

# Do invasive plants threaten the Sundarbans mangrove forest of Bangladesh?

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## Abstract

Sundarbans mangrove forest has substantial ecological and economic importance at local, national and global scales. Over the past decades, invasive species have spread significantly in the mangrove ecosystem. We conducted a study to identify the different types of invasive species present, the rate and pattern of invasion, its intensity, association of invaders and their habitat preference in the Sundarbans mangrove ecosystem. Vegetation was sampled in 250 quadrats, each 10 m × 10 m, and 125 line transects each 100 m × 20 m; through a combination of random and systematic sampling. Altogether 23 plant species of two broad types viz. aquatic weed and climbers were identified as invasive. Of the identified 23 invasive species, 19 are native or naturalized to Sundarbans mangrove. Invasives' abundance, diversity and rate of invasion (RI) were highest at the riverbanks and gradually decreased with increased proximity to the forests. Based on the severity of damage, species were classified as highly invasive, invasive and potentially invasive. Our study suggests that invasion in Sundarbans are still at a controllable stage. Continuous monitoring, policy change and management interventions must be triggered to target control of invasive plants of the Sundarbans.

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## 1. Introduction

Biological invasions are now considered one of the main threats to the world's biodiversity (Mooney and Hobbs, 2000). Invasion of biological organisms (e.g. plants, animals, microbes, etc.) in any ecosystem can be referred to as bio-invasion. Bio-invasion is a process or phenomenon; it can mean aggressive introduction of invasive species into a new place, new environment, or within the same ecosystem with a different role. This role might be a negative one and that should affect the ecosystems adversely (Biswas, 2003; IUCN, 2003). Invasion success depends on the ecological attributes of the invading plant, the characteristics of the invasion site, and a range of stochastic short term events (Davis et al., 2000; Hobbs and Humphries, 1995; Lambrions, 2002; Shigesada and Kwasaki, 1997). Indeed, the spread of invasive species is now recognized

as one of the greatest threats to the ecological and economic well being of the planet (GISP, 2004).

It is considered that invasive species can only spread into natural vegetation as a result of disturbance (Biswas, 2003). Disturbance, which initiates succession, is a natural process in mangrove ecosystems (Das and Siddiqi, 1985). A variety of biotic and abiotic processes, which vary in frequency (Iftekhar, 1999), magnitude, intensity, and timing, constitutes natural disturbance (Cattelino et al., 1979; Connell and Slatyer, 1977; Grime, 1977; Holling, 1981; Levin and Pain, 1974; Loucks, 1970; Shugart and West, 1980; Trudgill, 1977; Vogl, 1980; White, 1979). Chronic disturbance relates more to the frequency, or return interval, of a disturbance event, which alters the existing physical environment and community of organisms at a particular site (Ameen, 1999); in turn, this may lead to invasions of alien species (Biswas, 2003; Fox and Fox, 1986). However, successful invasion depends on the extent and type of disturbance (Rajmanek, 1989). In addition, cryptic ecological degradation, in which introgressive mangrove associated vegetation or minor mangrove species slowly start to dominate a forest of true mangrove species without loss of spatial extent (Dahadough-Guebas et al., 2005) is also

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common feature of the Sundarbans (Biswas, 2003). Chronic disturbance is of special concern in Sundarbans and may alter the species composition (Ameen, 1999), relative abundances of selected species (Ameen, 1999; Hossain, 2003), ecosystem structure (Biswas, 2003; Mack et al., 2000; OTA, 1993; Mooney and Hobbs, 2000; Pimentel et al., 2000; Vitousek et al., 1996), function (Ameen, 1999; Mack et al., 2000; Mooney and Hobbs, 2000; Pimentel et al., 2000; OTA, 1993; Vitousek et al., 1996), or provide a platform for some native species to become invasive (IUCN, 2003).

Most botanical publications on Sundarbans mangrove concentrate on floristic structure, composition and species distribution in natural communities. Literature on invasive plants in Bangladesh is sparse (e.g. Barua et al., 2001; Biswas, 2003; Hossain, 2003; Hossain and Pasha, 2001). The Sundarbans mangrove forest is one of the most biodiversity rich sites in Bangladesh (Iftekhar, 1999; Prain, 1903). However, unlike other ecosystems, little is known about the invasive plants of Sundarbans, and its invasion patterns. In this study our objectives were to identify the different types of invasive species present, the rate and pattern of invasion, its intensity, association of invaders and their habitat preference in the Sundarbans mangrove ecosystem.

### 1.1. Sundarbans mangrove forest: the study area

Sundarbans is the world's largest continuous single block of mangrove forest (Ali, 1988; Das and Siddiqi, 1985; Iftekhar, 1999; Rahman, 2003). It lies between 89°00' and 89°55' East and 21°30' and 23°30' North at the south west corner of Bangladesh extending over 6,000,386 hectares of which 189,159 hectares is water (Ali, 1998; Rahman, 1998; Runkel and Ahmad, 1997). Its rich mixture of flora, fauna and complex ecosystem function makes it a unique ecosystem in the world. The forest is intersected by a complex network of rivers, streams and water bodies (Anon, 1998; Iftekhar and Islam, 2004). Geologically, Sundarbans is of recent origin (Iftekhar, 1999), as the swamp forest was still under the sea only a few thousands years ago (Das and Siddiqi, 1985). It has been estimated that present day Sundarbans came into existence about 4000 years ago (Ali, 1998).

The Sundarbans mangrove forests have been under management for over 100 years. In comparison to other forests of Bangladesh, Sundarbans were first administered for resource harvesting. With changing attitudes and understanding, Sundarbans become listed as a 'World Heritage Site' and the conservation of its biodiversity become central to its management. However, due to a lack of well planned and long term studies many questions remain concerning the floral or faunal diversity of the region.

Four dominant species of the forests are *Heritiera fomes*, *Excoecaria agallocha*, *Ceriops decandra* and *Sonneratia apetala*. Some of the species, particularly *Cynometra ramiflora*, *Amoora cuculata* and *Rhizophora* spp., are threatened due to unregulated felling.

Disturbances in Sundarbans can be characterized by (i) altered salinity (Iftekhar, 1999); (ii) illegal timber harvesting;

(iii) exotic plantation of terrestrial forest (Siddiqi et al., 1994); (iv) conversion of forest land for agriculture (v) construction of dams for shrimp farming (IUCN, 2003); (vi) oil spills from sea going vessels; (vii) overexploitation of forest resources by management authority and (viii) natural calamities (IUCN, 2003).

Climate is humid, maritime, and tropical with a marked seasonality shared between heavy monsoon rains and a dry relatively cool winter (Iftekhar, 1999). Mean annual rainfall is 1700 mm (Ali, 1998) and varies from 1600 mm in the west to 2000 mm in the east (Chowdhury and Ahmed, 1994). Mean annual relative humidity varies from 70 to 80% (Karim, 1995). Cyclonic storm are very frequent in the monsoon and the wind velocity can reach up to 120 km/h (Iftekhar, 1999) causing immense disturbance to mangrove flora and fauna (Ali, 1998).

## 2. Methods

### 2.1. Sampling technique

We identified invasive species through 125 line transects, each were 100 m long and 20 m wide. We walked along the transects and recorded the invasive species encountered. Quadrats were used for more detailed analysis of vegetation. Quadrat size was determined as 10 m × 10 m by using species–area curve (Misra, 1968). In this study 250 quadrats were used for sampling. A total of 25 biodiversity rich sites were selected for the study, and transects and quadrats were placed both randomly and systematically over the forest (Fig. 1).

The first quadrat was set immediately after landing in a boat. Quadrats were added in a straight line at every subsequent 5 min walking interval or 50 m. This system continued until reaching the mid point of the forest delta, so that maximum variations could be covered (Fig. 2). Since the forest is crisscrossed by numerous water bodies, similarity is found on both sides of the forest, i.e., variations at the mid point of the delta in one side resembles other sides. This process has been replicated for all the study sites. The sample size was satisfactory with ±10 standard deviation and 30% co-efficient of variation (CV) according to Avery (1967).

During the transect walks, plants were identified using Brandis (1906), Heining (1925) and Prain (1903) descriptions. Until now, no absolute definition to distinguish clearly between the mangrove and non mangrove species has been used (Jayatissa et al., 2002). We followed the definition of Duke (1992) as "tree, shrub, palm or ground fern, generally exceeding one half meter in height, and which normally grows above mean sea level in the intertidal zone of marine coastal environments, or estuarine margins". Plant names were recorded as per Tomlinson (1986). Invasive plants were identified to species and life form using Raunkiaer (1934). A voucher specimen for each recorded invasive species was collected and identified at the Bangladesh National Herbarium. The vegetation data were analyzed for density, rate of invasion (RI), intensity of invasiveness, ecological association and impacts of invasive species on the native mangrove ecosystem.

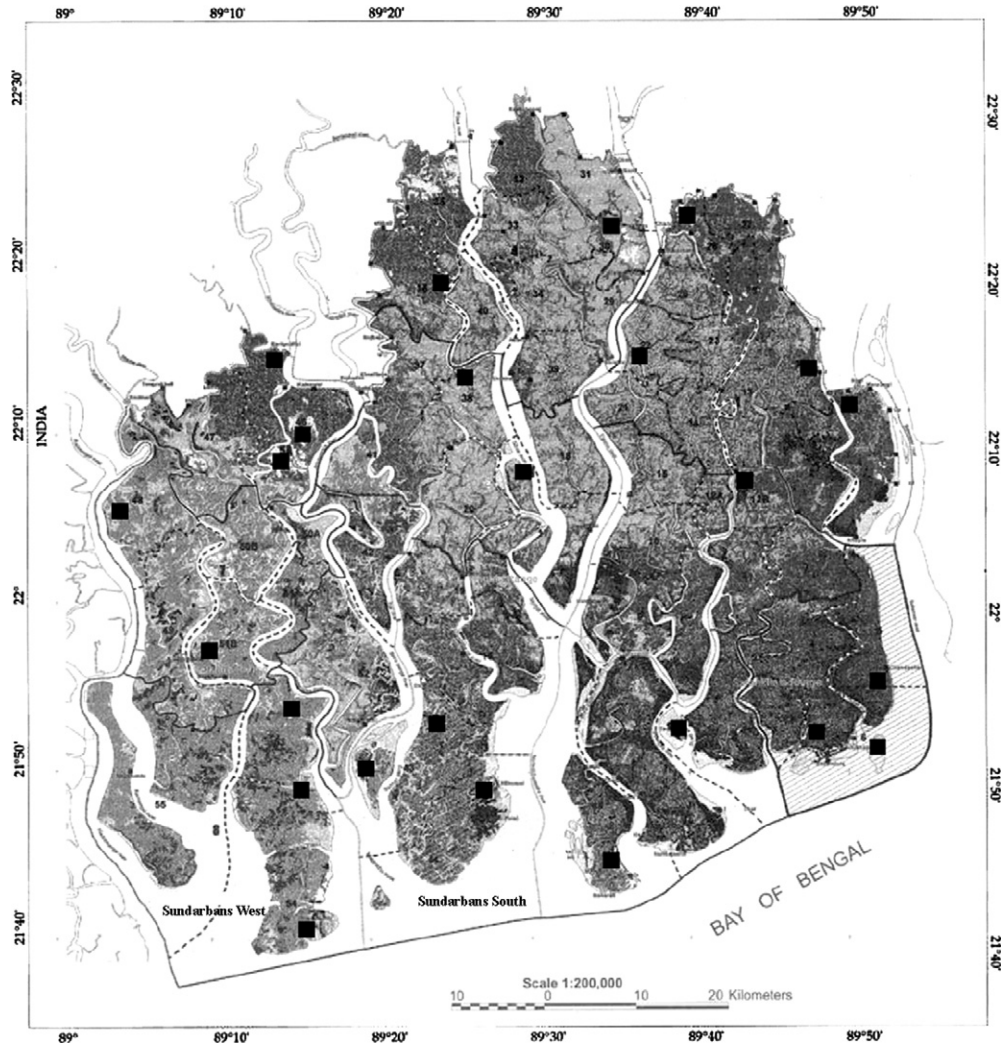


Fig. 1. Map of the Sundarbans mangrove forest.

Density was calculated following Shukla and Chandal (1993). Rate of invasion is the change in the percent cover of plants at which invasive species invade inside the forest from forest border (river side). We calculated the RI using the following equation:

$$RI = \frac{\sum(|D_b - D_m|)/d}{n} \quad (1)$$

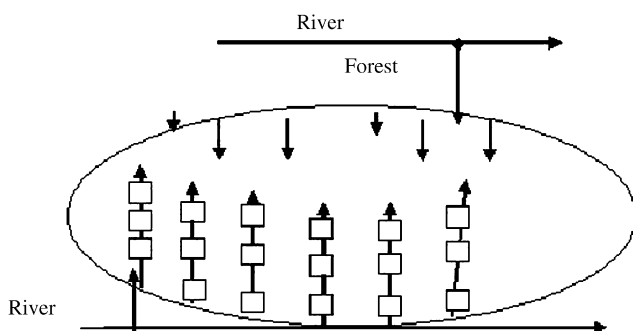


Fig. 2. Sampling framework of the study.

where  $D_b$  = density of invasive species at the border of the forest;  $D_m$  = density of invasive species at the middle of the forest;  $d$  = distance between initial and end plot in meters;  $n$  = number of sample lines covered.

We investigated the ecological association of the invasive species with host/native species. We used simplified  $X^2$  test to determine the statistical significance of the association.

In case of climber species, it seems that there is a correlation between girth of host species and girth of invasive species (IUCN, 2003). We defined girth as the circumference of plant cover over bark. It was measured approximately 1.3 m above ground. We calculated the girth ratio (GR) of climbers using the following formula. In case of widely branched climber such as *Derris trifoliata*, we considered each branch as an individual.

$$GR = \frac{GI}{GH} \quad (2)$$

where GI = girth of invasive species; GH = girth of host species.

We used this girth ratio to calculate the intensity of invasiveness, i.e., for the determination of the severity of

damage to the host species. We used three categories viz. not significantly affected (NS), moderately affected (MS) and severely affected (SA). Based on the severity of damage and magnitude of spread, we classified the invasive species into three broad categories viz. highly invasive (HI), invasive (I) and potentially invasive (PI).

### 3. Results

#### 3.1. Invasive plants

We recorded 23 invasive species, which belong to 18 families and 23 genera (Table 1). Among the identified species, three species are highly invasive, six species are moderately invasive and the remaining are potentially invasive. Climbers (6 out of 23) were the most frequently encountered invasive species followed by trees (5 out of 23) and shrubs (4 out of 23). The three highly invasive plants were *Derris trifoliata* (climber), *Eichhornia crassipes* (aquatic shrub) and *Eupatorium odoratum*, respectively. Of the 23 invasive species only four are exotic or alien.

Density of most invasive species is very low except for *Derris trifoliata* and *Eichhornia crassipes*. Density also differs significantly from the forest border inward ( $P \geq 0.0045$ ). Among the identified invasive plants, *Derris trifoliata* and *Eichhornia crassipes* showed highest density followed by *Acrosticum aureum* and *Micania scandans* (Fig. 3).

#### 3.2. Pathway of invasion

The majority of invasive species possess higher density at the riverbank or forest border than inner side. Such negative

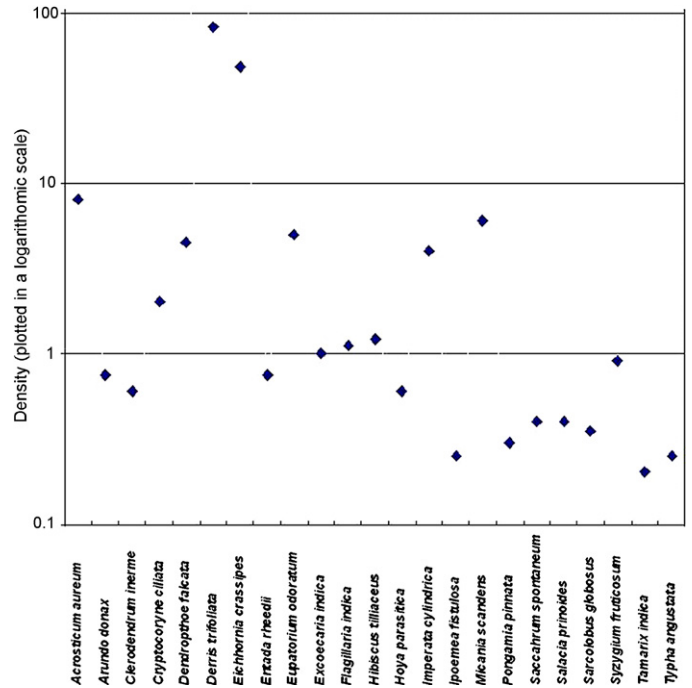


Fig. 3. Density distributions of the recorded invasive species.

correlation between invasive species density and distance from the forest border ( $P \leq 0.005$ ) did not hold for two species *Eupatorium odoratum* and *Micania scandens*. However, these two species showed significant correlation in their rate of invasion with the canopy openings ( $r = +0.91$ ,  $P \leq 0.005$ ).

For *Derris trifoliata* and *Eichhornia crassipes*, density was highest at the forest border and decreased, becoming almost

Table 1  
Recorded invasive plants from Sundarbans mangrove forests

Species	Family	LF <sup>a</sup>	Status <sup>b</sup>
<i>Acrosticum aureum</i> L.	Polypodiaceae	F	I
<i>Arundo donax</i> L.	Gramineae	G	PI
<i>Clerodendrum inerme</i> (L.) Gaertn	Verbenaceae	S	PI
<i>Cryptocoryne ciliata</i> (Roxb) Fischer ex Waylder	Araeaceae	S	PI
<i>Dendrophoe falcata</i> (L.f.) Etting	Loranthaceae	E	PI
<i>Derris trifoliata</i> Lour	Leguminosae	C	HI
<i>Eichhornia crassipes</i>	Pontederiaceae	H	HI
<i>Entada rheedii</i> Spreng	Leguminosae	C	I
<i>Eupatorium odoratum</i> L.	Compositae	C	HI
<i>Excoecaria indica</i> (Wild.) Muell.-Arg.	Euphorbiaceae	T	I
<i>Flagillaria indica</i> L.	Flagillariaceae	C	PI
<i>Hibiscus tiliaceus</i> L.	Malvaceae	S	PI
<i>Hoya parasitica</i> (Roxb.) Wall. ex Wight	Asclepiadaceae	E	PI
<i>Imperata cylindrica</i> (L.) Rauschel	Gramineae	G	PI
<i>Ipomeea fistulosa</i> Mart. Ex Choisy	Convolvulaceae	S	PI
<i>Micania scandens</i> Willd	Compositae	C	I
<i>Pongamia pinnata</i> (L.) Pierre	Leguminosae	T	PI
<i>Saccahrum spontaneum</i> L.	Poaceae	G	PI
<i>Salacia prinoides</i> DC	Celastraceae	T	PI
<i>Sarcobolus globosus</i> Wall	Asclepiadaceae	C	PI
<i>Syzygium fruticosum</i> (Roxb.) DC	Myrtaceae	T	I
<i>Tamarix indica</i> L.	Tamaricaceae	T	I
<i>Typha angustata</i> Borry f	Typhaceae	H	PI

<sup>a</sup> Life forms: T, tree; S, shrub; H, herb; C, climbers; AS, aquatic shrub; E, epiphyte; F, fern; G, grass.

<sup>b</sup> Status: HI, highly invasive; I, invasive; PI, potentially invasive.

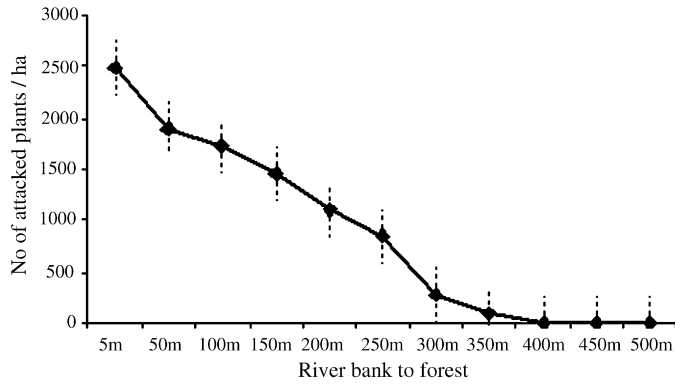


Fig. 4. Rate of invasion from forest border towards interior.

absent, 450–500 m inside the forest (Fig. 4). This situation may not be mirrored where there are crisscrossing creeks within this range. This correlation however cannot be generalized for Sundarbans.

The source of *Eichhornia crassipes* is linked to the Balleswar River (which is the major source of fresh water flow) and its connecting water ways. *Eichhornia crassipes* basically anchors on the deposition side of those water ways and reaches several meters into the forest. In the fresh water zone the density of *Eichhornia crassipes* is approximately  $63 \pm 4.5$  per square meter along with *Pistia* and *Salvia*.

### 3.3. Intensity of invasiveness

Almost 88% of our investigated plots were affected more or less by invasive species. More than 55% of the investigated plots were severely affected (SA), 25% are moderately affected (MA) and only 8% did not show any significant affect. Among the affected plants, we observed that more than 83% trees were severely infested with *Derris trifoliata*, 10% were affected by *Micania scandens* with the remaining 7% affected by other species. Beside climbers, other invasives are intensively distributed over the forest, mostly on the forest borders.

The intensity of invasiveness of most of the invasive species was found to be correlated with the rate of invasion ( $P \leq 0.05$ ). But in *Derris trifoliata* beside rate of invasion, intensity of invasiveness also positively correlated with the girth ratio of host species ( $P \leq 0.0045$ ). We observed that when the GR is  $\geq 0.33$ , the host species become severely affected. The host species affected moderately when the  $GR \geq 0.18$  but  $< 0.33$ .

### 3.4. Ecological association

We found that few invasive species show some kind of ecological association. For example, in pure stand of *Sonneratia apetala*, *Heritiera fomes*, *Excoecaria agallocha*, *Ceriops decandra*, the invasion is low. In mixed forest the spread of invasive species is really high. Generally invasives do not prefer *Sonneratia apetala* stands ( $P \leq 0.05$ ), but in Dimer char (a newly accreted char in Sundarbans), huge spread was noticed. *Eichhornia crassipes*, another floating aquatic invasive species, showed significant association with *Sonneratia* stands.

The main species of Sundarbans, i.e., *Heritiera fomes* is positively associated with *Derris trifoliata*, *Hoya parasitica* and *Micania scandens* ( $P \leq 0.05$ ).

## 4. Discussion

There is a growing concern about the ecological and economic impacts invasive species have on ecosystems worldwide. Biological invasion may be generated by all taxonomic groups at all taxonomic levels (Shine, 2003). Currently, a complete list of invasive species in Bangladesh is not available (Barua et al., 2001); this study provides a start. We found invasive species in every quadrat (all 250 quadrats) and transects. It is a matter of concern that among the invasive species from Sundarbans several species were mangrove associates, with the combination of salt and flood tolerance to become problematic as invasive species to Sundarbans mangroves. Binggeli (2003) made similar notes while studying introduced and invasive plants of Madagascar, and added that disturbance may be the underlying causes of spread of invasive species in islands ecosystems (Binggeli et al., 1998) like Sundarbans. There are apparent wide differences among species in the extent of their spread in the forests and mode of negative impact. For example, *Derris trifoliata* twists the host plant, where as *Eichhornia crassipes* impedes propagule movement, competes effectively for nutrients from the water column, and affects mangrove regeneration.

While analyzing and investigating biological invasion in Sundarbans, we considered that mangrove development follows land formation (Lugo, 1980). This theory suggests that once vegetation establishes on the new substrate, mangroves contribute to the accretion of land (Davis, 1938; Bird, 1971) and potentially accelerates successional processes (Lugo, 1980). Disturbances may arrest succession at any stage and contribute to the biological invasion of invasive plants.

*Derris trifoliata*, a climber, poses a threat to many regenerating tree seedlings owing to its aggressive twining and strangulating habit. This species is widely distributed throughout the mangrove forest irrespective of local ecological and environmental conditions. The dense populations of *Derris trifoliata* form a cover over the seedlings and saplings of *Heritiera fomes*, *Excoecaria agallocha*, *Sonneratia apetala*, among others. There are few additional invasives that inhibited normal growth of these mangroves.

In general, forest borders are severely affected by invasive species. This may be due to disturbances at the border of the forests. It is implied that the number of impacted plants that are affected does not represent an estimate of the actual numbers of invasives at certain distances from the river bank. Also, among the invasives, *Eichhornia crassipes* is a floating aquatic of open sunny sites, explaining why it diminishes in frequency as one gets deeper into the shaded forest areas. At the moment, comprehensive data are not available for in depth quantitative analysis of these effects that includes comparisons across the Sundarbans. However, the opportunities for invasion are becoming more numerous as more natural areas are transformed by rapid development (McNeely et al., 2001), and other human induced disturbance regimes are increasing (Biswas,

Table 2  
Impact of invasive species on Sundarbans mangrove forests

Impacts	Associated species
Compete with indigenous plants for light, nutrients and moisture.	<i>Eupatorium odoratum</i> , <i>Micania scandens</i> , <i>Syzygium fruticosum</i> , <i>Derris trifoliata</i>
Impede natural regeneration.	<i>Acrosticum aureum</i> , <i>Eichhornia crassipes</i> , <i>Eupatorium odoratum</i> , <i>Micania scandens</i> , <i>Syzygium fruticosum</i> , <i>Derris trifoliata</i>
Cause physical damage to the native species	<i>Derris trifoliata</i> , <i>Eupatorium odoratum</i> , <i>Micania scandens</i> , <i>Entada rheedii</i>
Change water quality or characteristics and habitat for fish and other aquatic organisms.	<i>Eichhornia crassipes</i> , <i>Pistia</i> , <i>Salvia</i>
Accumulate allelopathic toxins in the soil affecting biota, poisoning of animals.	<i>Derris trifoliata</i> , <i>Excoecaria indica</i>
Provide habitat and/or shelter for pest animals (and some indigenous animals).	<i>Derris trifoliata</i> , <i>Excoecaria indica</i>
Change the shape of the land (e.g. on newly formed land).	<i>Eichhornia crassipes</i>
Increase soil erosion by shading out ground plants that would normally hold the surface soil together.	<i>Micania scandens</i>
Replace indigenous plant communities	<i>Acrosticum aureum</i> , <i>Eichhornia crassipes</i> , <i>Eupatorium odoratum</i> , <i>Micania scandens</i> , <i>Syzygium fruticosum</i> , <i>Derris trifoliata</i>

2003). The identified ecological association of invasive species with host plants indicates that mixed forest are more susceptible to invasive species.

The three most harmful invasive species in the Sundarbans ecosystem are *Derris trifoliata*, *Eichhornia crassipes* and *Eupatorium odoratum*. The negative ecological impacts of invasive species highlighted in this study (Table 2) stresses several reasons for concern. Invasive populations are abundant, constantly spreading, and locally very dense; threatening to out-compete native species. Choudhury and Faisal (2003) identified that there are significant gaps in the diameter class of native mangroves in comparison to normal forest curve (Fig. 5). These may be due to recruitment limitations of mangrove species.

It is quite clear that invasive plants are causing enormous economic damage to the Sundarbans mangrove ecosystem. Economic assessments of the levels of damage caused by

invasive species in USA have exceeded \$1 billion (USD) per year since 1906 (US Congress, 1993). Kairo et al. (2002) also identified that the effect of shift in dominant species have reduced the economic return of the Kenyan mangrove species. Similar assessment exercises are almost absent in south east regions (MacKinnon, 2003) but given the size of the Sundarbans ecosystem (Biswas, 2003), and the total human population's direct dependence on biodiversity and primary production (Biswas, 2003; Iftekhar and Islam, 2004), it is clear that the damage to ecosystem and economics must also be counted in billions of US dollars per annum.

Environmental risk on Sundarbans mangrove is an amalgam of ecological and economic effects. The environmental conditions of an ecosystem can be assessed through forest health (Biswas, 2003) Forest health can be measured as the capacity across the landscape for renewal, recovery from a wide range of disturbances, and retention of ecological resiliency, while meeting current and future needs of people for desired levels of values, uses, products, and services. Sundarbans is a very complex ecosystem (Iftekhar, 1999; Iftekhar and Islam, 2004). Its components incorporate multiple spatial and temporal scales, and recognize the human dimension as well as the biophysical dimension. Compilation of all these factors addresses Sundarbans health. Invasive species interrupt the normal functioning of the ecosystem and, threatens the health of Sundarbans ecosystem (Fig. 6).

Although, the prevention and control of invasive species presents scientific, political and ethical challenges (McNeely, 2001), a key to invasive mitigation is early detection (Rahman, 2003) and interventions (Barton et al., 2003), preferably before they become too well established (Richardson et al., 2000). Invasion is a process that is often complex, resulting in considerable scientific uncertainty (Mack et al., 2000; Mooney and Hobbs, 2000). If the identification of the invasive species and the subsequent intervention measures to control their spread are delayed (Biswas, 2003) the cost will be higher (Hobbs and Humphries, 1995; Kowarik, 1995; Mack et al., 2000; Silander and Klepeis, 1999) for the economy (Biswas, 2003; Perrings et al., 2000) and ecology (Rahman, 2003) of the Sundarbans.

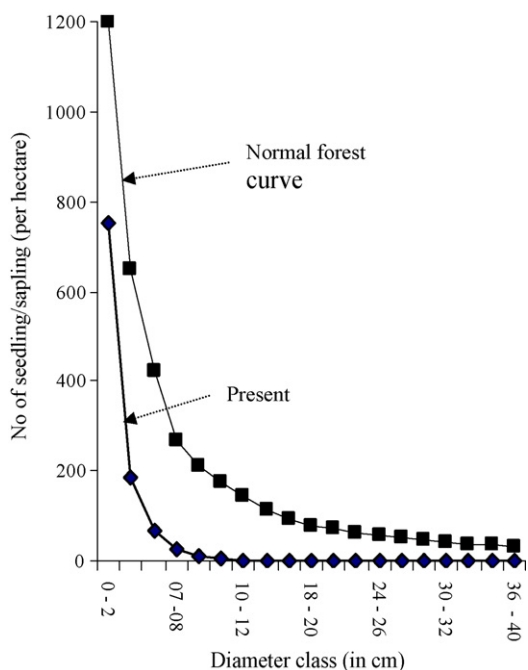


Fig. 5. Diameter class distribution of Sundarbans mangrove forest.

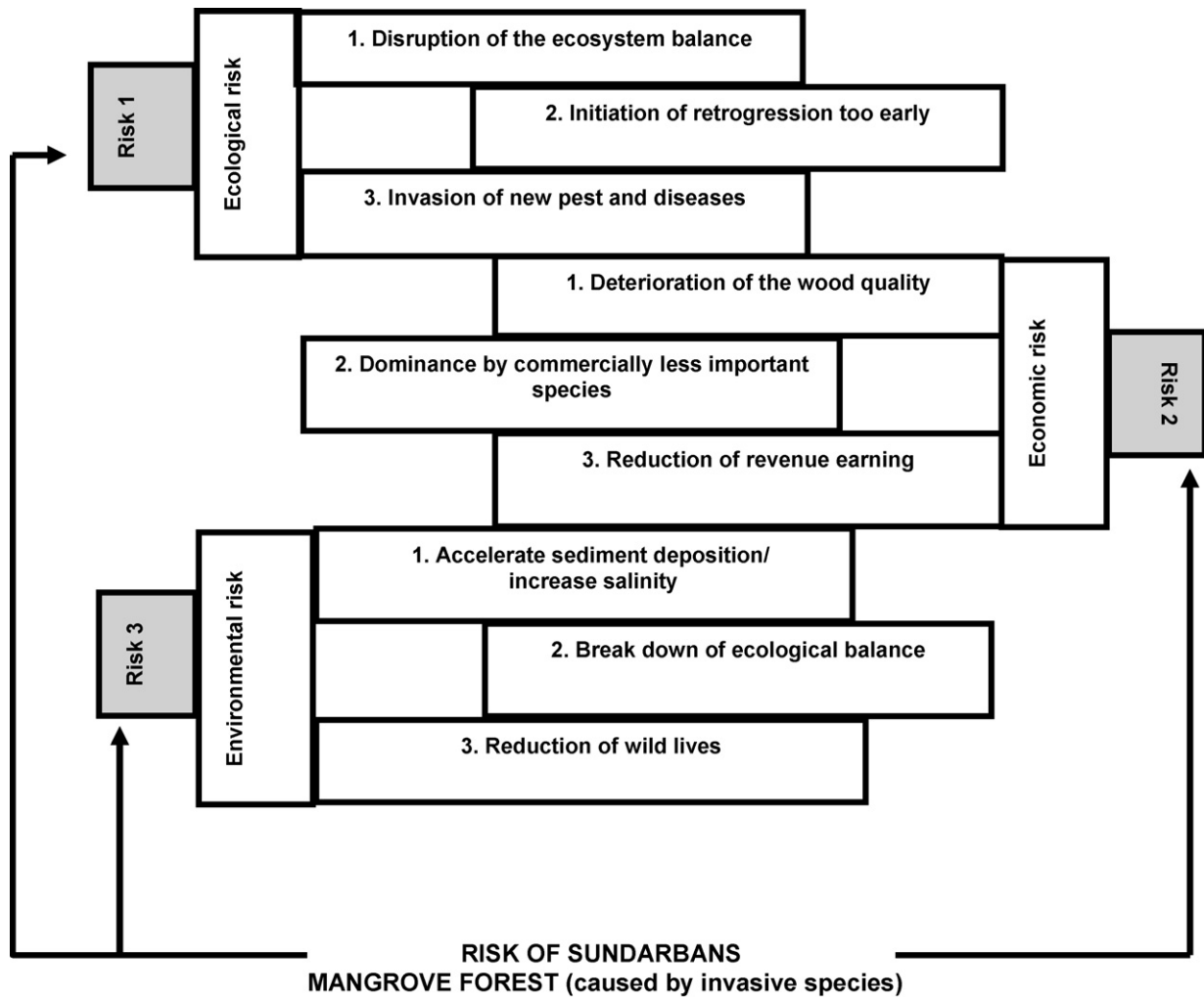


Fig. 6. Risk of Sundarbans mangrove forest due to biological invasion.

In Bangladesh, the forest management system is based on the division of the management unit into working circles, which have specific management objectives. At present, Sundarbans have no such working plan in action. The forest is being regulated to achieve the objectives of biodiversity conservation. Also, there is no separate forest policy for the Sundarbans mangrove forests. Even though the previous management was capable to maintain a permanent forest boundary for a reasonably long period, the efficiency of the protection of the Sundarbans mangrove resources is not satisfactory. In very early stages of forest management, most of the tree species, except few economic ones, were not even regulated for conservation. The phenomena led to quick depletion of growing stock of those plants. In recent times, higher anthropogenic and change in the disturbance regimes resulted in the depletion of the species diversity as well as invasion of other plants.

## 5. Conclusion

A number of invasive species are known, or would appear, to have a major impact on Sundarbans ecosystem. These species affect the mangrove ecosystem through different ways. These negative impacts are ecological, economic and environmental.

The ecological effects include replacement of native plant species and reduction in ground cover, which leads to loss of biodiversity, forage, habitat and scenic quality, and even soil productivity. The economic impact includes loss/reduction of revenue earnings from the forest. In Sundarbans, as far as our investigation shows invasion is still at controllable stage. However, extensive in-depth long term investigation on the invasive plants of Sundarbans and their impacts need to be further studied and monitored continuously. Proper policy formulation and management interventions also need to be triggered targeting the control of the invasive plants of Sundarbans.

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