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Forest structure and soil properties of mangrove ecosystems under different management scenarios: Experiences from the intensely humanized landscape of Indian Sunderbans

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ABSTRACT

The mangrove stands in and around the densely populated rural areas of Indian Sunderbans are experiencing intense human induced stresses in the forms of widespread small-scale logging, shrimp monoculture, riverside prawn-seed and crab catching, forest trespassing, oil-spill etc. Here, restoration of degraded sites and management of remaining mangroves often remain unsuccessful in serving the dual purposes of biodiversity conservation and sustainable livelihood generation. In this context, the present study aims to evaluate the effects of different management scenarios on vegetation structure and composition as well as soil physico-chemical properties along salinity gradients of two mangrove sites located at village-fringe areas of Sunderbans. Transect cum quadrant-based analyses of vegetation and soil samples were adopted for this purpose in consultation with local community members. The results showed that the mangrove site jointly managed by a non-governmental organization and local forest dependents was performing noticeably better than the other site under surveillance of the State Forest Department. Most of the vegetation (basal area, species diversity index, tree density) and few of the soil (pH, cation exchange capacity, exchangeable Na%, soil total C, and organic C stocks) parameters were in significantly superior conditions in the first site than the later in terms of ecological health ($p < 0.01$). Soil salinity exhibited significantly negative correlations with the vegetation characteristics of both sites from riverbank towards inland. While the first site represented the growth of a multi-layered canopy with mixed species association, the later site was characterized by mono-specific dominance of the *Avicennia* varieties primarily due to indiscriminate exploitative activities. Thus, passive restoration or self-recovery of mangroves was considered inadequate in these circumstances for regaining natural ecological functionality. Alternatively, an active human intervention engaging the local forest dependents in decision-making and implementation initiatives regarding recognition of actual causes of degradation, zone-wise selection of species, fixation of gestation period, protection, and equitable usufruct sharing was recommended as the prerequisite towards successful restoration of these fragile mangrove ecosystems.

1. Introduction

Restoration of degraded mangrove sites throughout the tropical coasts is one of the prime areas of action research worldwide at present (Walters, 2004; Ren et al., 2008; Salmo et al., 2013; Thornton and Johnstone, 2015). In reality, restoration of an ecosystem in an area refers to the reintroduction and reestablishment of the ecological niche comprising all the species, environmental components, and habitat conditions that were characteristics of the natural ecosystem structure capable of sustaining itself at that area (Morrison et al., 1990; Kairo et al., 2001). As the global mangrove cover is diminishing at an alarming rate of 1–2% per year, successful implementation of mangrove restoration and management programmes becomes highly imperative more than ever primarily due to the diverse biological, economic, socio-cultural, and protective functions of mangrove ecosystems (FAO, 2007; Alongi, 2008; Giri et al., 2011). However, many of the hitherto implemented plantation programmes in the tropics have been heavily criticized by the researchers as mere failures in restoring the natural ecological functionality (Ellison, 2000; Walters, 2004;

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Lewis and Gilmore, 2007; Bosire et al., 2008; Datta et al., 2012). On the contrary, few researchers had documented the rare success of some plantation programmes in almost regaining the original biodiversity and habitat conditions within two decades of initiation (Twilley et al., 1998; McKee and Faulkner, 2000). In general, failure (or success) of mangrove restoration programmes are related to over-emphasis on timber, charcoal, and fuelwood productions, competition with commercial shrimp farms for land and resources, failure in identifying the prime causes of deforestation at that site, faulty choice of species and timings of planting, lack of proper monitoring and conservation efforts, and illegal harvests (Field, 1999; Sudtongkong and Webb, 2008). Consequently, these failures not only deter the local communities from getting access to their traditional livelihoods as well as ecological services and products of mangroves but also bring havoc within their socio-economic structures by wasting the invested capital and labour (Datta et al., 2012).

In India, several mangrove restoration and management programmes have been initiated by various public and private agencies since the early 1980s (Bhatt et al., 2011; Selvam et al., 2012). Although the reports and official documents published by the government agencies claim many of these programmes as successful, acclamation from the scientific research community has been received for a rare few (Sanyal, 1998; Stone et al., 2008; Datta et al., 2010; Pandey and Pandey, 2012). In reality, success of these programmes should be judged in terms of achieving ecological, socio-economic, and institutional sustainability but that requires a considerable long time-scale (at least of 30 years) of management and monitoring (Datta et al., 2012). However, these sorts of comprehensive as well as long-term evaluation of management efficiency are still very rare in India.

In this study, an attempt had been made to assess the level of success achieved in a restoration site managed by a non-governmental organization (NGO) in comparison to a naturally grown but virtually unmanaged site in the Indian Sunderbans. The prime objective was to examine not only the forest community structures and associations but also the variations in soil physico-chemical properties of the two mangrove sites under different management scenarios. The research hypothesis was that the active restoration techniques were considerably more effective than the passive ones in managing the village-fringe mangroves amidst severe anthropogenic disturbances like that of the present study region. Here, analyses of soil characteristics were purposively taken into consideration as health of forest stands were found to be directly influenced by the conditions of soil (especially salinity) as the age of mangrove forest increases (Boto, 1984; Alongi and de Carvalho, 2008). Similarly, mature mangroves with healthy structure and productivity ensure enhanced production of forest litter and organic detritus that subsequently affect nutrient regeneration and redox potential of forest soils (Ukpong, 1994; Ren et al., 2008). Thus, the chief purpose of adopting this research approach was to comprehensively appraise the similarities and dissimilarities of restoration trajectories of these sites as soil-plant coupled systems with respect to salinity gradients (Sylla et al., 1995; Lewis, 2005; Luo et al., 2010). Accordingly, relevant ecological indicators suitable for rapid in-situ measurements (vegetation structure and composition) and sample based laboratory analyses (soil characteristics) were selected from peer-reviewed literature on mangrove restoration for this study (Cardona and Botero, 1998; Salmo et al., 2014; Ferreira et al., 2015; Thornton and Johnstone, 2015). The second site was considered as unmanaged since it was found to be open towards detrimental anthropogenic activities like uncontrolled logging and crab catching despite being under the legal supervision of State Forest Department (FD). In the present context, such comparisons are more relevant in the village-fringe forests of Indian Sunderbans since the outcomes of the study are supposed to unearth how far the restoration and management programmes have become successful in re-establishing the natural ecological composure in an increasingly humanized landscape as well as ensuring capacity for sustainable livelihood for the local villagers.

2. Materials and methods

The methods used in this research work include delineation of study sites, analyses of soil characteristics, assessment of vegetation structure and composition, and statistical analyses. Collection of soil samples and vegetation data from the study sites were conducted between December 2015 and February 2016.

2.1. Delineation of study sites

This study was carried out in two mangrove sites situated on the western banks of River Matla in Indian Sunderbans (Fig. 1). Sunderbans is world's largest contiguous mangrove forest spread across the Ganges-Brahmaputra estuary of India and Bangladesh (Chaudhuri and Choudhury, 1994). The Indian parts of Sunderbans has an approximate mangrove cover of 4263 sq. Km and designated as a World Heritage Site by IUCN in 1987 as well as Biosphere Reserve by UNESCO in 1989 (WBFD, 2007). The region is endowed with an abundance of biodiversity comprised of 87 plant species of which 37 are true mangroves, 127 species of euryhaline fishes, 1287 species of animals including 186 bird species and innumerable microorganisms (Gopal and Chauhan, 2006).

Sunderbans has a tropical wet type of climate with an average maximum and minimum annual temperature of 29.6 °C and 22.9 °C, average precipitation of 1859 mm as per FAO ClimWat 2.0 database with a pronounced monsoonal outburst (Muñoz and Grieser, 2006). The soils here are either saline or saline-alkali types. A gradual increase in soil salinity from inner to outer estuaries and east to west is found to be having profound impact on the vegetation structure and community (Bandopadhyay, 1998). Since the early 18th Century, continuous conversion of land from mangroves to other land uses, primarily agriculture, shrimp farms, and human habitations, have resulted in a gradual shrink of forest cover and alterations of soil-plant-water interaction patterns (Datta and Deb, 2012). Changes in upstream river regimes have almost terminated the supply of freshwater in many tidal mudflats making soils more saline and endangering several native floral species like *Heritiera fomes* (WBFD, 2007). Deforestation induced soil erosion has also enhanced the rates of siltation in riverbeds throughout the Sunderbans. However, changes in global climatic pattern and consequent rise of sea levels possess a direct threat to the existence of this fragile ecosystem by accentuating the frequency and magnitude of tropical cyclones, sea surges, and coastal inundations (Akhter et al., 2008). The vulnerabilities are generally greater along the forest fringes and transition zones of Sunderbans, where natural ecosystem dynamics are frequently disturbed by the local populace due to their unsustainable livelihood practices like illegal cutting, pruning, and removal of economically valuable tree species (*Sonneretia apetala, Xylocarpus granatum* and *Xylocarpus mekongensis*), brackish-water fish and shrimp monoculture, riverside prawn-seed and crab collection, poaching of wildlife, unregulated mass tourism and related constructional activities etc. (Datta et al., 2010; Giri et al., 2011; Gopal and Chauhan, 2006). In order to manage the remaining mangroves sustainably, both state controlled forestry and community forestry programmes have been conducted in this region since the last few decades (WBFD, 2007). Although, all forests (including mangroves) in India are virtually under the jurisdiction of FD as expounded in the Indian Forest Act,