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Salinity based allometric equations for biomass estimation of Sundarban mangroves

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ABSTRACT

Biomass estimation was carried out for three even-aged dominant mangrove species (*Avicennia alba*, *Excoecaria agallocha* and *Sonneratia apetala*) in two regions of Indian Sundarbans with two distinct salinity regimes for three consecutive years (2008–2010) and the results were expressed in tons per hectare (t ha^{-1}). In the western region, the total mean biomass of the mangrove species varied as per the order *A. alba* (41.65 t ha^{-1} in 2008, 55.79 t ha^{-1} in 2009, 60.86 t ha^{-1} in 2010) > *S. apetala* (31.76 t ha^{-1} in 2008, 32.81 t ha^{-1} in 2009, 39.10 t ha^{-1} in 2010) > *E. agallocha* (13.89 t ha^{-1} in 2008, 15.54 t ha^{-1} in 2009, 18.28 t ha^{-1} in 2010). In the central region, the order was *A. alba* (42.06 t ha^{-1} in 2008, 57.09 t ha^{-1} in 2009, 64.57 t ha^{-1} in 2010) > *E. agallocha* (15.30 t ha^{-1} in 2008, 20.02 t ha^{-1} in 2009, 24.24 t ha^{-1} in 2010) > *S. apetala* (6.77 t ha^{-1} in 2008, 9.46 t ha^{-1} in 2009, 11.42 t ha^{-1} in 2010). Significant negative correlation was observed between biomass of *S. apetala* and salinity ($p < 0.01$), whereas in case of *A. alba* and *E. agallocha* positive correlations were observed ($p < 0.01$). Species-wise linear allometric regression equations for biomass prediction were developed for each salinity zone as a function of diameter at breast height (DBH) based on high coefficient of determination (R^2 value). The allometric models are species-specific, but not site-specific.

1. Introduction

Mangroves are a taxonomically diverse group of salt-tolerant, mainly arboreal, flowering, plants that grow primarily in tropical and subtropical regions [1]. Estimates of mangrove area vary from several million hectares (ha) to 150,000 km^2 worldwide [2]. The most recent estimates suggest that mangroves presently occupy about 14,653,000 ha of tropical and subtropical coastline [3]. The field survey of mangrove biomass and productivity is rather difficult due to muddy soil conditions and the heavy weight of the wood. The peculiar tree form of mangroves, especially their unusual roots, has attracted the attention of botanists and ecologists [4]. Allometric equations for mangroves have been developed for several decades to estimate biomass and subsequent growth. Most studies have used allometric equations for single stemmed trees, but mangroves sometimes have multi-stemmed tree forms, as often seen in *Rhizophora* (Garjan), *Avicennia* (Baen), and *Excoecaria* (Gewan) species [5,6] that often create difficulty in developing allometric equations with accuracy. Clough et al. [5] showed that the allometric

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relationship can be used for trunks in a multi-stemmed tree. Moreover, for dwarf mangrove trees, allometric relationships have been used to estimate the biomass [7]. Basically the dwarfness of mangroves is caused due to high salinity. Presence of salt is a critical factor for the development of mangrove ecosystems. At lower intensities it favors the development of mangroves eliminating more vigorous terrestrial plants which other wise could compete with. On the contrary at increased level it might cause overall degradation of mangroves. Salinity is also a controlling factor for mangrove seedling recruitment and the relation is negatively proportional. Siddiqi [8] noted reduced recruitment of *Heritiera fomes* (Sundari) and *Excoecaria agallocha* seedling in the Sundarbans mangrove forest with increased salinity. Ball and Pidsley [9] observed adverse impact of increased salinity on canopy development, leaf initiation, and leaf area expansion in *Sonneratia alba* (Sada Keora) and *Sonneratia lanceolata* (Keora).

In the maritime state of West Bengal, situated in the northeast coast of India, the adverse impact of salinity on the growth of mangrove species has been documented [10,11]. Salinity, therefore, greatly influences the overall growth and productivity of the mangroves [12]. The Indian Sundarbans exhibits two significantly different salinity regimes due to siltation that prevent the flow of Ganga–Bhagirathi–Hooghly water to the central region. This has made the ecosystem a unique test bed to observe the impact of salinity on the biomass and allometric trait of the mangrove species.

2. Methodology

2.1. The study area

The Sundarban mangrove ecosystem covering about 10,000 km^2 in the deltaic complex of the Rivers Ganga, Brahmaputra and Meghna is shared between Bangladesh (62%) and India (38%) and is the world's largest coastal wetland. Enormous load of sediments carried by the rivers contribute to its expansion and dynamics.

A unique spatial variation in terms of hydrological parameters is observed in Indian part of Sundarbans. The western region of the deltaic lobe receives the snowmelt water of Himalayan glaciers after being regulated through several barrages (primarily Farakka) on the way. The central region on the other hand, is fully deprived from such supply due to heavy siltation and clogging of the Bidyadhari channel in the late 15th century [13]. Such variation caused sharp difference in salinity between the two regions [11,14]. Ten sampling stations were selected in this geographical locale (Fig. 1). The stations in the western region (stations 1–5) lie at the confluence of the River Hooghly (a continuation of Ganga–Bhagirathi system) and Bay of Bengal. In the central region, the sampling stations (stations 6–10) were selected adjacent to the tide fed Matla River. Study was undertaken in both these regions through three seasons (pre-monsoon, monsoon and post-monsoon) during 2008–2010.

In both regions, selected forest patches were even-aged (~ 9 years old during the initial year 2008). In each station, 15 sample plots (10 m × 10 m) were established (in the river bank) through random sampling in the various qualitatively classified biomass levels and sampling was carried out in the low tide period.

2.2. Above-ground biomass estimation

Above-ground biomass (AGB) in mangrove species refers to the sum total of stem, branch and leaf biomass that are exposed above the soil.

The stem volume of five individuals from each species in each of the 15 plots per station (n = 5 individuals × 15 plots = 75 trees/species/station) was estimated using the Newton's formula [15].

$$V = h/6\ (A_b + 4A_m + A_t)$$

where V is the volume (in m^3), h the height measured with laser beam (BOSCH DLE 70 Professional model), and A_b, A_m, and A_t are the areas at base, middle and top respectively. Specific gravity (G) of the wood was estimated taking the stem cores by boring 7.5 cm deep with mechanized corer. This was converted into stem biomass (B_S) as per the expression $B_S = GV$. The stem biomass of individual tree was finally multiplied by the number of trees of each species in 15 selected plots (per station) in both western and central regions of the deltaic complex and expressed in t ha^{-1}.

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized on the basis of basal diameter into three groups, viz. <6 cm, 6–10 cm and >10 cm. The leaves on the branches were removed by hand. The branches were oven-dried at 70 °C overnight in hot air oven in order to remove moisture content if any present in the branches. Dry weight of two branches from each size group was recorded separately using the equation of Chidumaya [16].

$$B_{db} = n_1 bw_1 + n_2 bw_2 + n_3 bw_3 = \Sigma\, n_i bw_i$$

where B_{db} is the dry branch biomass per tree, n_i the number of branches in the ith branch group, bw_i the average weight of branches in the ith group and $i = 1, 2, 3, \ldots, n$ are the branch groups. The mean branch biomass of individual tree was finally multiplied with the number of trees of each species in all the 15 plots for each station and expressed in t ha^{-1}.

For leaf biomass estimation, one tree of each species per plot was randomly considered. All leaves from nine branches (three of each size group) of individual trees of each species were removed and oven dried at 70 °C and dry weight (species-wise) was estimated. The leaf biomass of each tree was then calculated by multiplying the average biomass of the leaves per branch with the number of branches in that tree. Finally, the dry leaf biomass of the selected mangrove species (for each plot) was recorded as per the expression:

$$L_{db} = n_1 Lw_1 N_1 + n_2 Lw_2 N_2 + \ldots n_i Lw_i N_i$$

where L_{db} is the dry leaf biomass of selected mangrove species per plot, $n_1 \ldots n_i$ are the number of branches of each tree of three dominant species, $Lw_1 \ldots Lw_i$ are the average dry weight of leaves removed from the branches and $N_1 \ldots N_i$ are the number of trees per species in the plots. This exercise was performed for all the stations in each region and the results were finally expressed in t ha^{-1}.