International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 08-01-2023, Accepted: 24-01-2023, Published: 10-02-2023
Volume 5, Issue 1, 2023, Page No. 9-14

Estimating carbon storage potential of chinnapalam mangrove, southeast coast of India using allometric methods

J Prasanna[1*], M Anand[2], K Gautam[3], KM Tullanithi[4], K Jayakumar[5]

[1] P.G & Research Department of Microbiology, Vivekanandha College of Arts and Sciences for Women, Tiruchengode, Namakkal, Tamil Nadu, India

[2] Department of Marine and Coastal Studies, School of Energy, Environment and Natural Resources, Madurai Kamaraj University, Madurai, Tamil Nadu, India

[3] P.G & Research Department of Microbiology, Asan Memomorial College of Arts and Science, Chennai, Tamil Nadu, India

[4] Department of Biochemistry, Vivekanandha Dental College for Women, Namakkal, Tamil Nadu, India

[5] Department of Animal Behaviour & Physiology, School of Biological Sciences, Madurai Kamaraj University Madurai, Madurai, Tamil Nadu, India

Abstract

We evaluated carbon stocks in the above-ground biomass (AGB) of two dominant mangrove species (*Avicennia marina* and *Rhizophora mucronata*) in the Chinnapalam mangrove, Pamban, Southeast coast of India. We examined whether these carbon stocks vary with spatial locations (Central region vs. Western region) and with seasons (pre-monsoon, summer, monsoon, and post-monsoon). Among the two studied species, *R. mucronata* showed the maximum above-ground biomass (AGB) and above-ground carbon content (AGCC) (t ha^{-1}) followed by *A. marina* (t ha^{-1}). The AGB varied significantly with spatial locations ($p < 0.05$) but not with seasons ($p < 0.05$). The variation may be attributed to different environmental conditions to which these areas are exposed such as higher siltation and salinity in the central region compared to the western region. The relatively higher salinity in the central region caused the subsequent lowering of biomass and stored carbon of the selected species. There is no previous study available relevant to carbon storage and this is the first-hand study of carbon sequestration in Chinnapalam mangrove.

Keywords: above ground carbon, above ground biomass, allometric estimation, pamban, chinnapalam, mangrove, southeast coast of India

Introduction

Coastal and marine ecosystems are an important biological carbon sink, capable of sequestering four times more carbon per unit area than rain forests and they absorb up to 35% of atmospheric CO2. Their mean rate of aboveground net primary production (NPP) is ~11 Mg ha−1 yr−1, which is in the same order of magnitude as terrestrial evergreen forests and peat swamp forest [1]. Around ~15% of all carbon burial accounts of organic carbon in marine environments, and significantly considered as long-term storage [2]. Besides complex mangrove plant structures and sedimented soils trap allochthonous organic material on upper layer of deep carbon rich peat composed mainly of deadly organic material, sometimes extending deep up to 10 m depth [3] and the level of soil organic carbon can up to 90% of mangrove carbon stocks [4]. Moreover carbon mitigation, mangrove forests pays additional key ecosystem services [5], such as coastal barriers from erosion and extreme weather [6] and shelter for ecological communities. Completely, the financial return of mangrove ecosystem services is assessed at US$ 194,000 ha−1 year−1, with a global value of US$ 2.748 trillion year−1[7]. Over the past 50 years, due to deforestation activities lead to destroying an approximately one-third of the total world's mangrove forests [8]. The interdependent pooled effect of climate change can increase due to the loss of mangroves at global scales.

In mangrove, above ground carbon content of has been broadly studied in all over the world. However, mangroves are ecologically diverse and their organic carbon (OC) sequestration capability can vary extensively. Hence, the results obtained at one place may not be applicable to another place. [9] Therefore, it is very obligatory to assess the dynamics of OC content of individual mangrove species for better estimation of global carbon budget. The globally occupied mangrove biomass of carbon is estimated as 4.0 gigatons (i.e. 8.7 gigatons of total dry biomass [10]) stored as above and below ground biomass. The annual carbon sequestration rate of mangrove system ranges between 6 and 8 Mg CO2 e/ ha (tons of CO2 equivalent per hectare) [11]. The CO2 sequestration rates of mangrove compared with mature tropical forests, shows 2 to 4 times higher and considered as world largest carbon pool than this.

Mathematically, various methodologies has been developed for estimation of above ground biomass, it means the relationship between tree biomass and, their measured components, such as the diameter of the stem at breast height (DBH), stem height (H), Basal area (BA). One of the most possible methods is developing allometric equations by destructive biomass, which requires harvested/ scarified tree samples it directly propositional to either the whole or partial tree weight from the measurable tree dimension [12, 13], The above the grove biomass estimation, accumulating of carbon considered in leaves, fruits, flowers, stems, branches, twigs, stumps and proop-roots. This organic carbon defined carbon capture and storage of carbon dioxide (CO_2) for a long time.

The application of biomass estimation methods or studies of mangroves have mostly concentrated in natural stands [14]. The average rate of wood production is 738.9 Mg ha–1, which is equivalent to a global estimate of 6.17 Pg Corg stored in mangrove biomass [15].

In recent study shows 4.0% global mangrove looses or slowing between the year of 1996 and 2016 [16]. Another study shows around >300 million Mg of CO_2e were emitted due to mangrove deforestation between 2000 and 2012. Deforestation of mangrove mainly happens for the land conversion such as agri/aquaculture land-use [17]. National level programs have been initiated for further avoid this land conversion and restoration by effective manner to offsetting GHG emissions [18], although the prevention of further forest loss, by far, outweighs gains from restoration [19]. The presence study aim is estimation of above ground biomass of Chinnapalam mangrove, southeast coast of India. Also identify higher carbon sequesting mangrove species for more carbon accumulation.

Material and Methods

Study area description

The study area Chinnapalam is located close to Pamban, Ramanathapuram, Southeast coast of India (9°16’24.88” to 9°15’58.30” N and longitudes 79°12’57.16” to 79°13’47.27” E) (Figure 1). The average annual rainfall fluctuates between 762 mm and 1270 mm. The recorded atmospheric temperature ranges between 25°C and 37.9°C during different seasons. The Chinnapalam mangrove is unglued from the sea by a sand bar. Sea grass vegetation covers over 152.82 ha of dense and 370.54 ha sparse distribution [20]. Cultivable fin fishes were recorded in this region, fishes like Chanos;Mugil, Siganus (oramin) [21]. The different true mangrove flora such as Avicennia, Bruguiera, Ceriops and Rhizophora were commonly found in the entire mangrove. Nearly 900 peoples are living close to coastal area; they depend on the Chinnapalam mangroves for various purposes such as collection of crab, fish, bivalves and gastropods [22].

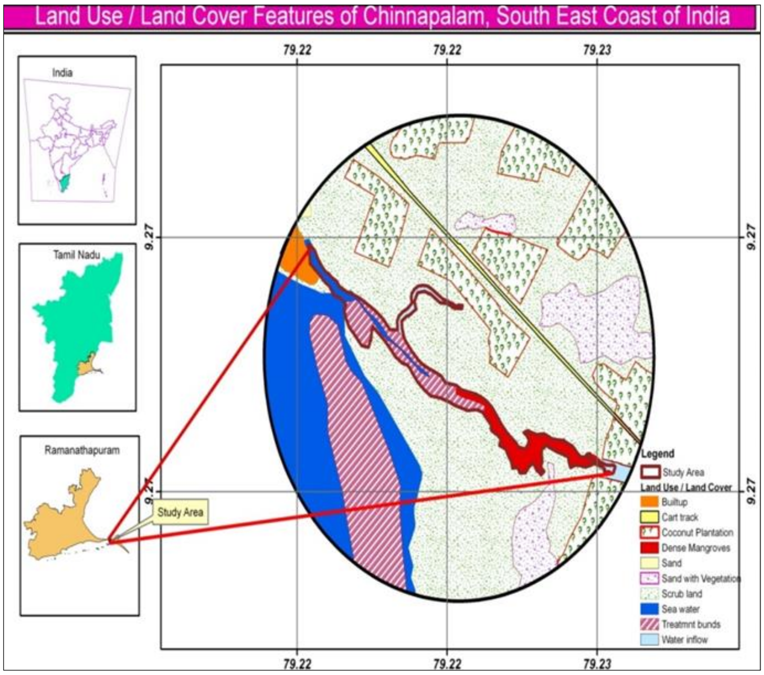

Fig 1: The map shows the Chinnapalam mangrove region, land use and land cover features of study site.

Fig2: Shows ploting and measurement of DBH at 1.37 m from the ground at Chinnapalam mangrove.

Sampling design

Totally 42 individual trees were harvested and each sample was recorded for DBH, H and BA. The harvested trees were separated into the following compartments: leaves branch and stem [23].

Community structure

The height (H), diameter at breast height (DBH) (Figure 2), density and basal area (BA) of the mangrove trees were recorded in each sub-plot. The stems of individual mangrove tree were analyzed for the estimation of mangrove biomass.

Estimation of leaf biomass

The leaf biomass of mangrove trees were estimated from representative single tree in each sub-plot. The average biomass of the leaves per branch was multiplied with the number of branches present in the tree by using the following standard equation [23, 24].

Ldb = n1 Lw1 N1 + n2 Lw2 N2 + ------ + ni + Lwi + Ni

where,

Ldb – Dry leaf biomass

n1------ni –Number of branches in each tree

Lw1------Lwi – Average dry weight of leaves removed from the branches

N1------Ni – Number of trees present in the plots.

Estimation of branch biomass

The number of branches present in each tree was counted manually. The dry weight of the each branch per sub-plots was recorded and estimated using the following Equation [23, 25].

Bdb = n1 bw1 + n2 bw2 + n3 bw3 = Σ ni + bwi

Where,

Bdb – Dry branch biomass

ni – Number of branches in the tree

bwi – Average weight of branches

Estimation of stem biomass

The stem biomass was estimated by using the Newton's formula [23, 26].

V = h/6 (Ab + 4Am + At)

Where,

V – Volume of stem biomass

h – Height of stem by using a tab

Ab, Am and At – Areas of base, middle and top

Statistical analysis

Based on the relationships between AGB, DBH, H, BA, leaf, branch and stem biomass along with stored carbon scatter plots, allometric equations and correlations were developed. The best allometric relationships were examined with the relative variables such as DBH, H and BA for estimation of AGB & AGCC. All statistical calculations were performed using Microsoft Excel 2007.

Results

Many studies have been carried out by adapting different regression equations for the estimation of tree biomass based on the parameters like diameter, height and basal area [23, 27]. The physical observation of tree diameter, density, height and basal area were identified for each mangrove tree in individual plots. The height of the trees was grouped into three classes *viz.*, small (0 to 2 m) medium (2 to 5 m) and tall (above 5 m). The mean average height of

A. marina and R. mucronata in central and western region was observed from 4.0 to 2.8m and 2.06 to 1.28 m, respectively. The mean value of average DBH of A. marina and R. mucronata was 53.2 and 28.33 cm, respectively at central region and 25.1 and 22.3 cm, respectively in western region. The mean average basal area of A. marina at central region was calculated as 1.705 m2/ 0.1 ha and 0.143 m2/ 0.1 ha for R. mucronata. In western region, it was 0.148 m2/ 0.1 ha for A. marina and 0.159 m2/ 0.1 ha for R. mucronata. The density of the mangrove trees was varied between the central and western region. The total average density of A. marina was 322 trees/ha and for R. mucronata it was 357 trees/ha at central region and 700 trees/ha for A. marina & 277 trees/ha of R. mucronata at western region.

Leaf biomass

In A. marina leaf biomass exhibited strong relationship when regressed with DBH and BA (Table 1a & 1b) in central region & western region and there was no significant relationship with height. There was no significant difference observed in the seasonal variation of central and western region ($p < 0.05$). The leaf biomass of R. mucronata showed highest R2 value when regressed with BA and also positive correlation with DBH and height in central and western region (Table 2a & 2b). There was no significant difference observed in the seasonal variation.

Branch biomass

The branch biomass of A. marina exhibited strong relation when regressed with DBH and BA (Table 1a & 1b) and insignificant with height was observed in central and western region. The significant spatial variation in branch biomass between the trees was noticed, however no seasonal variation was observed. In R. mucronata showed strong positive relation when regressed with BA comparatively DBH and height at central region. There was no significant relation was observed between height and branch biomass at western region (Table 2a & 2b).

Stem biomass

A strong positive relation was observed for A. marina when regressed with DBH than BA (Table 1a & 1b) in central region and there is no significant relation was observed with height. The ANOVA results confirmed that there was no seasonal variation ($p < 0.05$). Notably stem biomass of R. mucronata exhibited highest R2 value when regressed with BA (Table 2a & 2b) and strong positive relation were observed than leafs and branches at central region. In western region the stem biomass showed no significant relation when regressed with height. The ANOVA results confirmed that there was no seasonal variation ($p < 0.05$). The prop root biomass was only noted only in R. mucronata, which revealed strong positive correlation when regressed with BA, H and DBH in central region. In interestingly, it shows negative correlation, when regressed with height at western region. There was no seasonal difference observed ($p < 0.05$).

Carbon content

In A. marina the best correlation was found between AGB and DBH (R2 = 0.959) in central region and (R2 = 0.954) in western region. The following relationship has been developed for estimation of above ground biomass (AGB).

Y = 1.083X – 0.643

(R2 = 0.959) in central region (Table 1a), Y = 1.011X + 0.873 (R2 = 0.954) in western region (Table 1b). In R. mucronata the best correlation was found between AGB and BA
(R2 = 0.981) in central region (Table 2a) and (R2 = 0.950) in western region (Table 2b).

Table 1a: Relationship (R2) of tree biomass with independable variables of A. marina in central region, Chinnapalam mangrove

S. No	Tree component	DBH (cm)	H (m)	Basal area(m^2)
1	Leaf	0.922	0.419	0.884
2	Branch	0.849	0.517	0.842
3	Stem	0.774	0.348	0.714
4	Aboveground biomass	0.959	0.394	0.893

Table 1b: Relationship (R2) of tree biomass with independable variables of A. marina in western region, Chinnapalam mangrove

S. No	Tree component	DBH (cm)	H (m)	Basal area (m^2)
1	Leaf	0.873	0.018	0.820
2	Branch	0.887	0.025	0.826
3	Stem	0.940	0.001	0.886
4	Aboveground biomass	0.954	0.010	0.913

Table 2a: Relationship (R2) of tree biomass with independable variables of R. mucronata in central region, Chinnapalam mangrove

S. No	Tree component	DBH (cm)	H (m)	Basal area (m^2)
1	Leaf	0.929	0.806	0.939
2	Branch	0.955	0.780	0.961
3	Stem	0.976	0.850	0.963
4	Prop root	0.919	0.942	0.926
5	Aboveground biomass	0.978	0.873	0.981

Table 2b: Relationship (R^2) of tree biomass with independable variables of *R. mucronata* in western region, Chinnapalam mangrove

S. No	Tree component	DBH (cm)	H (m)	Basal area (m^2)
1	Leaf	0.861	0.615	0.850
2	Branch	0.895	0.425	0.928
3	Stem	0.914	0.555	0.921
4	Prop root	0.910	0.560	0.895
5	Aboveground biomass	0.944	0.560	0.950

The following relationship has been developed for estimation of above ground biomass (AGB). Y = 524.4X + 14.82 (R2 = 0.981) in central region, Y = 948.4X + 16.57
(R2 = 0.950) in western region. The average carbon content present in the above ground biomass of A. marina and R. mucronata in central region was ranged between 0.71 and 1.57 t/0.1ha & 0.54 and 3.52 t/0.1 ha and western region was varied between 0.1 and 5.28 t /0.1 ha & 0.94 and 4.58 t/0.1ha. The total average carbon content of two species in central region and western region was 15.85 and 13.26 t/ha, & 15.85 and 13.26 t/ha, respectively. No significant difference was observed between central and western region. In A. marina, relationship of above ground carbon content (AGCC) with dry biomass of leaves, branch and stem showed positive correlation. Leaves and stems revealed much strong correlation when compared to branches. It revealed that branches and stems were much stronger with AGCC than leaves. Likewise in R. mucronata, the relationship of AGCC with dry biomass of leaves, branch, stem and prop root shows positive correlation. Prop root show very perfect correlation than other plant parts of R. mucronata.

Discussion

The concept of carbon sequestration is encapturing the atmospheric CO2 into Green storages [28] such as trees, plants and soil components in the biosphere. The accumulation of soil carbon is determined by the balance between carbon input (leaf litter fall and rhizo-decomposition) and its decomposition [29]. In biological carbon processing in the planet Earth direct propositional to the Photosynthesis and decomposition process0. The [30] amount of above ground biomass (AGB) of the forest area reveals the information on carbon stock, carbon estimation, carbon exchange and effect of deforestation were happens. Mangrove ecosystems are present in tropical and subtropical coastlines and its act as major source of food and breeding grounds for fishes besides anthropogenic activities like coastal development, cattle grazing and aquaculture caused a considerable decline to an extend of 30–50% of mangrove cover over the past decades.

Allometric estimation is a most common and powerful tool to calculate the volume or above ground biomass of forest ecosystem by using inventory data or independent variables of trees such as trunk diameter and height, but they have exhibited varied relationship between different species. The above ground biomass of A. marina and R. mucronata is influenced by the height of tree, stem density, stem diameter and basal area31. In this study, DBH (cm) and BA (m2) of A. marina exhibited a strong relationship with the above ground biomass and it was coincided by the observation made at northern Australia in A. marina. Other Studies conducted with the other tree species revealed a strong relation between above ground biomass of trees and BA [31, 32], as well as height of tree and wood density or specific gravity [32]. It has been established through this study over the development of an allometric equation using DBH for A. marina and BA for R. mucronata seems to be a strong predictor for the assessment of above ground biomass. The tree height for A. marina and R. mucronata is one of the major structural components even though it does not influence the estimation of biomass. The DBH and H are the main structural parameters to determine the standing tree populations of a forest. Hence, the distribution of DBH and H of the A. marina and
R. mucronata in Chinnapalam mangrove was divided spatially in each plot. We observed that there was an insignificant relationship between DBH and H (R2 = 0.394) in central region, (R2 = 0.010) in western region of A. marina species. Similar kind of results
(R2 = 0.592 and R2 = 0.176) were observed in the studies conducted in Shinas at Northern part of Oman and in Quriyat at Central part of Oman. The insignificant relationship between DBH and H also observed in R. mucronata (R2 = 0.549) at western region of Chinnapalam mangrove. Eventhough, the DBH and H are excellent predictors for the estimation of AGB; the height of A.

marina and R. mucronata trees was not exhibited significant correlation or better relationship with the above ground biomass in Chinnapalam mangrove. Similar studies conducted with the same parameters were used DBH alone for the estimation of AGB. The mangrove biomass is not only determined by the geographical features such as micro and macro climate change in an environment, but also the age and growth of the trees and community structure also played a significant role [33, 34].In most cases, the relationship between the BA and AGB is not linear, as in the vast majority of published allometric equations are based on the diameter of tree and that allometric equations for individual trees can be modified to produce stand-level equations in which the basal area is an additional independent variable. Here, R. mucronata shows strong relationship of BA (R2 = 0.981), (R2 = 0.950) against with AGB at central and western region, respectively. It shows better relationship than DBH (R2 = 0.978) in central region and (R2 = 0.944) in western region of Chinnapalam mangrove. The DBH, height and Basal area are excellent predictors of total above ground biomass for mangrove forest. However, attempts to use height as a parameter were not successful in this study, since no relationship between height and the above-ground biomass components was not found for the Chinnapalam mangrove (Biomass = a Height b, R2 = 0. 0394 in central region and 0.010 for western region). In practice, DBH was measured very accurately and with great ease in the field, whereas stem height is very difficult to measure non-destructively, especially in a muddy mangrove forest, and so most authors were simply used DBH alone to study allometric relationships of mangrove forests [35]. In estimates from specific trees harvested in this study, the leaves, stems, branches and total above-ground total biomass were clearly related to the variable DBH. The allometric relationships with DBH showed significant correlation, and in particular, there was the greatest regression between above-ground biomass and DBH with R2 of 0.944 for central region and 0.954 for western region. The estimated AGB of A. marina was calculated 18.272 t ha–1 in central region and 14.1 t ha–1 in western region. These results can be compared with other researcher have done in various region of world. The average AGB of A. marina in China was

77.1 t ha–1 [37] and mixed forest 8.5 t ha−1 of A. marina with a stand density of 260 trees ha−1 [33]. Relatively similar results were observed in Australia (110, 162 and 341 t ha−1) [37], South Africa (19.8 t ha−1), New Zealand (6.8 and 104.1 t ha−1), Taiwan (13.5 t ha−1) (22.7 t ha−1). The AGB of other Avicennia species in India was estimated as 118.7 t ha−1, A. germinans in French Guiana as 31.5 and 315 t ha−1 and mixed forest of A. germinans in U.S.A as 0.02 and 0.73 t ha−1. The amount of standing biomass stored in mangrove forest is a function of the system's productivity, age and organic matter allocation and exportation strategies. The total AGB is greatly affected by density, BA, and height [38]. In the present study, the AGB of

R. mucronata in Chinnapalam mangrove was estimated as 31.71 t ha−1 at central region and 26.51 t ha−1 at western region. This is close to the AGB of 25.6 t ha−1 for Ile D'Ambre and 13.7 t ha−1for Maconde) and 26.96 t ha−1 and 16.63 t ha−1 at Trou D'eau Douce and Petite Riviere Noire (Island of Mauritius), respectively. Comparative study has been carried out in Kenya where a high AGB of 244 t ha−1 was reported. Similarly, in Japan, an AGB of 108.1 t ha−1 in a mangrove stand dominated by R. mucronata [38]. According to the previous study the AGB of mangrove forests was less than 100 t ha−1 which is mostly secondary forests or concession areas.

Mangroves act as a carbon receiver or storehouse in the biosphere. The method of total carbon stock of AGB was evaluated by adding the carbon content of stems, branches and leaves of the tree. Estimation of carbon is hardly possible in such cases; hence it is appreciated to estimate approximately 50% of the dry matter and generally scientist assumed the range of carbon value to be 50% of dry biomass [39]. In the Chinnapalam mangrove, the above ground carbon content (AGCC) of A. marina biomass was ranged from 9.14 to 6.97 t ha−1 and 15.85 to13.26 t ha−1 for R. mucronata at central and western regions respectively. The total area of mangroves was occupied in the year 2000 as 137,760 km2 in tropical and sub-tropical regions of the world. The average rate of wood production is 12.08 t ha–1yr–1, which is equivalent to a global estimate of 0.16 Pg C/yr stored in mangrove biomass. The net ecosystem production in mangroves was about 0.18 Pg C/yr [10]. It was estimated that mangroves sequester approximately 25.5 million tonnes of carbon every year. Mangroves sequester approximately 1.5 metric tons/hectare/yr of carbon or 3.7 lbs/acre/day (1336 lbs/acre/yr) of carbon. Almost 225,000 metric tons of carbon sequestration potential is lost each year with current rates of mangrove destruction. Disturbed mangrove soils release greater than an additional 11 million metric tons of carbon annually.

Conclusion

It is concluded from the present finding that, the level of carbon sequestration rate varied between the mangroves with spatial temporal patterns. The maximum level of sequested carbon was calculated for A. marina and R. mucronata. There is no previous study available relevant to carbon storage and this is the first of its kind study of carbon level in Chinnapalam mangrove. Hence, the distribution of mangrove species is distinct in the entire study area. Restoration of Chinnapalam mangrove will improve the maximum level of carbon storage and also other benefits includes providing habitat and nurseries for many finfish and shell species, increase the aquatic biodiversity and livelihood for local fishermen by collecting crabs and catching both finfish and shellfish fingerlings for aquaculture purpose.

Conflict of interest

Authors do not have any conflict of interest to declare.

References

1. Alongi DM, Mukhopadhyay SK. Contribution of mangroves to coastal carbon cycling in low latitude seas, Agric For Meteorol,2015:213:266-272.
2. Alongi DM. The impact of climate change on mangrove forests, Curr Clim Change Rep,2015:1(1)30-39. https://doi. org/10.1007/s40641-015-0002-x.
3. McKee KL, Cahoon DR, Feller IC. Caribbean mangroves adjust to rising sea level through biotic controls on change in soil elevation, Glob Ecol Biogeogr,2007:16 (5):545-556.
4. Cooray PLIGM, Jayawardana BD, Gunathilake TM, Pupulewatte PGH. Characteristics of tropical mangrove soils and relationships with forest structural attributes in

the northern coast of Sri Lanka, Reg Stud Mar Sci,2021:44:101741.
5. Mitra A, Ecosystem services of mangroves: An overview, In Mangrove forests in India, (Springer, Cham), 2020.
6. Doughty CL, Langley JA, Walker WS, Feller IC, Schaub R *et al*. Mangrove range expansion rapidly increases coastal wetland carbon storage, Estuaries and Coast,2016:39(2):385-396.
7. Costanza R, De Groot R, Sutton P, Van der Ploeg S, Anderson SJ *et al*. (Changes in the global value of ecosystem services, Glob Environ Change,2014:26(1):152-158.
8. Valiela I, Bowen JL, York JK. Mangrove forests: One of the world's threatened major tropical environments, Bioscience,2001:51(10):807-815.
9. Kirui B, Kairo JG Karachi M. Allometric Equations for estimating aboveground biomass of Rhizophora mucronata (L.) (Rhizophoraceae) Mangroves at Gazi Bay, Keny, West Indian Ocean J Mar Sci,2006:5(1):27–34.
10. Ong JE. Mangroves - a carbon source and sink, Chemosphere,1993:27(6):1097-1107.
11. Murray B, Pendleton L, Jenkins W, Sifleet S. Green payments for blue carbon: economic incentives for protecting threatened coastal habitats. Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC, 2011.
12. Komiyama A, Ong JE, Poungparn S. Allometry, biomass, and productivity of mangrove forests, A review, Aquat Bot,2008:89(2):128-137.
13. Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS *et al*. Improved allometric models to estimate the aboveground biomass of tropical trees, Glob Chang Biol,2014:20(10):3177-3190.
14. Soares MLG, Schaeffer-Novelli Y. Above-ground biomass of mangrove species. I. Analysis of models, Estuar Coast Shelf Sci,2005:65(1-2):1-18.
15. Alongi DM. Present state and future of the world's mangrove forests. Environ Conserv,2002:29(3):331-349.
16. Richards DR, Thompson BS, Wijedasa L. Quantifying net loss of global mangrove carbon stocks from 20 years of land cover change, Nat Commun,2020:11:4260.
17. Adame MF, Connolly RM, Turschwell MP, Lovelock, CE, Fatoyinbo T *et al.* Future carbon emissions from global mangrove forest loss, Glob Chang Biol,2021:27(12):2856-2866.
18. Cameron C, Hutley LB, Friess DA, Brown B. High greenhouse gas emissions mitigation benefits from mangrove rehabilitation in Sulawesi, Indonesi, Ecosyst Serv,2019:40:101035.
19. Kauffman BJ, Arifanti VB, Hernández Trejo H, Jesús García MDC, Norfolk J, *et al*. The jumbo carbon footprint of a shrimp: carbon losses from mangrove deforestation, Front Ecol Environ,2017:15(4):183-188.
20. Thangaradjou T, Sridhar R, Senthilkumar S, Kannan S. Seagrass resource assessment in the mandapam coast of the Gulf of mannar biosphere reserve, India, 2007.
21. Marichamy R. Culture of fin fishes along the coast of Tamil Nadu, Marine Fisheries Information Service,1987:75:5-11.
22. Prasanna J, Seshapriya Ve, Anand M, Kumaraguru AK, Rangesh K. Biodiversity assessment of crabs, gastropods and bivalves in Chinnapalam creek, of the southeast coast of India, Indian J Geo-Mar Sci,2017:46(09):1751-1757.
23. Prasanna J, Anand M, Vijayasekaran D, Kumaraguru A. Allometric model for estimating aboveground biomass and carbon storage in Karankadu mangrove swamp, Palk bay, Southeast coast of India, Indian J Geo-Mar Sci,2017:46(08):1682-1692.
24. Mitra A, Sengupta K, Banerjee K. Standing biomass and carbon storage of above ground structures in dominant mangrove trees in the Sundarbans, For Ecol Manag,2011:261(7):1325-1335.
25. Chidumaya EN. Aboveground woody biomass structure and productivity in a Zambezian woodland. For Ecol Manag,1990:36 (1):33-46.
26. Husch B, Miller CJ, Beers TW. Forest mensuration, Ronald Press, New York, 1982, 474.
27. Newbould PJ. Methods for estimating the primary production of forests, (IBP Blackwell Scientific Publication-U K), 1967, 60.
28. Lal R. Soil carbon sequestration impacts on global climate change and food security, Science,2004:304(5677):1623–1627.
29. Jandl R, Lindner M, Vesterdal L. How strongly can forest management influence soil carbon sequestration? Geoderma,2007:137(3-4):253-268.
30. Berg B, McClaugherty C. Plant litter: decomposition, humus formation, carbon sequestration, (Springer Nature-Cham), 2020.
31. Brunig EF. Structure and Growth. In Ecosystems of the World 14A, Tropical Rain Forest Ecosystems Structure and Function, edited by F B Golley (Elsevier, New York) 1983, 49-75.
32. Cannell MGR. Woody biomass of forest stands, For Ecol Manag,1984:8(3-4):299-312.
33. Tam NFY, Wong YS, Lan CY, Chen GZ. Community structure and standing crop biomass of a mangrove forest in Futian Nature Reserve, Shenzhen, China, Hydrobiologia,1995:295(1):193–201.
34. Kathiresan K, Bingham BL. Biology of mangroves and mangrove ecosystem,2001:12:81-251.
35. Smith TJ, Whelan KRT. Development of allometric relations for three mangrove species in South Florida for use in the Greater Everglades Ecosystem restoration, Wetl Ecol Manag,2006:14(5):409-419.
36. Baowen L, Songfa Z, Yunjun C, Mei L, Yide L. Biolofical characteristics and ecological adaptability for non-indigenous manfrove species Sonneratia apetala, Chinese J Ecol,2004:23(1):10-5.
37. Mackey AP. Biomass of the mangrove Avicennia marina (Forsk.) Vierh. near Brisbane, south-eastern Queensland, Mar. Freshw. Res,1993:44(5):721-5.
38. Suzuki E Tagawa H. Biomass of a mangrove forest and a sedge marsh on Ishigaki Island, South Japan, Jpn J Ecol,1983:33(2):231–234.
39. Losi CJ, Siccama TG, Condit R, Morales JE. Analysis of alternative methods for estimating carbon stock in young tropical plantations, For Ecol Manag,2003:184 (1-3):355-368.