ACTA SCIENTIFIC AGRICULTURE (ISSN: 2581-365X)

Volume 3 Issue 5 May 2019

Research Article

Natural Oxygen Counters in Indian Sundarbans, The Mangrove Dominated World Heritage Site

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Received: March 18, 2019; **Published:** April 27, 2019

Abstract

Mangroves provide a wide spectrum of ecosystem services which include upgradation of air quality, stabilizing temperature, reduction of ultraviolet radiation, oxygen generation, carbon sequestration, habitat of several flora and fauna (enhancement of biodiversity), aesthetic beauty etc. Oxygen production is one of the most common but under-researched benefits of mangroves. The primary aim of this article is to estimate the oxygen production potential of dominant mangrove species in Indian Sundarbans.

Keywords: Indian Sundarbans; Mangroves; Oxygen Generation

Introduction

Mangroves provide several ecosystem services like erosion control, protection against storms, bioremediation, carbon sequestration, oxygen production etc. apart from providing timber, fuel wood, honey, wax, and fishes. All these ecosystem services have been studied and quantified in details by several researchers throughout the world [1-12].

The release of oxygen by mangrove floral species has not been studied so far, although studies on oxygen production by urban trees have been done in details [12-15]. Mangrove trees release oxygen when they use energy from sunlight to make glucose from carbon dioxide and water. It takes 6 molecules of carbon dioxide through the process of photosynthesis and 6 molecules of oxygen are released as by-product. Most of the mangrove forests are usually oxygen-neutral or oxygen-negative system as they produce equal or less oxygen compared to what they consume. The dead mangrove trees and the mangrove litter along with detritus consume oxygen to carry out the process of decomposition, which pushes the mangrove system toward oxygen-negative. In order to make the system oxygen-positive, it is essential to retard the process of decomposition. A study was conducted on the oxygen consumption patterns in a mangrove swamp on the Pacific coast of Costa Rica. This study documented the process of oxygen consumption by decomposition. Thus it is clear that a mangrove system can be oxygen positive by either of the two ways or both namely 1) retardation of the process of decomposition and 2) acceleration of the process of photosynthesis. The second option is mostly carried out by the seedlings of mangroves, which are in a growing phases. Similar types of researches have been carried out in different mangrove patches in several parts of the world. Measurements of the oxygen consumption of the suspended organisms, the sediment biota and the prop root-epibiont system in mangrove forests were made to determine the rate of decomposition of organic material in a mangrove swamp on the Pacific coast of Costa Rica. The tidal range in this area is about 2.5 m. The sediment consists mainly of clay with 12-15% organic material. The dominant mangrove species bordering the swamp channels was *Rhizophora mangle*. The O_2 consumption in the free water varies between 35 and 47 mg $m^{-3}h^{-1}$. The oxygen uptake of the sediment lies between 8.4 and 37.2 mg $m^{-3}h^{-1}$. The respiration of the root-epibiont system depends on the position of the root in relation to the low water line. Values between 0.65 and 29.5 mg O_2 h^{-1} in 1000 cm^{-3} of root surface have been recorded.

In a transect between two tidal channels the O_2 consumption per sediment surface area and the percentage consumption by the three subsystems show a great range of variation depending mainly on the water depth at high tide and the period of water coverage. The mean oxygen uptake per square meter was 1310 mg per day. Of this 40.5% was consumed by the organisms suspended in the water column, 13.5% by the sediment biota and 46% by the epibiotic community on the prop roots. Thus, the decomposition of organic material was about 410 mg C m^{-3} day^{-1}. The present paper, however, aims to throw light on the oxygen generation potential of dominant mangrove tree species in Indian Sundarbans on the foundation stone of their respective stored carbon.

Materials and Methods

Sites selection

The mighty River Ganga emerges from a glacier at Gangotri, about 7,010 m above mean sea level in the Himalayas and flows down to the Bay of Bengal covering a distance of 2,525 km. At the apex of Bay of Bengal, a delta has been formed which is recognized as one of the most diversified and productive ecosystems of the tropics and is referred to as the Indian Sundarbans. The deltaic complex has a Biosphere Reserve area of 9,630 sq. km and houses about 102 islands [16]. Eighteen sampling sites were selected each in the western, central and eastern sectors of Indian Sundarbans (Figure 1). The western sector of the deltaic lobe receives the snowmelt water of mighty Himalayan glaciers after being regulated through several barrages on the way. The central sector on the other hand, is fully deprived from such supply due to heavy siltation and clogging of the Bidyadhari channel since the 15th century [17]. The eastern sector of Indian Sundarbans is adjacent to the Bangladesh Sundarbans (which comprises 62% of the total Sundarbans) and receives the fresh water from the River Raimangal and also from the Padma - Meghna - Brahmaputra river system of Bangladesh Sundarbans through several creeks and inlets. Samplings in these sectors were carried out in low tide period during two phases after a gap of 10 years (i.e., Feb, 2009 and Jan, 2019).

Figure 1: Location of sampling stations in Indian Sundarbans.

Estimations of biomass

The entire network of the present study initiated with the selection of six sampling zones in each of the three sectors of Indian Sundarbans. In each zone five 10m×10m quadrates were selected (at random) for the study and the average readings were documented from each such quadrate.

The Above Ground Biomass (comprising of stem, branch and leaf) of individual trees of dominant species in each quadrate was estimated as per the standard procedure stated here and the average biomass values (of all quadrates of each zone) were finally expressed as tonnes per hectare. The methodologies adopted for assessing the above ground biomass (sum total of leaf, stem and root) in the present study are explained in details through three sections.

Stem biomass estimation

The stem biomass for each tree species in every plot was estimated using non-destructive method in which the Diameter at the Breast Height (DBH) was measured after assessing the circumference with a measuring tape and height with laser beam (BOSCH DLE 70 Professional model). Form factor was determined with Spiegel relascope as per the method outlined by Koul and Panwar [18]. The stem volume (V) was then calculated using the expression $FH\Pi r^2$, where F is the form factor, r is the radius of the tree derived from its DBH and H is the height of the target tree. Specific gravity (G) of the wood was estimated taking the stem cores, which was further converted into stem biomass (B_S) as per the expression $B_S = GV$.

Branch biomass estimation

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. <6cm, 6–10cm and >10cm. Dry weight of two branches from each size group was recorded separately using the equation of Chidumaya [19].

Total branch biomass (dry weight) per sample tree was determined as per the expression:

$$B_{db} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \Sigma\, n_ibw_i$$

Where, B_{db} is the dry branch biomass per tree, n_i the number of branches in the i_{th} branch group, b_{wi} the average weight of branches in the i_{th} group and i = 1, 2, 3, ...n are the branch groups. This procedure was followed for all the dominant tree species separately for every quadrate.

Leaf biomass estimation

Leaves from nine branches (three of each size group as stated in section ii) of individual trees of each species were removed. One tree of each species per quadrate was considered for estimation. The leaves were weighed and oven dried separately (species wise) to a constant weight at 80 ± 5^0C. The leaf biomass was then estimated by multiplying the average biomass of the leaves per branch with the number of branches in a single tree and the average number of trees per plot as per the expression:

$$L_{db} = n_1Lw_1N_1 + n_2Lw_2N_2 + \ldots\ldots\ldots n_iLw_iN_i$$

Where, L_{db} is the dry leaf biomass of the tree species per quadrate, n_1......n_i are the number of branches of each tree species, Lw_1 ....Lw_i are the average dry weight of leaves removed from the branches and N_1.........N_i are the number of trees per species in the quadrate.

Estimation of stored carbon and carbon sequestration

Direct estimation of percent carbon was done by a CHN analyzer. For this, a portion of fresh sample of stem, branch and leaf from selected trees (two trees/species/plot) of individual species (covering all the selected plots) was oven dried at 70°C, separately ground to pass through a 0.5mm screen (1.0mm screen for leaves).

The carbon content (in %) was finally analyzed for each part of each species through a *Vario MACRO elementar* CHN analyzer. The total stored carbon in the above ground biomass was estimated by considering the mean relative abundance of each species in the selected quadrates and finally the sequestered carbon in the above ground biomass was estimated for each species by dividing the values with the respective age of the species..

Estimation of oxygen production

Carbon sequestration is the rate of stored carbon that is the amount of stored carbon per year. Considering the concept of magnitude of carbon sequestration per unit area, it is expressed as tonnes/ha/yr. Thus, to determine carbon sequestration, it is important to know the age of the tree. The net oxygen generated by the selected floral species can be estimated by applying the expression.

Net O_2 release (tonnes/ha/yr) = Net C sequestration (tonnes/ha/yr) × 32/12

Results and Discussion

The net oxygen release (tonnes/ha/yr) of mangroves is a function of carbon sequestration and table 1 presents the net oxygen release (tonnes/ha/yr) of five dominant species namely *Sonneratia apetala*, *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, and *Exocecaria agallocha*. The values are average of five species for each of the three sectors.

Sector	Carbon sequestration (tonnes ha^{-1} y^{-1})	Net O_2 release (tonnes ha^{-1} y^{-1})	No. of O_2 cylinders needed to fill up by the O_2 gas (capacity 6 lt.)	Total price of cylinder (INR)
Central	3.014	8.047	1341	871650
Western	2.800	7.476	1246	809900
Eastern	2.916	7.785	1297	843050

Table 1: Sector-wise net O_2 release (in tonnes ha^{-1} y^{-1}) by dominant mangrove floral species in Indian Sundarbans**.**

Above ground biomass (AGB)

The AGB of *Sonneratia apetala* seedlings was relatively higher in the sampling sites of the eastern sector compared to the western and central sectors. In the present study AGB ranged from 149.99 tonnes/ha (in Chandkhali) to 166.85 tonnes/ha (in Arbesi) in the eastern sector, 104.59 tonnes/ha (in Jambu Island) to 142.33 tonnes/ha (in Lothian Island) in the western sector, and 41.39 tonnes/ha (in Goashaba) to 68.75 tonnes/ha (in Matla) in the central sector.

The AGB of *Avicennia marina* seedlings was highest in the central sector followed by the western and eastern sectors. The AGB ranged from 64.224 tonnes/ha (in Chulkathi) to 70.224 tonnes/ha (in Pirkhali) in the central sector, 39.863 tonnes/ha (in Muriganga) to 45.781 tonnes/ha (in Jambu Island) in the western sector, and 35.668 tonnes/ha (in Jhila) to 41.326 tonnes/ha (in Chandkhali) in the eastern sector.

Similar trends are observed in *Avicennia alba* seedlings. The values were higher in the central sector compared to the western and eastern sectors of Indian Sundarbans. The values ranged from 67.965 tonnes/ha (in Goashaba) to 73.103 tonnes/ha (in Pirkhali) in the central sector of Indian Sundarbans, 41.224 tonnes/ha (in Muriganga) to 47.117 tonnes/ha (in Prentice Island) in the western sector of Indian Sundarbans and 38.615 tonnes/ha (in Harinbhanga) to 43.269 tonnes/ha (in Arbesi) in the eastern sector of Indian Sundarbans.

The AGB of *Avicennia officinalis* seedlings followed the order central sector > western sector > eastern sector. In the central sector the AGB ranged from 68.995 tonnes/ha (in Thakuran) to 75.116 tonnes/ha (in Dhulibasani). In the western sector values ranged from 42.008 tonnes/ha (in Muriganga) to 49.004 tonnes/ha (in Jambu Island), and in the eastern sector the range was 36.208 tonnes/ha (in Jhila) to 42.819 tonnes/ha (in Arbesi).

The order of AGB in *Excoecaria agallocha* seedlings is central sector > western sector > eastern sector. In the central sector the AGB ranged from 58.017 tonnes/ha (in Chulkathi) to 65.883 tonnes/ha (in Pirkhali). In the western sector, the values ranged from 38.112 tonnes/ha (in Muriganga) to 43.559 tonnes/ha (in Lothian Island) and in the eastern sector the range was 33.220 tonnes/ha (in Jhila) to 38.777 tonnes/ha (in Chandkhali).

Above ground carbon (AGC)

The AGC of *Sonneratia apetala* seedlings followed the order eastern sector > western sector > central sector. The AGC ranged from 70.645 tonnes/ha (in Chandkhali) to 78.586 tonnes/ha (in Arbesi) in the eastern sector, 48.216 tonnes/ha (in Jambu Island) to 66.096 tonnes/ha (in Prentice Island) in the western sector, and 18.791 tonnes/ha (in Goashaba) to 31.281 tonnes/ha (in Matla) in the central sector.

The AGC of *Avicennia marina* seedlings varied as per the order central sector > western sector > eastern sector. In the central sector the AGC ranged from 30.699 tonnes/ha (in Dhulibasani) to 33.778 tonnes/ha (in Pirkhali). In the western sector values ranged from 18.018 tonnes/ha (in Muriganga) to 21.013 tonnes/ha (in Jambu Island), and in the eastern sector the range was 16.122 tonnes/ha (in Jhila) to 18.886 tonnes/ha (in Chandkhali).

The AGC of *Avicennia alba* seedlings was relatively higher in the sampling sites of the central sector compared to the western and eastern sectors. In the present study AGC ranged from 32.771 tonnes/ha (in Thakuran) to 35.747 tonnes/ha (in Pirkhali) in the central sector, 18.716 tonnes/ha (in Muriganga) to 21.719 tonnes/ha (in Jambu Island) in the western sector, and 17.917 tonnes/ha (in Harinbhanga) to 19.817 tonnes/ha (in Arbesi) in the eastern sector.

Similar trends are observed in *Avicennia officinalis* seedlings. The values were highest in central sector compared to western and eastern sectors of Indian Sundarbans. In this study we observed 31.600 tonnes/ha (in Thakuran) to 36.131 tonnes/ha (in Dhulibasani) in the central sector of Indian Sundarbans, 19.786 tonnes/ha (in Muriganga) to 23.032 tonnes/ha (in Jambu Island) in the western sector of Indian Sundarbans and 17.380 tonnes/ha (in Jhila) to 20.467 tonnes/ha (in Arbesi) in the eastern sector of Indian Sundarbans.

The order of AGC in *Excoecaria agallocha* seedlings is central sector > western sector > eastern sector. In the central sector the AGC ranged from 27.442 tonnes/ha (in Chulkathi) to 30.636 tonnes/ha (in Pirkhali). In the western sector the values ranged from 18.103 tonnes/ha (Muriganga) to 19.950 tonnes/ha (in Lothian Island) and in the eastern part the values ranged was 15.713 tonnes/ha (in Jhila) to 18.186 tonnes/ha (in Chandkhali).

Carbon sequestration

The age of the mangrove floral species is 10 years in the present study. The initial reading was taken during 2009 (when the selected floral species were in the seedling stage) and the final reading was taken during 2019 (when the species attended their mature stage). The stored carbon per year (carbon sequestration) for each of these species was calculated by subtracting the initial stored carbon from the final stored carbon values and dividing results by 10 (age gap between the final and initial years).

In this study, carbon sequestration by *Sonneratia apetala* seedlings was highest in the eastern sector followed by the western and central sectors. Carbon sequestration ranged from 7.050 tonnes/ha/yr (in Chandkhali) to 7.835 tonnes/ha/yr (in Arbesi) in the eastern sector, 4.814 tonnes/ha/yr (in Jambu Island) to 6.595 tonnes/ha/yr (in Prentice Island) in the western sector, and 1.874 tonnes/ha/yr (in Goashaba) to 3.116 tonnes/ha/yr (in Matla) in the central sector.

Carbon sequestration of *Avicennia marina* seedlings varied as per the order central sector > western sector > eastern sector. In the central sector the carbon sequestration ranged from 3.051 tonnes/ha/yr (in Chulkathi) to 3.349 tonnes/ha/yr (in Pirkhali). In the western sector values ranged from 1.794 tonnes/ha/yr (in Muriganga) to 2.085 tonnes/ha/yr (in Jambu Island) and in the eastern sector the range was 1.605 tonnes/ha/yr (in Jhila) to 1.882 tonnes/ha/yr (in Chandkhali).

Similar trends are observed in *Avicennia alba* seedlings. The values were relatively higher in the sampling sites of the central sector compared to the western and eastern sectors. In the present study, carbon sequestration values ranged from 3.251 tonnes/ha/yr (in Chulkathi) to 3.549 tonnes/ha/yr (in Pirkhali) in the central sector, 1.850 tonnes/ha/yr (in Muriganga) to 2.149 tonnes/ha/yr (in Jambu Island) in the western sector, and 1.785 tonnes/ha/yr (in Harinbhanga) to 1.969 tonnes/ha/yr (in Arbesi) in the eastern sector.

Carbon sequestration of *Avicennia officinalis* seedlings followed the order central sector > western sector > eastern sector. In the central sector the carbon sequestration ranged from 3.109 tonnes/ha/yr (in Thakuran) to 3.579 tonnes/ha/yr (in Dhulibasani). In the western sector the values ranged from 1.957 tonnes/ha/yr (in Muriganga) to 2.282 tonnes/ha/yr (in Jambu Island), and in the eastern sector the values ranged from 1.724 tonnes/ha/yr (in Jhila) to 2.033 tonnes/ha/yr (in Arbesi).

The order of carbon sequestration in *Excoecaria agallocha* seedlings is central sector > western sector > eastern sector. In the central sector the carbon sequestration ranged from 2.738 tonnes/ha/yr (in Chulkathi) to 3.049 tonnes/ha/yr (in Pirkhali). In the western sector, the values ranged from 1.797 tonnes/ha/yr (in Muriganga) to 1.982 tonnes/ha/yr (in Lothian Island) and in the eastern sector the values ranged 1.565 tonnes/ha/yr (in Jhila) to 1.806 tonnes/ha/yr (in Chandkhali).

Net oxygen release

The net oxygen release in *Sonneratia apetala* varied as per the order eastern sector > western sector > central sector. In the eastern sector the net oxygen release ranged from 18.823 tonnes/ha/yr (in Chandkhali) to 20.919 tonnes/ha/yr (in Arbesi). In the western sector, the values ranged from 12.853 tonnes/ha/yr (in Jambu Island) to 17.608 tonnes/ha/yr (in Prentice Island) and in the central sector, the values ranged from 5.003 tonnes/ha/yr (in Goashaba) to 8.319 tonnes/ha/yr (in Matla).

In this study, the net oxygen release in *Avicennia marina* seedlings was highest in the central sector followed by the western and eastern sectors. The net oxygen release ranged from 8.146 tonnes/ha/yr (in Chulkathi) to 10.463 tonnes/ha/yr (in Goashaba) in the central sector, 4.789 tonnes/ha/yr (in Muriganga) to 5.566 tonnes/

ha/yr (in Jambu Island) in the western sector, and 4.285 tonnes/ha/yr (in Jhila) to 5.024 tonnes/ha/yr (in Chandkhali) in the eastern sector.

In *Avicennia alba* seedlings, the net oxygen release was highest in the sampling sites of the central sector compared to the western and eastern sectors. The values ranged from 8.680 tonnes/ha/yr (in Chulkathi) to 9.475 tonnes/ha/yr (in Pirkhali) in the central sector, 4.939 tonnes/ha/yr (in Muriganga) to 5.737 tonnes/ha/yr (in Jambu Island) in the western sector and 4.765 tonnes/ha/yr (in Harinbhanga) to 5.257 tonnes/ha/yr (in Arbesi) in the eastern sector.

In *Avicennia officinalis* seedlings, the order is central sector > western sector > eastern sector. In the central sector, the net oxygen release ranged from 8.301 tonnes/ha/yr (in Thakuran) to 9.555 tonnes/ha/yr (in Dhulibasani). In the western sector values ranged from 5.225 tonnes/ha/yr (in Muriganga) to 6.092 tonnes/ha/yr (in Jambu Island), and in eastern sector the values ranged from 4.603 tonnes/ha/yr (in Jhila) to 5.428 tonnes/ha/yr (in Arbesi).

In *Excoecaria agallocha* seedlings, the net oxygen release showed the order central sector > western sector > eastern sector. In the central sector, the net oxygen release ranged from 7.310 tonnes/ha/yr (in Chulkathi) to 8.141 tonnes/ha/yr (in Pirkhali). In the western sector values ranged from 4.798 tonnes/ha/yr (Muriganga) to 5.292 tonnes/ha/yr (in Lothian Island) and in the eastern sector the values ranged from 4.179 tonnes/ha/yr (in Jhila) to 4.822 tonnes/ha/yr (in Chandkhali).

The net oxygen release by mangrove trees is a function of the amount of oxygen produced through the process of photosynthesis minus the amount of oxygen utilized during plant respiration. Considering the data of the present study, it seems that the mangroves of Indian Sundarbans is a unique oxygen generation counter, which is definitely region- and species-specific, *e.g*., the potential of oxygen generation by *Sonneratia apetala* in the low saline region (like western/eastern sector) may not generate optimum result if planted in the hypersaline central sector. Hence region-specific plantation is a food for thought to transform this World Heritage Site into a healthy, oxygen-rich zone of the tropics.

Looking for a new horizon

The entire research on the oxygen production potential of mangroves shows that the dominant mangrove species in Indian Sundarbans can release on an averge about 7.7 tonnes of oxygen per hecatre in 1 year, which amounts to INR 841533 for filling 1295 cylinders of 6 litre capacity. As an assuarance to the quality of the data, the entire system of research can be linked with cryptography, which is a mechanism of securely encoding the picture of a system *i.e*. whether the sector is following the rules of conservation or deforestation is going on at massive scale. Also the estimation protocol will also be encrypted in this technology, which enables quality control of the data. The data generated in the present study in context to oxygen generation by mangroves is basically a blockchain based supply chain which means that the field sampling, analyses and computation are scanned as QR code (like a bar code) through smartphone and every step can be monitored. In such case the data generated are quality data of highest degree. Till date no academic papers have linked the blockchain to know the ecosystem service like oxygen generation by mangroves. In this case, we suggest as conclusion the term eco-Tech which can be a new technology where blockchain can be applied to monitor the services offered by flora and fauna. However, there are several drawbacks, *e.g*., the blockchain is still slow. It handles 7 transactions per second compared to 2000 for the VISA network. Another issue is that the blockchain is a giant hub in context to energy consumption consuming a large space in the google. Hence, it is needed to develop a more energy efficient algorithm. Another important drawback is that if by any chance the digital signature is lost then all the data are lost forever. In this context it is of utmost importance to hide the cryptographic complexity in smartphone Apps so that the big data of environments can be saved.

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