Estimation of stored carbon in *Sonneratia apetala* seedlings collected from Indian Sundarbans

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*Sonneratia apetala* grows luxuriantly in the low saline zone of Indian Sundarbans. Considering the carbon storing potential of the species we attempted to identify the best fitting allometric equation with stored carbon per unit area by *S. apetala* seedlings as the dependent variable and biomasses of vegetative parts of the seedlings (leaf, stem, root and total biomass) separately as independent variables. The sampling was undertaken during monsoon 2016 in two selected stations, Chemaguri and Bali island located in the western and central sectors of the deltaic complex respectively, with contrasting salinity profile. Another purpose of this study was to observe the impact of salinity (if any) on the allometric equations of *S. apetala* seedlings. We observed that common allometric equation can be used (considering stem and total biomasses of the seedlings as independent variable) to predict the stored carbon per unit area in the seedlings growing in different salinity gradient.

[Keywords: *Sonneratia apetala* seedling, Indian Sundarbans, stored carbon, allometric equation]

**Introduction**

Natural systems such as wetlands, salt marshes, rivers, forests and grasslands provide a wide spectrum of ecosystem services such as bioremediation, storm and flood protection, upgradation of air-quality through carbon sequestration etc. that benefit human communities. Yet the connections between ecosystems and these services are sometimes neither readily apparent nor easy to measure and translate into market investments. As a result, these ecosystem services are often not taken into account in decisions about land, water and resource management and use. This neglect has resulted in under investment in environmental protection and corresponding losses of natural system functions and their benefits to human communities.

Recent researches have shown that coastal ecosystems such as sea grasses, salt marshes and mangroves provide climate mitigation services because they are particularly effective in sequestering and storing carbon dioxide, referred to as ‘blue carbon’. Unfortunately, degradation of blue carbon ecosystems due to anthropogenic impacts contributes to carbon emissions from land use impacts and prevents these ecosystems from continuing to sequester and store carbon. Considering the carbon sequestration and storage potential in coastal ecosystems, many countries with coastal floral resources are beginning to implement blue carbon restoration projects using carbon financing mechanisms. The primary success indicators of this restoration project are the biomass and stored carbon of the seedlings. This is because the effective growth and survival of the seedlings are the foundation stones of ecorestoration programme. Seedlings planted (naturally or artificially) and raised in stressful environment often exhibit biomass and stored carbon in lower range. We compare here the variations of biomass and stored carbon in the seedlings of a common mangrove floral species *S. apetala* (locally known as Keora) collected from two different regions of Indian Sundarbans namely Chemaguri in the western sector and Bali island in the central sector of the deltaic complex. Since the estimation of the stored carbon is costly and involves the availability of sophisticated instrument like CHN analyzer, therefore development of allometric equation is extremely important to know the amount of stored carbon from easily measurable variables
like seedling biomass. Thus another aim of this paper is to develop allometric equation for two sampling sites considering total stored carbon of the seedling per unit area as the dependent variable (Y) and biomasses of the vegetative parts of that seedling as independent variable (X). The main reason behind this approach to develop site-specific allometric equation is the contrasting variations in salinity between the two selected stations, which is characteristic feature of Indian Sundarbans. Chemaguri, situated in the western Indian Sundarbans receives the fresh water from Farakka barrage discharge and hence the region is hyposaline in nature. On contrary, the aquatic phase in and around the Bali island is hypersaline due to complete blockage of fresh water as a result of Bidyadhari siltation since the late 15th century, which has retarded the growth and survival of blue carbon domain in the central sector. However none of these references focused on development of site-specific or species-specific allometric model for mangrove seedlings. The present work is therefore an approach to develop a baseline databank on the allometric model of S. apetala seedlings integrating stored carbon and biomass of the target species.

Material and Method

Study Site Description

The Gangotri glacier, which is about 7010 m above the mean sea level in the Himalayas, is the origin of the mighty River Ganga. After emanating from the Himalayas the River Ganga flows south east through a number Indian cities and towns covering a distance of 2,525 km and finally drains into the Bay of Bengal. The delta that is formed at the apex of Bay of Bengal is known as the Indian Sundarbans and is recognized as one of the most diversified and prolific ecosystems of the tropics. The mangrove dominated deltaic complex houses about 102 islands covering an area of 9,630 sq. km with the designation of Sundarban Biosphere Reserve (SBR). The western sector of the deltaic lobe receives the snowmelt water of the mighty Himalayan glaciers after being regulated through several barrages on the way. The central sector on the other hand, is fully deprived of fresh water supply due to heavy siltation and clogging of the Bidyadhari channel since the 15th century. Thus the present study area is an experimental bed to test the influence of salinity on mangrove seedlings and develop salinity based allometric equation to estimate stored carbon on the basis of seedling biomass. With this aim, we selected two stations with contrasting salinity namely Chemaguri (21°38'25.86"N and 88°08'53.55"E) in the western sector (mean salinity = 19.46 ± 3.46 psu) and Bali island (22°04'35.17"N and 88°44'55.70"E) in the central sector (mean salinity = 25.43 ± 2.24 psu) of the study area. Samplings in these stations were carried out in low tide period during July, 2016.

Biomass Estimation

Quadrate sampling technique was used in each station which contained 3 to 4 months old seedlings of S. apetala. 30 sample quadrates (1.0 m × 1.0 m) were established (on the intertidal mudflats) through random sampling. Above Ground Biomass (AGB) is the sum total of stems and leaves of the seedlings and Below Ground Biomass (BGB) comprises the roots of the seedlings. The seedlings of the species after collection from each quadrate were thoroughly washed with double distilled water to remove any sticking debris, dried at 70°C and the average values of about 120 seedlings from 30 quadrates from each station were finally converted into biomass (gm/m²) in the study area.

Carbon Estimation

Direct estimation of percent carbon in the AGB was done by Vario MACRO elementar CHN analyzer, after grinding the oven-dried stems, leaves and roots of the seedlings separately. For this, a portion of fresh sample of root, stem and leaf from the collected seedling samples was separately oven dried at 70°C and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves). Similar exercise was performed for seedlings collected from both the stations.

Statistical analysis

Allometric equations for each station were determined (n = 120 from 30 quadrates/station) as a function of leaf biomass (models CL1 and BS2), stem biomass (models CS1 and BR2), root biomass (models CR1 and BR2) total biomass (models CT1 and BT2), which are the most easily measurable parameters. The precision of the model in predicting the stored carbon of individual seedling was ascertained by the magnitude of the $R^2$ value of the simple regression and percentage difference of predicted and observed stored carbon values of the seedlings. All statistical calculations were performed with SPSS 9.0 for windows.
Result

The mean leaf biomass of S. apetala seedlings is 1.575 gm/m² in Chemaguri, which is higher compared to Bali Island (1.237 gm/m²). Similar trends are observed for stem biomass (mean value 9.144 gm/m² in Chemaguri and 8.144 gm/m² in Bali island), root biomass (mean value 1.771 gm/m² in Chemaguri and 1.391 gm/m² in Bali island). This trend is reflected directly in total biomass and total carbon stored per unit area by the seedlings of the selected species. Higher mean values of total biomass in Chemaguri (12.491 gm/m²) compared to Bali island (10.773 gm/m²) may be attributed to population density of the species, which is much higher in Chemaguri (11.5 m⁻²) compared to Bali island (6.8 m⁻²). The allometric equation, however, reflects the contribution of stem and total biomass (Table 1).

The total carbon stored in the seedlings per unit area is higher in Chemaguri (6.639 gm/m²) compared to Bali island (5.726 gm/m²) and is mostly contributed by total biomass (R² values = 0.9975 in Chemaguri and 0.9979 in Bali island) and to some extent by the stem biomass (R² values = 0.5053 in Chemaguri and 0.5411 in Bali island). The biomasses of leaves and roots have no regulatory effects on the stored carbon of the seedlings (Table 1 and 2).

Table 1- Allometric equation for stored carbon estimation in S. apetala seedlings per unit area

<table>
<thead>
<tr>
<th>Model name</th>
<th>Dependent variable</th>
<th>Independent variable</th>
<th>Regression model</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL1</td>
<td>Stored carbon</td>
<td>Leaf biomass</td>
<td>y = 0.5891x + 5.8169</td>
<td>0.2987</td>
</tr>
<tr>
<td>CS1</td>
<td>Stored carbon</td>
<td>Stem biomass</td>
<td>y = 0.4742x + 2.3026</td>
<td>0.5053</td>
</tr>
<tr>
<td>CR1</td>
<td>Stored carbon</td>
<td>Root biomass</td>
<td>y = 0.3854x + 5.9561</td>
<td>0.1767</td>
</tr>
<tr>
<td>CT1</td>
<td>Stored carbon</td>
<td>Total biomass</td>
<td>y = 0.5315x - 0.0001</td>
<td>0.9975</td>
</tr>
<tr>
<td>BL2</td>
<td>Stored carbon</td>
<td>Leaf biomass</td>
<td>y = 0.4863x + 5.1244</td>
<td>0.2009</td>
</tr>
<tr>
<td>BS2</td>
<td>Stored carbon</td>
<td>Stem biomass</td>
<td>y = 0.4750x + 2.3181</td>
<td>0.5411</td>
</tr>
<tr>
<td>BR2</td>
<td>Stored carbon</td>
<td>Root biomass</td>
<td>y = 0.3585x + 5.2272</td>
<td>0.1297</td>
</tr>
<tr>
<td>BT2</td>
<td>Stored carbon</td>
<td>Total biomass</td>
<td>y = 0.5306x - 0.0004</td>
<td>0.9979</td>
</tr>
</tbody>
</table>

Table 2- Quality assurance of the model

<table>
<thead>
<tr>
<th>Model name</th>
<th>Mean observed stored carbon per unit area (n=120)</th>
<th>Mean predicted stored carbon per unit area (n=120)</th>
<th>% Deviation</th>
<th>Significance level of t-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CL1</td>
<td>6.639 9.035</td>
<td>36.09</td>
<td>0.0180</td>
<td></td>
</tr>
<tr>
<td>CS1</td>
<td>6.639 7.002</td>
<td>5.47</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>CR1</td>
<td>6.639 9.811</td>
<td>47.78</td>
<td>0.0200</td>
<td></td>
</tr>
<tr>
<td>CT1</td>
<td>6.639 6.681</td>
<td>0.63</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>BL2</td>
<td>5.726 8.117</td>
<td>41.76</td>
<td>0.0120</td>
<td></td>
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<tr>
<td>BS2</td>
<td>5.726 5.905</td>
<td>3.13</td>
<td>0.0001</td>
<td></td>
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<tr>
<td>BR2</td>
<td>5.726 7.917</td>
<td>38.26</td>
<td>0.0275</td>
<td></td>
</tr>
<tr>
<td>BT2</td>
<td>5.726 5.803</td>
<td>1.34</td>
<td>0.0002</td>
<td></td>
</tr>
</tbody>
</table>

Index: CL1= Leaf carbon of seedlings from Chemaguri; CS1= Stem carbon of seedlings from Chemaguri; CR1= Root carbon of seedlings from Chemaguri; CT1= Total carbon of seedlings from Chemaguri; BL1= Leaf carbon of seedlings from Bali island; BS2= Stem carbon of seedlings from Bali island; BR2= Root carbon of seedlings from Bali island; BT2= Total carbon of seedlings from Bali island

Discussion

The development and functioning of mangrove ecosystem is considerably influenced by salinity²,⁴,⁵,⁶. In the present work, the reduced biomass of the S. apetala seedlings in the Bali island in the central sector may be attributed to high salinity in this sector compared to Chemaguri in the western sector of Indian Sundarbans. Salinity affects plant growth in a variety of ways: i) by limiting the availability of water against the osmotic gradient, ii) by reducing nutrient availability, and iii) by causing accumulation of Na⁺ and Cl⁻ in toxic concentration causing water stress conditions, enhancing closure of stomata and reduced photosynthesis¹². The contrasting spatial variation of salinity in the study area may be the results of three factors i) the study area experiences the subtropical monsoon climate with an annual rainfall of 1600 to 1800 mm¹³ and the subsequent runoff passes mostly through the Hooghly estuary in the western sector (where the station Chemaguri is located), ii) the siltation of the Bidyadhari River since the 15th century completely cut-off the supply of fresh water in the central sector (where Bali island is located) imparting hypersaline environment iii) the presence of Farakka barrage in the upstream zone of western Indian Sundarbans¹⁴. These
three factors are responsible for freshening and salinification of the western and central sectors respectively that have profound influence on allometric models of the mangrove flora.

So far most of the allometric equations for mangrove have been developed for single stemmed mangrove species. However, some allometric equations have also been developed for multi-stemmed mangrove species such as *Rhizophora*, *Avicennia* and *Excoecaria*. Saenger (2002) has mentioned 43 allometric equations for the above ground biomass of mangroves. It has been found by several researchers that species-specific allometric equations show significant spatial variations. Therefore, the question arises as to whether such species-specific allometric equation may be applicable to different mangrove forests of the world.

Considering the significant spatial variation of salinity in the present geographical locale \( F_{\text{obs}} = 379.58 > F_{\text{crit}} = 1.66 \) as revealed from secondary data, we attempted to develop site-specific allometric models for *S. apetala* seedlings. However from the nature of allometric equations (through comparison of ‘a’ and ‘b’-values in the model \( y = ax + c \), \( R^2 \) values and percentage deviation between the observed and predicted seedling biomass, it appears that there is negligible deviation of the model between the western and central sectors, when the stem biomass and total biomass of the seedlings are considered as independent variables. This is contrary to the finding of Clough et al. (1997) who found different relationships in different sites, although Ong et al. (2004) reported similar equations applied to two different sites while working on *Avicennia* spp. This issue is extremely important for practical applications of allometric equations. If the equations are segregated by species and site, then different equations have to be determined for each site. In the present study, although models CL1, CS1, CR1, CT1, BL2, BS2, BR2, BT2 were developed for different stations with contrasting salinity, the estimation of total stored carbon per unit area by *S. apetala* seedlings produced from these models only differ by 1.25% to 1.66% (in case of stem) and 0.94% to 1.93% (in case of total biomass). Such a good agreement between these two estimates (observed and predicted) leads us to conclude that allometric regression model produced from the same species of similar aged seedlings and similar methods will not exhibit statistically significant spatial variation. The allometric models developed in the present study on the basis of stem and total biomasses can, therefore predict the magnitude of stored carbon by *S. apetala* seedlings in different salinity zones of deltaic Sundarbans without much cost involved in the exercise.

Finally we list a few of our core findings:

1. Pronounced spatial variation of salinity exists in the Indian Sundarban deltaic complex (secondary information).
2. The aquatic phase in western Indian Sundarbans is freshening due to barrage discharge and the central sector of the deltaic complex is getting hypersaline owing to silation of the Bidyadhari River that used to supply fresh water to the Matla estuary in the central sector (secondary data). The selected stations in the present study, Chemaguri and Bali island are representatives of western and central sectors respectively.
3. The hypersaline environment has an inhibitory effect on the growth of *S. apetala* seedlings as revealed from the biomass values (both AGB and BGB) of the seedlings sampled from the selected stations.
4. Allometric equations reveal the suitability of stem biomass and total biomass of *S. apetala* seedlings as proxies to represent the stored carbon in both the stations with almost no impact of salinity in the seedling stage.

**Acknowledgement**

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