022), which can be promoted for commercial cultivation of such seaweeds by the local people, as done in many parts of the East Coast (Chennubhotla *et al*., 2013; Ganesan *et al*., 2019). Seaweeds have high economic and industrial potentiality in various ways such as food, fodder, and in various industries. In many parts of the South East Asian countries, seaweeds are widely cultivated at large scale and used sustainably, which not only provide the additional income to the locals, but also boost the local economy. Therefore, the floristic resources of the Sundarban need focused strategies for conservation and sustainable utilisation for long term benefits to the society.

CONCLUSION

The marine ecosystem is one of the most productive ecosystems. The Sundarban Biosphere Reserve is one of the UNESCO heritage site. It is also recognised as the world's largest contiguous mangrove forest and habitat for the iconic Royal Bengal Tiger. The Indian Sundarban is spreading in *ca* 4200 sq km, with 102 islands, of which 54 are reclaimed for human habitation. The region is very rich in biodiversity and support considerable number of flora and fauna. The present comprehensive study reveals 32 taxa of true mangroves under 22 genera and 15 families, 47 taxa of mangroves associates under 41 genera and 22 families, 28 taxa of seaweeds under 13 genera and 9 families, 6 taxa of seagrasses under 2 genera and 2 families and 77 taxa of Phytoplantons under 66 genera and11 families. The ecosystems services provide by this natural treasure is exceptional, and support the livelihood of millions of people in its vicinity. Therefore, long term proper management of Sundarban Biosphere Reserve, with sustainable utilisation of the resources, in the line of the vision of *Blue Economy* is essential for the conservation of the biodiversity and improvement in the livelihood of the local people.

ACKNOWLEDGEMENTS

The authors express sincere gratitude to Dr. A. A. Mao, Director, Botanical Survey of India, Kolkata for facilities and encouragements. We are also thankful to the PCCF, Directorate of Forests, and Sundarban Biosphere Reserve, Govt. of West Bengal, Kolkata for granting permission and necessary help during field exploration.

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