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Biogeochemical cycle of nitrogen in a tropical mangrove ecosystem, east coast of India

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A B S T R A C T

Like many coastal systems, nitrogen is the critical limiting factor for mangrove net production. This study used a box model approach to assess the nitrogen budget in the Sundarban mangrove ecosystem, which acts as a sink for atmospheric nitrogen in terms of NO_x, NH_3, N_2, and water column dissolved inorganic nitrogen. The coupling of biosphere and atmosphere in terms of atmospheric NO_x and NH_3 uptake showed that uptake of ammonia (130×10^6 mol yr^{-1}) was about six fold as large as that of NO_x (22×10^6 mol yr^{-1}). The nitrogen stored by the processes such as plant uptake of NO_x, NH_3 from the atmosphere, nitrogen fixation (5×10^9 mol yr^{-1}), and sediment water exchange (8×10^6 mol yr^{-1}) was about two times as large as that of recycled nitrogen from litter (3×10^9 mol yr^{-1}), and could account 74% of the nitrogen required for mangrove net production. Most of the nitrogen was conserved in the living biomass (living biomass: 118×10^3 mol ha^{-1} versus soil: 3×10^3 mol ha^{-1}). The loss of nitrogen was 23% of the total amount that was conserved from the external sources in the Sundarban mangrove system. Thus, the coastal ecosystem like Sundarban mangroves could retain only 0.2% (8×10^6 mol) of the annual river flux of nitrogen to the coastal waters and nitrogen is generally conserved within the system.

1. Introduction

Mangroves dominate the majority of the world's tropical and subtropical coastline, forming 15 million ha of forest worldwide and accounting for 0.7% of the tropical forest area (Giri et al. 2011) that provide habitat for rich biodiversity (FAO, 2004). They act as nurseries for commercially important aquatic organisms that contribute to coastal, estuarine and deep-sea fisheries that serve important economic and ecological functions (Ronnback, 1999; Mumby et al. 2004), as habitat for resident and migratory birds, and as sink for atmospheric carbon dioxide and riverine nutrient. Mangroves trap sediment resulting in land accretion (Pernetta, 1993), which protects coasts from physical damage of the shoreline due to tidal waves, erosion, hurricanes, and tsunamis (Mitch and Gosselink, 1993). Mangrove biogeochemistry focuses on the large, slow moving chemical reservoirs and their smaller but more active exchange or cycling either driven by biological activity in the mangrove reservoirs. These cycles of elements falls into two groups: 1) atmospheric gasses containing C, N, O, and S and 2) sediment derived elements such as P and Fe. Deforestation of more than half of the world's original mangrove habitats (Kelleher et al. 1995; Spalding et al. 1997) occurred with about 70% of that loss in the last 20 years (Valiela et al. 2001). Their destruction by human perturbations such as over-harvesting for timber and fuel-wood (Hussein, 1995), clearing for aquaculture and agriculture (Terchunian et al. 1986; Primavera, 1997), sewage release and pollution, damming of rivers to alter salinity levels in the mangrove water (Wolanski, 1992), etc. makes them vulnerable for changes of the biogeochemical processes and the composition of the large reservoirs (the biosphere, the hydrosphere, the atmosphere, and the geosphere) particularly with respect to nitrogen (Thorsten and José, 2001). The primary production in some coastal systems is nitrogen limited (Howarth, 1988; Howarth and Marino, 2006) and microbial rather than chemical processes govern the mangrove nitrogen cycle (Alongi et al. 1992).

The Indian Sundarban mangrove is the largest delta on the globe (world's heritage site, www.unesco.org/en/list/452) and covers about 2.8% of the global mangrove area (15×10^4 km^2). The change of atmospheric composition could depend on the feedback from the biogeochemical processes. Biosphere–atmosphere coupling in the Sundarban mangrove ecosystem occurs through 1) the biophysical pathway in terms of partitioning incoming radiation (Ganguly et al. 2008), 2) and the biogeochemical pathway of carbon in association with the exchange of atmospheric CO_2 (Biswas et al. 2004) and CH_4 (Biswas et al. 2007; Dutta et al. 2013). In general, mangroves are highly productive, fixing ($15–46 \times 10^{12}$ mol yr^{-1}) and storing (3×10^{14} mol) large amount of carbon (Twilley et al. 1986; Gattuso et al. 1998; Alongi, 2009), and in

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particular, the Sundarban mangrove forest acts as a sink for atmospheric CO_2 (about 25×10^{10} mol yr^{-1}) and is potentially sensitive towards the inter-annual increasing atmospheric CO_2 (Ray et al., 2013). Ganguly et al. (2011) showed that the biogeochemical cycle of carbon at the land–ocean boundary, NE coast of India along with the micrometeorological factors played an important role on seasonal variation of atmospheric CO_2 concentration.

The vast majority of nutrients in mangrove forests are stored in soil. However, many mangrove soils have extremely low nutrient concentrations (Alongi et al. 1992; Lovelock et al. 2005), suggesting highly efficient recycling of nutrients, which are regenerated by mangrove litter decomposition (Holguin et al. 2001).

The availability of nitrogen (N) in mangrove ecosystems depends on a complex pattern of bacterial activity within the thin oxic (oxygen-containing) and the anoxic zone of mangrove mud. Nitrogen was found to limit the growth of *Avicennia marina* in South Africa (Naidoo, 2009) and New Zealand (Lovelock et al. 2007). High litter fall in the Sundarban (Ray et al. 2011) and its degradation and remineralization could be one of the major sources of nitrogen (Ramos et al., 2007) apart from anthropogenic inputs due to proximity of Sundarban to human inhabitation, aquaculture farms, waste discharge from Industries adjacent to Haldia port and domestic sewage discharge-points of Kolkata mega city. The recycled N released in the sediment could substantially contribute to the nitrogen requirement of mangroves. Plants showed uptake of both NO_x and NH_3 (Takahashi et al. 2005; Eller and Sparks, 2006; Sutton et al. 1995; Schjoerring et al. 1998), and Biswas et al. (2005) and Ganguly et al. (2009) observed that mangrove plants use atmospheric NH_3 and NO_x as a N source depending on the micrometeorological conditions. Mangrove could provide important ecosystem service in recycling different forms of atmospheric and aquatic nitrogen, thereby protecting the coastal ecosystems from negative impacts of nutrient enrichment and atmospheric pollution.

This study addressed the biogeochemical cycle of nitrogen (N) in the Sundarban mangrove ecosystem with focus on:

1) Quantifying the N stock in sediments and live biomass.
2) Examining the transport and transformation of sediment N and its availability to sustain mangrove productivity.
3) Describing the coupling of biosphere and atmosphere in terms of atmospheric NO_x and NH_3 uptake by mangrove.

2. Materials and methods

2.1. Study area

The study sites (Fig. 1) are located in the Sundarbans mangrove (21° 32′ and 22° 40′ N; 88° 50′ and 89° E) along the estuarine portions of the river Ganges and this comprises 9630 km^2 out of which 4260 km^2 is regarded as forest sub-ecosystem and 1781 km^2 as aquatic sub-ecosystem. The rest of the area has been reclaimed for human settlement and agricultural purposes. The intertidal habitat is covered with dense mangrove forest at the last frontier of Bengal flood plains, sprawling archipelago of 102 islands out of which 54 are reclaimed for human settlement. The tidal islands at the central positions show elevations in the order of 3–8 m from mean sea level. The Ganges–Brahmaputra system drains 1 billion tons of sediment generated from Himalayan erosion and buried in the Bengal fan annually (Galy et al. 2007). The whole Sundarban area consists of an intricate network of criss-crossed channels and creeks and these are starting from the Hooghly towards east, the Saptamukhi, the Thakuran, the Matla and the Gosaba. The Hooghly

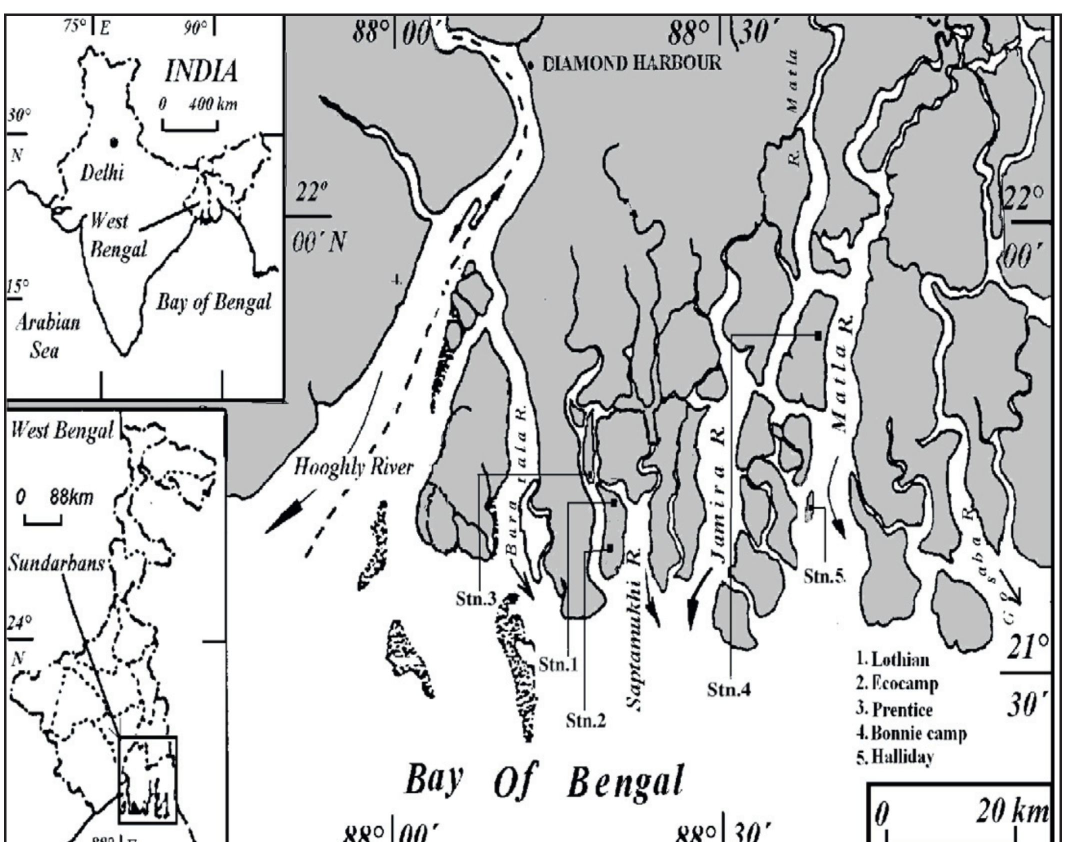

Fig. 1. Location of the study site in the Indian Sundarban, northeast coast of the Bay of Bengal.