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VEGETATION DYNAMICS OF COASTAL MANGROVE FOREST

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Abstract

In the man-made coastal forest, the vegetation dynamics of protected and unprotected coastal forests have been identified. This study examined and quantified the impacts of grazing on coastal vegetation. The investigation was conducted between January 2013 and December 2020. In a transect line, fifty-two distinct tree, herb, and shrub species were found in unprotected coastal areas, and 36 were found in protected areas. After eight years, the number of saplings (p=0.031), poles (p=0.030), and total (p=0.026) (seedling, sapling, and pole) regeneration were substantially different between protected and unprotected areas. The current study found no significant differences in regeneration and tree density after one and five years of establishing the protected zones. The greatest number of natural poles were found in protected and unprotected areas from 2017 to 2020. The changes in tree density were considerable (p=0.03) after eight years. From 2014 to 2017, the highest rate of seedling recruitment was 36622 to 43439 individuals observed in protected and unprotected areas. In protected areas, *Excoecaria agallocha* L. and *Avicinnia officinalis* L. had the most extensive regeneration coverage, and nine species of seedlings, saplings, and poles were seen in 2013 protected areas. After 8 years, *E. agallocha* had a 47.01% while *Phoenix paludosa* Roxb. had a 30.81% success rate. In 2020, seedlings of *Pongamia pinnata* L. (6.6%), *Herietiera fomes* Buch.-Ham. (5.5%), *A. officnalis* (5.30%) and the remaining six species were also seen. The species *E. agallocha* comprised 69.11% of the trees at Soner Char tree density, followed by *Sonneratia apetala* Buch.-Ham. (23.30%), *P. paludosa* (8.82%), *H. fomes* (3.43%), and the remaining two species in 2020. After eight years, the species *S. apetala* declined by 43.64% and 23.90% in protected and unprotected areas, respectively. The species *Phoenix paludosa*, *H. fomes*, *A. officinalis,* and *Dolichandrone spathacea* (L.F) Baill. Ex K. Schum. was found to replace *S. apetala* in protected areas. Grazing affects the natural recruitment stage of saplings and poles and tree stem density in unprotected areas. The observations assume that *S. apetala* will diminish due to climatic conditions, and *E. agallocha* will become the main dominating species in coastal areas.

Keywords: Vegetation, Soner Char, Char Kashem, Protected area, Tree density, Natural regeneration, Man-made coastal forest.

Introduction

The coastline of Bangladesh is 710 km long and is associated with various environmental and production activities (Ahsan, 2013). Bangladesh is a world leader in mangrove and

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coastal afforestation. An afforestation program was started in newly accreted *char*lands along the coastal belt in 1966 (Rahman and Pramanik, 2015). Mangrove plantation areas have increased in Bangladesh daily (Hasan, 2013). The Bangladesh Forest Department has established approximately 209,140 hectares of coastal plantation in coastal regions, with mangrove species accounting for more than 93% (DoE, 2015). The actual area under the coastal plantation now stands at 61,574 hectares due to the plantation's failure and extermination from natural adversity (BFD and UNDP 2018). Plantations along the coast are seen as a successful adaptation strategy against the extreme weather events that climate change is projected to bring about more frequently (Ahammad and Nandy, 2012). It performs a wide range of beneficial ecological and biophysical tasks, such as expanding the nation's forest cover, acting as a highly effective carbon sink, trapping sediment, preventing erosion, stabilizing the land, providing habitat and a breeding ground for wildlife and fisheries, and enhancing the recreational value of coastal areas (Uddin *et al*., 2014; Iftekhar and Islam, 2004; Alongi, 2012; Saintilan *et al*., 2014; Krauss *et al*., 2014; Lee *et al*., 2014). The coastal man-made forests are a source of various economic products, including fish, mollusks, crabs, honey, fuelwood, timber, and thatching materials (Islam and Wahab, 2005). Also, coastal forests are used as pasture land for buffalo and cattle in Bangladesh. Approximately 0.5 million buffalo and many cows have been grazing in Bangladesh's artificial coastal forest. (Faruque *et al*., 1990; Huque and Borghese, 2013).

Forest protection practiced in Bangladesh was introduced by both *in situ* and *ex-situ* conservation methods to maintain the country’s biological diversity (Mukul, 2007). The Char Kukri-Mukri wildlife sanctuaries in the Bhola district, the Nijhum Dweep National Park in the Noakhali district, the Kua-Kata eco-park (Fatrar Char), and the Soner Char wildlife sanctuaries in the Patuakhali district are the coastal forest's protected areas (Chowdhury and Koike, 2010; Mukul *et al*., 2017). Forest protection zones are a powerful and effective tool for preserving the environment and the world's natural resources for the long term (Mukul, 2007).

In Bangladesh, mangrove afforestation has been ongoing for about 55 years (Hasan, 2013). The forest floors of plantations and surrounding areas contain enormous amounts of seeds. Any forest ecosystem's natural regeneration is a biological process of reproduction. The assessment of regeneration is a fundamental tool for detecting the overall condition of a forest (Wang *et al*., 2008; Rahman *et al*., 2019). To assess the regeneration, vegetation, and tree density of the artificial coastal forest, Islam *et al*., 2015, undertook a partial assessment of various islands or char in the coastal regions of Patuakhali, Bhola, Hatiya, and Chattgram. Before now, no information was available

regarding long-term observation of protected and unprotected vegetation in coastal forests.

Additionally, recent grazing is seriously hampering the growth of the artificial coastal forest (Islam *et al*., 2013; Miah *et al*., 2014). For baseline comparisons and to assess the vegetation dynamics and regeneration condition of these forests, we included unprotected forests. Our study aims to define tree vegetation change in both protected and unprotected coastal forest areas. The impact of grazing on coastal forests was also considered. The current study's findings will likely improve our knowledge of the status of protected forest vegetation, including how it relates to artificial grazing as common land use.

Materials and Methods

Study sites: The two study sites were under the Rangabali Upazilla. The Rangabali Upazilla is located in the Patuakhali coastline district of Bangladesh. Both protected and unprotected man-made coastal forests were chosen as the study areas. Soner Char Wild Life Sanctuary was the protected coastal forest, and Char Kashem was the unprotected coastal forest. These two islands had mangrove plantations developed in 1973-1974 and 1975, approximately the same periods, with similar tree diversity. There have been 2377 mm of rain, and the weather is humid (District Statistics, 2011). The soil is non-calcareous alluvium. The combined actions of the rivers Meghna, Brahmaputra, and Ganges have influenced the landforms (FAO, 1988; SRDI, 2010). During the monsoon season, the experiment sites almost experienced ebb and tide. Soner Char and Char Kashem sites were submerged for nine to twelve months and three to five months.

Soner Char: The Soner Char Wildlife Sanctuary is situated in Bangladesh's Patuakhali District, near Rangabali Upazila. It is located in the Patuakhali district's most southern region. Soner Char Wildlife Sanctuary was established in December 2011 and had a 2026.5-hectare forest (Mukul *et al*., 2016). The IUCN classifies these areas as protected areas. According to the Vulture Safe Zone-2 Schedule issued by the government of Bangladesh in 2012, it is one of the safe zones for vultures (BFD, 2020). The Soner Char Wildlife Sanctuary's soil was non-saline for most of the year in the northern regions, but it became saline to variable degrees during the dry season. During the rainy season, some moderately deep flooding occurred in the northeast (IPAC, 2012). It is the floodplain of the Ganges. The little river and canal that ran through this island group split it into smaller islands. Soner char inhabits coastal plantation-type forests. The Soner Char wildlife reserve is located at latitude $21^{0}50'$-$26^{0}30'$ N and longitude $88^{0}47'$-$90^{0}10'$ E (IPAC 2012).

The mangrove plantation began at Soner Char in 1974-1975, covering 7270 hectares (Char Development and Settlement Project-4 2012). These locations support a considerable number of weed species. Initial plantings in the Soner char included *Sonneratia apetala* and *Avicennia officinalis*. Later, in 1995, the Bangladesh Forest Research Institute introduced several significant mangrove species as experimental bases, including *Heritiera fomes*, *Excoecaria agallocha*, *Xylocarpus molucencis* (Lam) M. Roem., *Xylocarpus granatum* J. Koenig., *Bruguira sexangula* (Lour.) Poir., *Aegiceras corniculatum*, *Ceriops decandra* (Griffith) Ding Hou., and *Phoenix paludosa*, *Lumnitzera racemosa* willd. (Islam *et al*., 2013). Additionally, certain mainland plants were introduced on an experimental basis on the raised ground of Soner Char Island, including *Thespesia populnea* (L.) Sol. Ex Correa. on small mounds, *Pithocellobium dulce* (Roxb.) Benth., *Samania Saman* (Jacq.) Merr., *Casuarina equisetifolia* L. *Acacia nilotica* (L.) Delile and *Albizia lebbeck* (L.) Benth. (Islam *et al.,* 2014). Most experiments were successful, and the current plantations' growth performance is impressive (Islam *et al*., 2013). Islam *et al*., (2015), conducted a partial investigation of this island and discovered the regeneration of *A. officinalis*, *H. fomes* (Sundri), *E.agallocha* (Gewa), *X. mekongensis* (Passur), *A. corniculatum* (Khalshi), *P. paludosa* (Hantal), *Tamarix indica* (Nona Jhao). There are restrictions on this island because it is a wildlife sanctuary, and grazing has not been allowed after December 2011. This one is safer from anthropogenic disruptions than other nearby or coastal islands. Generally speaking, this island is home to various wildlife species, including deer, monkeys, feral buffalo, wild boar, pigs, rats, snakes, and other creatures. Among the notable bird species are spines, cranes, wild geese, ducks, and jungle fowl.

Char Kashem: An adjoining island of Rangabali called Char Kashem is divided from the main island by the Buragauranga River. It is located at latitude $21^{0}52'$-$21^{0}54'18''$N and $90^{0}25'$-$90^{0}27'48''$E. The mangrove plantation at Char Kashem was created over roughly 10,000 hectares during the fiscal years 1973-1974. However, due to soil degradation, the current mangrove forest is only 4459.5 acres (Ahmed, 2019). This coastal habitat is not protected. Grazing is permitted for cattle, buffalo, and other animals. Grazing and soil erosion have seriously disrupted the Char Kashem coastal forest. Eighty-seven homesteads and 600 people live in Char Kashem, adjacent to a forest (BBS, 2011). These people rely entirely on the forest to supply their fuelwood needs. They depend on fishing, a small quantity of agriculture, and collecting fuel wood to survive. Initially, pioneer mangrove species were tried in these chars and other recently accreted chars in the coastal areas. In the 1990s, the Bangladesh Forest Research Institute planted some experimental plantations with notable mangrove and non-mangrove species like Soner

Char under the *S. apetala* forest. The cultivated species demonstrated Impressive growth rates (Islam *et al*., 2013; Islam *et al*., 2014). *A. officinalis*, *H. fomes*, *E. agallocha*, *X. molucensis*, *P. paludosa*, *T. indica*, *D. spathacea* (pani kapila/gorshingra/vaterkathi), *P. pinnata*, and other kinds of herbs were identified to regenerate (Islam *et al*., 2015). A few weeds flourish on each of these islands. As well as certain mammal species, including wild boar, monkey, and deer, this area is home to notable bird species like wild geese, wild ducks, jungle fowl, cranes, and spines.

Data collection: In the chosen Permanent Sample Plots (PSP) regions, the transect approach was used to determine the tree species currently serving as seed suppliers. When measured parallel to the water channel, the transect width was 3 meters, and its length was 200 meters. In each location, there were five transects. Data on only the tree species used as seed sources were collected from these transect lines to understand the diversity of mature tree species in the research sites. The Random Simple Selection Method was used to choose the Permanent Sample Plots (PSPs). Under artificial *S. apetala* plantations, PSPs were developed in both protected and unprotected areas. There were no other types of artificial plantations in the PSP areas. Each island had 12 PSPs created for 24 PSPs in protected and unprotected areas. The Permanent Sample Plots (PSPs) size was 10 meter×10 meter (100 m^2). The sample plots were chosen randomly from different age groups in both locations. The naturally existing information, such as seedlings noted (up to 0.5 height), saplings reported (0.51 m - 1.0 m height), poles noted (1.1 m - 3 m height), and trees documented (3 m above), was gathered for various tree species. Between January 2013 and December 2020, the survey was conducted in various PSP areas on the Soner Char and Char Kashem. From January 2013 through December 2020, data has been gathered once a year. Data on other types of plants, such as herbs and shrubs, was noted annually.

Data analysis: Data on various growth parameters and regeneration states were computed and examined using Excel and Minitab statistical software. T-tests were used to compare the protected and unprotected coastal forests regarding seedling, sapling, pole, new seedling recruitment, tree density, herb and shrub abundance, etc. The threshold for statistical significance was fixed at 0.05, and p-values below this threshold were regarded as significant.

Results and Discussion

Table 1 shows the presence of various plant species along the transect line. Thirty-six plant species were identified in January 2013 along the five transect lines of the Soner

Char protected forest, the sanctuary for wild animals. Thirty-six herb, shrub, and climber species and tree, palm, and rattan species were found in 2013 at Soner Char. Most of this island's tree and palm species were planted at various times. *D. spathacea*, *T. indica, S. caseolaris*, and other herbaceous, shrubby, climber, and rattan species were observed to be grown in natural conditions (Table 1).

Fifty-two species at Char Kashem's unprotected flora were documented simultaneously along the five transect lines. Most of the tree and palm species were planted, and the Char Kashem homesteads contained 15 cultivated species. Only three tree species—*Dolichandrone spathacea*, *Tamarix indica*, *Sonneratia caseolaris*, and all herbaceous shrub and climber species—were found in their natural habitat (Table 1).

Natural regeneration (seedling, sapling, pole) was recorded in the Soner Char protected areas in 2013, and these were 8 tree species, 2 palm species, and 8 species of herb and shrub. In the Char Kashem area, 9 tree species, 2 palm, and 7 herb and shrub species were identified at PSPs in 2013. In the PSP areas of Soner Char, 8 tree species, 2 palm species, 1 climber, and 7 species of herb shrub were found in 2020. In the case of Char Kashem, 9 trees, 1 palm, and 9 herbs and shrub regenerated species (seedling, sapling, and pole) were found in 2020 after eight years. Seven and nine species of herbs and shrubs were counted in PSP areas of Soner Char and Char Kashem in 2020 (Table 2). The naturally regenerating *Cynmetra ramiflora* and *Buruguiera sexangula* species were recorded in Char Kashem but not present on Soner Char in 2020. The natural regeneration of *Amoora cuculata* and *Calamus tenuis* was not present in Char Kashem in 2020, but they were found at Soner Char. On Soner Char island and Char Kashem, the largest total number of natural regeneration (seedlings, saplings, and poles) per hectare area was observed in 2013. Soner Char protected forest had higher seedlings (10644), saplings (4311), and poles (589) than that of Char Kashem unprotected forest (seedlings 7455, saplings 2778, and poles 522) in 2013. (Fig. 1).

However, there were no significant differences between Soner Char (protected area) and Char Kashem, 2013 (unprotected region) in terms of seedling ($p=0.92$), sapling ($p=0.91$), pole ($p=0.75$), or total regeneration number ($p=0.91$) (Fig. 1).

In 2016, after five years of declaration as a wildlife sanctuary, Soner Char registered more natural regeneration than Char Kashem (46722 nos, 33633 nos), seedlings (34067 nos, 26589 nos), and saplings (12144 nos, 6300 nos), respectively. In 2016, after four years, the establishment of PSP at Char Kashem (811) surpassed Soner Char (522) as the pole with the greatest number. However, there were no significant differences between

Table 1 The tree species, herbs, and shrubs that were present at Soner Char (a protected coastal forest) and Char Kashem (unprotected coastal forest) in 2013.

Sl. No	Name of Species	Vernacular Name	Family	Type of Plant	Forest type	Soner Char*	Char Kashem^{O}
1.	*Sonneratia apetala* Buch.-Ham.	Keora	Sonneratiaceae	Tree	Planted	+	+
2.	*Excoecaria agallocha* L.	Gewa	Euphorbiaceae	Tree	Planted	+	+
3.	*Avicennia officinalis* L.	Baen	Avicenniaceae	Tree	Planted	+	+
4.	*Heritiera fomes* Buch.-Ham.	Sundri	Sterculiaceae	Tree	Planted	+	+
5.	*Xylocarpus molucences* (Lam) M. Roem.,	Passur	Meliaceae	Tree	Planted	+	+
6.	*Aegiceras corniculatum* (L.) Blanco	Khalshi	Myrsinaceae	Tree	Planted	+	+
7.	*Phoenix paludosa* Roxb.	Hantal	Arecaceae	Palm	Planted	+	+
8.	*Cynometra ramiflora* L.	Shingra	Leguminosae	Tree	Planted	+	+
9.	*Xylocarpus granatum* J. Koenig.	Dhandul	Meliaceae	Tree	Planted	+	+
10.	*Cerops decandra* (Griffith) Ding. Hou.	Goran	Rhizophoraceae	Tree	Planted	+	+
11.	*Lumnitzera racemosa* willd	Kirpa	Combretaceae	Tree	Planted	+	+
12.	*Nypa fruticans* Van Wurmb.	Golpata	Arecaceae	Palm	Planted	+	+
13.	*Casuarina equisetifolia* L	Jhao	Casuarinaceae	Tree	Planted	+	+
14.	*Albizia lebbeck* (L.) Benth.	Kala koroi	Fabaceae	Tree	Planted	+	+
15.	*Albizia procera*(Roxb.) Benth.	Sada koroi	Fabaceae	Tree	Planted	+	+
16.	*Samanea saman Jacq.) Merr.*	Raintree	Fabaceae	Tree	Planted	+	+
17.	*Thespesia populnea* (L.) Sol. Ex Correa.	Sonboloi	Malvaceae	Tree	Planted	+	+
18.	*Calamus tenuis* Roxb.	Jalibet	Arecaceae	Climber	Natural	+	-
19.	*Dolichandrone spathacea* (L.F) Baill. Ex K. Schum	Panikapila/ Gorshinga	Bignoniaceae	Tree	Natural	+	+

*Protected, ^{O}Unprotected.

Contd.

Sl. No.	Name of Species	Vernacular name	Family	Type of plant	Forest type	Soner char	Char Kashem
20.	*Tamarix indica* Willd.	Nona Jhao	Tamaricaceae	Small tree	Natural	+	+
21.	*Sonneratia caseolaris* (L.) Engl.	Soyla	Sonneratiaceae	Tree	Natural	+	+
22.	*Pongamia pinnata* L.	Karanja	Leguminosae	Tree	Planted	+	+
23.	*Anodendron paniculatum* (Roxb.) A.Dc.	Bonjhul	Asclepiadaceae	Woody climber	Natural	+	+
24.	*Derris trifoliate* Lour	Kalialata	Fabaceae	Climber	Natural	+	+
25.	*Finlaysonia obovata* Wall.	Mamakola	Apocynaceae	Herb	Natural	+	+
26.	*Dalbergia spinosa* Roxb.	Tambulkata	Fabaceae	Armed shrub	Natural	+	+
27.	*Acanthus ilicifolius* L.	Hargoza	Acanthaceae	Thorny herbs ,woody	Natural	+	+
28.	*Sapium indicum* Willd.	Hurmuri	Euphorbiaceae	Herb	Natural	+	+
29.	*Ipomoea fistulosa* L.	DholKolmi	Convolvulaceae	Herb, woody	Natural	+	+
30.	*Mikania cordata*. (Burm.F.) B.L.Rob.	Germanlata	Asteraceae	Climber herb	Natural	+	+
31.	*Alternanthera philoxeroides* (Mart.) Griseb.	Helencha	Amaranthaceae	Herb	Natural	+	+
32.	*Crinum amoenum* Ker Gawl. Ex Roxb.	Bonroshun	Apocynaceae	Herb	Natural	+	+
33.	*Cynodon dactylon* (L.) Pers.	Durbaghash	Poaceae	Herb	Natural	+	+
34.	*Mucana monosperma* Roxb.ex Wigh.	Natai	Fabaceae	Woody climber	Natural	+	+
35.	*Vitis trifolia* L.	Amallata	Vitaceae	Climber	Natural	+	+
36.	*Salacia prinoides* L	Modhu phal	Celastraceae	Herb	Natural	+	+

Contd.

Sl No	Name of Species	Vernacular name	Family	Type of plant	Forest type	Soner Char*	Char Kashem[O]
37.	*Bruguiera saxangula (Lour.) Poir*	Kankra	Rhizophoraceae	Tree	Planted	-	+
38.	*Phoenix sylvestris* (L.) Roxb.	Khejur	Arecaceae	Palm	Homesteads	-	+
39.	*Cocos nucifera* L.	Narikel	Arecaceae	Palm	Homesteads	-	+
40.	*Areca catechu* L.	Supari	Arecaceae	Palm	Homesteads	-	+
41.	*Borassus flabellifer* L.	Tal	Arecaceae	Palm	Homesteads	-	+
42.	*Mangifera indica* L.	Aam	Anacardiaceae	Tree	Homesteads	-	+
43.	*Diospyros blancoi* A.Dc.	Gab	Ebenaceae	Tree	Homesteads	-	+
44.	*Artocarpus heterophyllus* Lam.	Kanthal	Moraceae	Tree	Homesteads	-	+
45.	*Psidium guajava* L.	Payara	Myrtaceae	Tree	Homesteads	-	+
46.	*Citrus maxima* (Burm.) Merr.	Jambura	Rutaceae	Tree	Homesteads	-	+
47.	*Tamarindus indica*	Tentul	Fabaceae	Tree	Homesteads	-	+
48.	*Citrus limon* (L.) Burm	Lebu	Rutaceae	Tree	Homesteads	-	+
49.	*Zizypus mauritania* Lam.	Boroi	Rhamnaceae	Tree	Homesteads	-	+
50.	*Cryptocoryne retrospiralis* (Roxb.) Kunth.	Antispiral water Trumpet	Araceae	Herb	Natural	-	+
51.	*Colocasia esculenta* (L.) Schott.	Kala kochu	Araceae	Herb	Natural	-	+
52.	*Cyperus rotundus* L.	Muthagash	Cyperaceae	Herb	Natural	-	+
53.	*Eichhornia crassipes*(Mart.) Solms	Kochoripana	Pontederiaceae	Herb	Natural	-	+

*Protected, [O]Unprotected.

Table 2. Regeneration of several species (seedling, sapling, and pole) identified at Soner Char and Char Kashem at PSPs between 2013 and 2020.

Sl. No	Name of Species	Location and Data Collection Year			
		Soner Char		Char Kashem	
		January 2013	December 2020	January 2013	December 2020
1.	*Excoecaria agalocha*	+	+	+	+
2.	*Avicinnea officinalis*	+	+	+	+
3.	*Nypa fruticans*	+	+	+	-
4.	*Hibiscus teliacea*	+	+	+	+
5.	*Phoenix paludosa*	+	+	+	+
6.	*Herietiera fomes*	+	+	+	-
7.	*Aegeras corniculatum*	+	+	+	-
8.	*Xylocarpus molucensis*	+	-	+	+
9.	*Tamarix indica*	+	-	+	+
10.	*Buruguiera sexangula*	+	-	+	+
11.	*Dolichandrone spathacea*	+	+	+	+
12.	*Anodendron paniculatum*	+	+	+	+
13.	*Derris trifoliate*	+	+	+	+
14.	*Dalbergia spinosa*	+	+	+	+
15.	*Acanthus ilicifolius*	+	+	+	+
16.	*Ipomoea fistulosa*	+	+	+	+
17.	*Mikania cordata*	+	+	+	+
18.	*Mucana monosperma*	+	+	+	+
19.	*Aglaia cuculata*	-	+	-	-
20.	*Pongamia pinnata*	-	+	-	+
21.	*Calamus tenuis*	-	+	-	-
22.	*Cynometra ramiflora*	-	-	-	+
23.	*Salacia prinoides*	-	-	-	+
24.	*Colocasia esculenta*	-	-	-	+

(+ present, - absent)

Soner Char and Char Kashem in terms of recruitment of seedlings (p=0.35), saplings (p=0.25), poles (p=0.87), and overall numbers of regeneration (p=0.31) (Fig. 2). The total number of regeneration (seedling, sapling, and pole) per hectare area was highest after eight years in 2020, with a value of 24233 stems in the Soner Char protected area and 11558 in the Char Kashem unprotected regions (p=0.026). After eight years, Soner Char and Char Kashem had the highest number of seedlings per hectare (15283 and 6500, respectively; p=0.084). After eight years, Soner Char Wild Life Sanctuary discovered 5767 and 2833 stems of the sapling and pole value, respectively (Fig. 3).

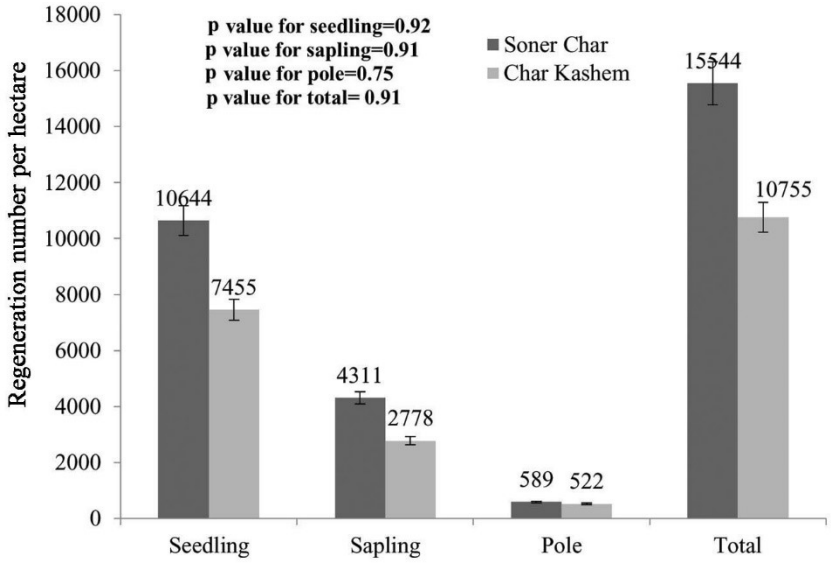

Fig. 1. Regeneration status of vegetation at protected forest (Soner Char) and unprotected forest (Char Kashem) in 2013 (at the initial stage of the wildlife sanctuary).

In Char Kashem's unprotected areas, after eight years, the numbers of sapling and pole stems were 3425 and 1633 per hectare, respectively. After eight years, the p values for the seedling, sapling, and pole were determined as (0.084), (0.030), and (0.030), respectively. After eight years, there was a noticeable difference between protected and unprotected forests in the overall number of regeneration, saplings, and pole stems. Conversely, there were no appreciable changes regarding seedling recruitment between protected and unprotected forests (Fig. 3).

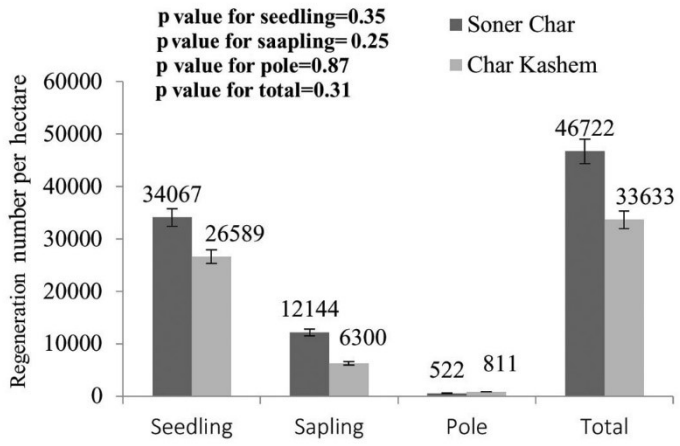

Fig. 2. Regeneration status of vegetation at wildlife sanctuary (Soner Char) and open forest (Char Kashem) in 2016 (after four years).

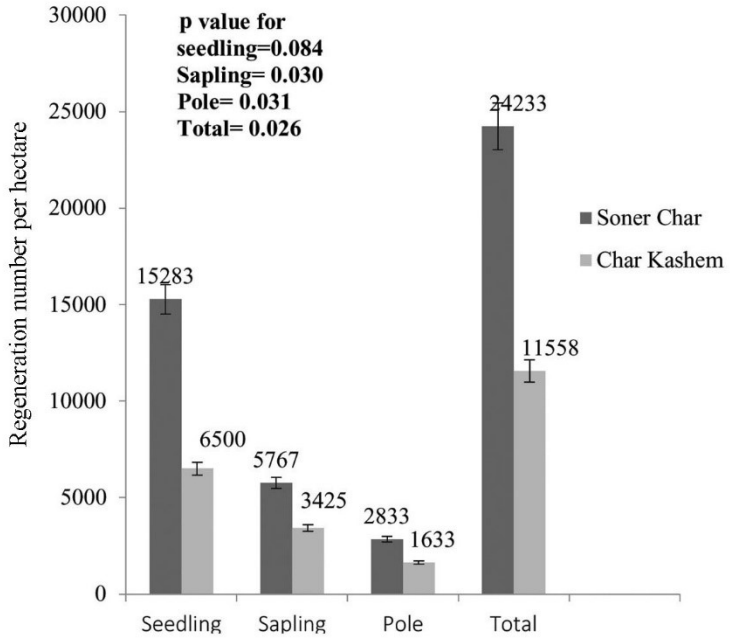

Fig. 3. Regeneration status of the vegetation (protected area (Soner Char) and unprotected area (Char Kashem) in 2020 (after eight years).

Between 2014 and 2017, the highest naturally occurring seedling recruitments were observed at Soner Char (a protected area) and Char Kahsem (an unprotected area) PSPs (36622 to 43439 seedlings per hectare) (Fig. 4).

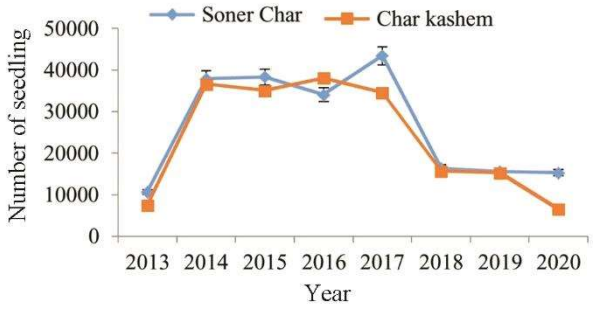

Fig. 4. Variations in recruitment of seedlings at Protected Forest (Soner Char) and Unprotected Forest (Char Kashem) in Selected PSP Areas from January 2013 to December 2020.

In protected regions, the greatest natural pole stems were seen between 2017 and 2020 with a value of 1132 to 2833/hectare, respectively, and in unprotected areas, the values were 930 to 1633/hectare, respectively (Fig. 5).

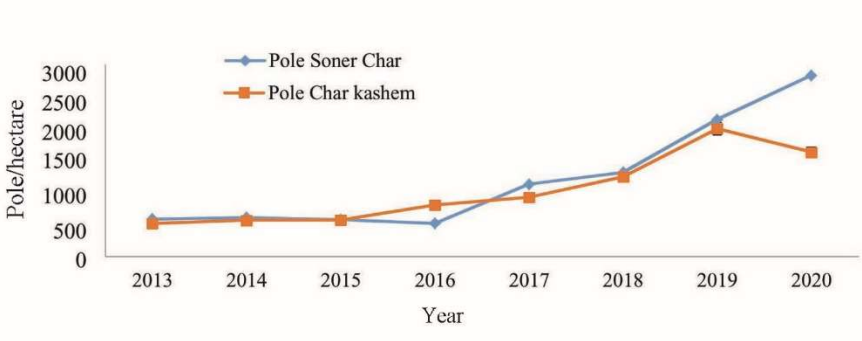

Fig. 5. Variations in the recruitment of pole stem at Protected Forest (Soner Char) and Unprotected Forest (Char Kashem) in Selected PSP Areas from January 2013 to December 2020.

After eight years of the proclamation of a wildlife sanctuary, Soner Char had the largest number of trees per hectare (2250). At the same time, Char Kashem had the lowest number of trees per hectare (1567). In the initial stages of the wildlife sanctuary, 355 trees per hectare at Soner Char and 811 trees per hectare at Char Kashem were observed in the PSPs area in January 2013. After four years, the protected and unprotected sites

had tree densities of 833 trees per hectare and 711 trees per hectare, respectively (Fig. 6). Calculated were the p values for tree density in 2013 (0.068), 2016 (0.44), and 2020 (0.013). After eight years, the forest cover per hectare (2250) in protected locations varies markedly from unprotected forests (1567). However, there were no apparent variations in the tree density between these two locations between 2013 and 2016 (Fig. 6).

In PSP areas in Soner Char, 27411, 12878, and 7677 herb, shrub, and climber stems per hectare were counted in 2016, 2020, and 2013, respectively. Conversely, Char Kahsem was the site where the greatest variety of herb, shrub, and climber species was identified, with 8678 stems in 2016, 8577 stems in 2020, and 5233 stems in 2013, respectively.

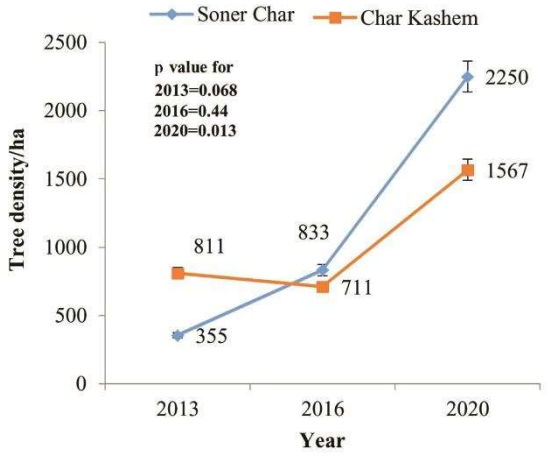

Fig. 6. Variations in tree density per hectare stems of Soner Char and Char Kashem between 2013 and 2020 of the PSP areas.

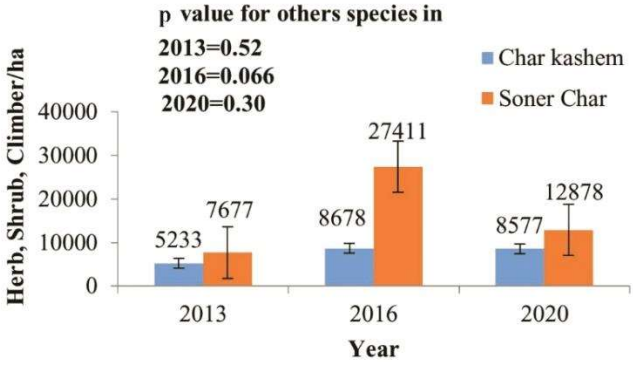

Fig. 7. State of the vegetation for various herb, shrub, and climber species in protected and unprotected PSP regions in 2013, 2016, and 2020.

The number of herb, shrub, and climber species between Soner Char and Char Kashem PSPs regions stayed the same in 2013, 2016, and 2020. (Fig. 7). *E. agallocha* made up 80.43% of the total number of seedling recruitments, followed by *A.officinalis* (10.45 %), *T.x indica* (2.48%), and eight other species, including *N. fruticans*, *H. teliacea*, *P. paludosa*, *H. fomes*, *A. corniculatum, X. molucensis*, *D. spathacea*, and *B. sexangula* (6.59%) were found in 2013 at Soner Char wildlife protected areas (Fig. 8).

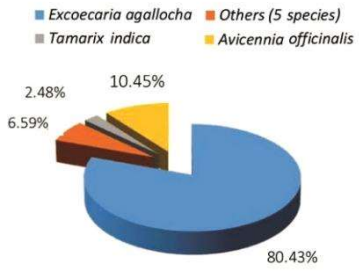

Fig. 8. Seedling recruitment of different species at the protected area (Soner Char) in 2013.

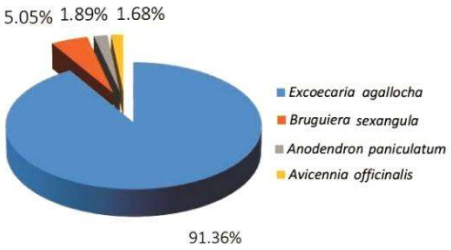

Fig. 9. Seedling recruitment of different species at the unprotected area (Char Kashem) in 2013.

Excoecaria agallocha made up 91.36% of the Char Kashem (unprotected forest) in 2013, followed by *Bruguiera sexangula* (5.05%), *Dolichandrone spathacea* (1.89%), and *Avicennia officinalis* (1.68%) (Fig. 9).

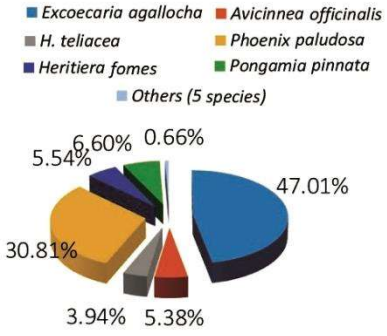

Fig. 10. Seedling recruitment of different tree species in 2020 at Soner Char.

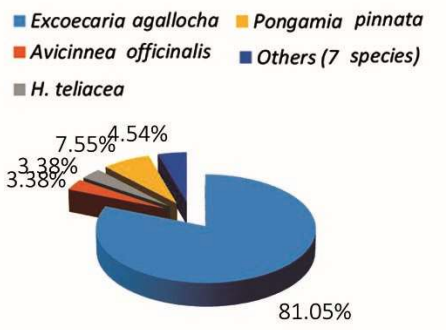

Fig. 11. Seedling recruitment of different tree species in 2020 at Char Kashem.

E. agallocha makes up 47.01% of all seedling recruitment at Soner Char Wild Life Sanctuary in 2020 PSPs, followed by *P. paludosa* (30.81%), *P. pinnata* (6.6%), *H. fomes* (5.5%), *A. officinalis* (5.3%), *H. teliacea* (3.94 %), and other 5 species (0.6%) (Fig. 10).

In 2020, *E. agallocha* accounts for 81.05% of seedling recruitment in Char Kashem unprotected areas, followed by *P. pinnata* (7.55%), *A. officinalis* (3.38%), *H. teliacea* (3.38%), and other 7 species (4.54%) (Fig. 11).

When Soner Char was first declared a wildlife sanctuary, *S. apetala* comprised 66.67% of the trees there, while *E. agallocha* made up 33.33%. At the same time, Char Kashem had 62.50% *E. agallocha* species and 37.50% *S. apetala* species (Fig. 12 and Fig. 13).

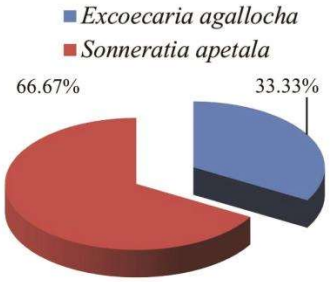

Fig. 12. Tree density of different species at Soner Char in 2013.

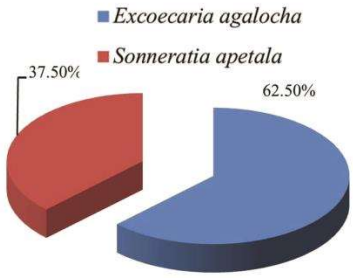

Fig. 13. Tree density of different species at Char Kashem in 2013.

Fig. 14. Tree density of different species at Soner Char in 2020.

Fig. 15. Tree density of different species at Char Kashem in 2020.

In 2020 at the PSP areas, *E. agallocha* made up 69.11% of the total tree vegetation of Soner Char Wild Life Sanctuary (a protected area), followed by *Sonneratia apetala* (23.03%), *Phoenix paludosa* (8.82%), *Heritiera fomes* (3.43%), *Dolichandrone spathacea* (0.98%), and *Avicennia officinalis* (0.49%). *E. agallocha* comprised 85.79% of the species documented at Char Kashem in the unprotected region, followed by

Sonneratia apetala (13.60%) and *Dolichandrone spathacea* (0.61%) in 2020. (Fig. 14 and Fig. 15).

The current study examined the human-developed forests in Bangladesh's coastal regions and changes in species composition over 8 years. Individual tree seedling, sapling, pole, naturally regenerated tree, herb, and shrub species distributions were described in coastal areas and contrasted with protected and unprotected forests. In this study, we observed that 10 different mangrove species could naturally regenerate in the Soner Char Wildlife Sanctuary and Char Kashem in 2020, respectively. In the coastal regions of Chattogram, Bhola, and Patuakhali Coastal Afforestation Division, Siddiqi *et al*. (1995) undertook a visual observation between 1985 and 1994, but they did not find any naturally occurring regeneration. Islam *et al*. (2014) found six natural regeneration species on Rangabali Island in seven separate islands. Additionally, the locations where the current study showed 46722 stems/ha of natural regeneration (seedling, sapling, and pole) in the Soner Char protected PSP area and 33633 stems/ha at Char Kashem in 2016, and each had the greatest seedling density of 36,000 stems per hectare. After eight years, Soner Char Wild Life Sanctuary PSPs and Char Kashem Unprotected Forest PSPs were found to have distinct total natural regeneration (stems, saplings, and poles) per hectare ($p=0.026$, Fig. 3). The graph of natural seedling recruitment from 2013 to 2020 showed that Soner Char Wild Life Sanctuary had the maximum number of seedlings from 2014 to 2017; that number substantially decreased in 2018 and was found there again in 2019 and 2020. Like Soner Char island, unprotected sites in Char Kashem displayed the largest seedling recruitment between 2014 and 2017. However, seedling recruitment in Char Kashem significantly fell in 2018 and declined through the end of 2020. This can result from grazing activity and human involvement (Fig. 4). In Char Kashem, the eye observation revealed that numerous significant tree species were illegal between 2018 and 2020. From 2013 to 2016, the pole stems regeneration recruitment pattern remained unchanged; from 2016 to 2020, it grew. The graph showed that protected regions had more pole stems per hectare. Between 2013 and 2019, pole recruitment increased at the unprotected Char Kashem site, but it decreased significantly in 2020 (Fig. 5). At the Char Kukri-Mukri islands, Siddiqi and Khan (2004) noted spontaneously growing seedlings of *S. apetala* and *S. caseolaris*. Additionally, they claimed that these species' seedlings, particularly *S. apetala*, rarely mature into saplings. Grazing was recognized as one factor contributing to this species extinction. The Char Kashem unprotected PSP area and the Soner Char wildlife sanctuary could increase the number of trees per hectare from 2013 to 2020.

When investigations began at Soner Char protected areas, *E. agallocha* seedlings were found in the greatest numbers, followed by *A. officinalis* in tenths of a percentage. According to the most recent findings, *E. agallocha*, *P. paludosa*, *P. pinnata*, *H. fomes*, and the other seven species had higher seedling recruitment rates in 2020 than the other species combined. The Soner Char Wildlife Sanctuary exhibited the recruitment of multiple species of seedlings. At Soner Char Wild Life Sanctuary, more *E. agallocha* seedlings are being recruited than in the first half of 2013. This pattern suggests that the Soner Char Wildlife Sanctuary will be converted into a forest with diverse species. Because of the established seed sources and untouched environment in the PSPs area of Soner Char, certain key species were found to regenerate there (Fig. 8 and Fig. 10). In the current research, due to observed tree vegetation and seedling recruitment during the most recent observation in Soner Char Wild Life Sanctuary, the species *E. agallocha* has been classified as a climax species and next *P. paludosa*. Only four distinct seedling recruitment patterns were observed in the Char Kashem PSP zones in 2013. Of these species, *Excoecaria agallocha* exhibited the highest recruitment (91.36%), followed by the other three species (Fig. 9 and Fig. 11). *Excoecaria agallocha* seedlings made up the majority (81.05%) of the PSPs in 2020, eight years after they were created, with the remaining *A. officinalis*, *Hibiscus teliacea*, *Phoenix paludosa*, *Herietiera fomes*, *Aegeras corniculatum*, *Aglaia cuculata*, *Pongamia pinnata*, *Dolichandrone spathacea* and *Calamus tenuis* species. In the seven chars of Rangabali, 95.41% of *E. agallocha* seedlings were documented by Islam *et al*. (2014), confirmed by the study's 2013 findings (Fig. 9 and Fig. 11). Buffalo and cattle commonly graze in the vast plains of Char Kashem. Grazing has recently reached an alarming level at Char Kashem. In the 2020 trial, *S. apetala* was found to be replaced by *E. agallocha* in both protected and unprotected regions. The current study found that between 2013 and 2020, the tree stems density of *S. apetala* decreased by 43.64% at Soner Char Wild Life Sanctuary and 23.90% at Char Kashem Unprotected PSPs, respectively. Whereas the tree stems density of *E. agallocha* increased by 35.78% and 23.29% between 2013 and 2020 in Soner Char and Char Kashem (Figs. 12, 13, 14, 15). After eight years, *E. agallocha* was shown to be the most abundant tree species in both research areas.

Additionally, under the current ecological conditions at these two trial locations, *S. apetala* will decline and may become a minor species. According to Das and Siddiqi (1985), *S. apetala* comes after *E. agallocha* in the ecological succession. Our investigation showed that *E. agallocha* had replaced *S. apetala* in both places. However, we also noticed that *P. paludosa*, *H. fomes*, and *D. spathacea* had done so at Soner Char Wild Life Sanctuary. The tree stems of *E. agallocha*, *P. paludoa*, *H. fomes*, *A. officinalis*,

and *D. spathacea* were spontaneously grown in the PSPs of Soner Char Wild Life Sanctuary rather than planted. Unfortunately, at Char Kashem, only two species of stems were identified as growing naturally simultaneously as Soner Char. In the current investigation of 2020, the principal tree stems of *E. agallocha*, *P. paludosa*, and *H. fomes* were recorded at Soner Char. After eight years, Soner Char Wild Life Sanctuary had greater tree stem counts per hectare than the Char Kashem PSPs area. According to the current research, Soner Char Wild Life Sanctuary will be converted into a mixed-species forest owing to natural disturbances. Grazing for the relocated mixed forest also impacted the Char Kashem areas.

Figs 16-19: (16). Transect line established in January 2013 at Soner Char. (17). Permanent sample plot no. 1 at Soner Char established in January 2013. (18). Regeneration plot at Char Kashem PSP areas (Photo: 2017). (19). Regenerated tree species of *D. sparthacea* and *P. paludosa* at Soner Char protected areas (December 2020).

Because seedling recruitment was essentially the same in forests with and without protection, after eight years, however, Soner Char Wild Life Sanctuary had more saplings and pole stems than Char Kashem. This finding shows that interference from humans,

livestock, and buffalo in Char Kashem areas affected the results. The current study states that Char Kashem will find it more difficult to convert from a mono-specific to a mixed-species forest due to human engagement and grazing influence. It should be mentioned that the Bangladesh Forest Research Institute (BFRI) underplanted trials in the two research regions. This has led to the seed sources of many mangrove species in this region.

The *S. apetala* plantations had been growing for around 46 years, and the trees in both study sites were already mature. The *S. apetala* species over-matured, and successional alterations occurred due to the geomorphological changes and absence of inundation in the planted regions. It is now important to develop various species of seed sources in the many chars beneath the *S. apetala* forest to retain the natural regeneration inside the coastal man-made forest. According to the current observation, grazing impacts natural regeneration in unprotected places. Eight years later, protected areas are densely covered in plants and have a diverse forest floor. Plans for the protected area include creating a mixed-species forest. To improve a dense, long-lasting mangrove forest, conserving more coastal forests that are not already protected is especially important. The main environmental governing aspects of these two locations are climate (rainfall, temperature, humidity, evaporation, wind, and cyclones), hydrological (tidal activities), edaphic (soil salinity, nutrient status, and accretion), and biotic. These components engage in mutual interaction and have an impact on ecosystem development. This study only focused on the vegetation's condition and the species' dynamics affected by grazing, leaving out the soil salinity, organic carbon levels, and other edaphic parameters in these two locations.

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