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Biomass and carbon stocks in two mangrove patches of Chettuva Estuary, south-west coast of India

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Original Article

Abstract

Mangroves support numerous ecosystem services, including fisheries production and nutrient cycling. The role of mangroves in mitigating climate change is also well known. In the present study, the biomass and carbon sequestration potential of two dense mangrove patches located in the Chettuva estuary, south-west coast of India were assessed. The carbon stocks of above-ground biomass, root biomass and that of sediment were estimated as 325.36±54.33 t C ha^{-1}, 158.33±25.41 t C ha^{-1} and 85.6±9.15 t C ha^{-1} respectively. The overall mean of C-stock in two mangrove patches in the Chettuva estuary was evaluated as 569.3 t C ha^{-1} which is equivalent to 2,089.33 t CO_2 ha^{-1} and the carbon sequestration potential of the study area is estimated as 1,119.68 t C which is equivalent to 4,109.24 t CO_2. The present results suggest that the mangrove patches in Chettuva estuary have a potential to sequester and store substantial amounts of atmospheric carbon and hence it is necessary to protect this mangrove ecosystem for climate change mitigation and sustainable management.

Keywords*: Biomass, carbon stocks, carbon sequestration, mangroves, Chettuva*

Introduction

Mangroves are salt-tolerant plants of tropical and subtropical intertidal regions of the world. Mangrove ecosystems are highly productive but extremely sensitive. Besides mangroves, the ecosystem harbours a much diversified flora and fauna, which makes it a unique environment. It also acts as a nursery ground for a plethora of commercially important species of fish and shellfishes. The presence of mangrove ecosystems along the coastline saves lives and property during natural hazards such as *tsunami*, cyclones, storms and erosion (Field, 1995).

In recent years, climate change has emerged as a hot environmental issue. Forests including mangroves have the capacity to sequester and store carbon and hence they act as a brake on climate change (FSI, 2017). Mangroves have a potential role in sequestering atmospheric carbon dioxide and to store the carbon in its biomass as well as in soil (Murdiyarso *et al.*, 2009; Chen *et al.*, 2012; Kauffman and Donata, 2012). Although only 0.7% of tropical forests of the world is contributed by the mangrove forests (Giri *et al.*, 2011), they have the potential to store up to 20 billion t C, which is much higher than the mean carbon stock in tropical upland, temperate and boreal forests (Donato *et al.*, 2011). Thus, mangroves are among the most carbon-rich forests in the tropics (Donato *et al.*, 2011).

Asia has the largest share of the world's mangrove area. India has a mangrove cover of 4975 sq.km, which is nearly 3.3% of the world's mangrove vegetation and 0.15% of the country's total geographical area (FSI, 2019). Thus, vast areas of mangroves are available in India which can sequester a considerable amount of atmospheric carbon dioxide and store as carbon. In Kerala, mangroves cover an area of 2,502 ha (Vidyasagaran and Madhusoodanan, 2014). The mangrove cover in Thrissur district was 25 ha (Mohanan, 1997) which had shrunken to 5 ha and represented only as relicts at Chettuva (Kumudranjan and Rathindranath, 1999). A few studies on the mangroves of Thrissur district were carried out by Saritha and Tessy (2011), Sreelekshmi *et al.* (2018) and Grinson *et al.* (2019). But, there is no information available so far on carbon sequestration of mangroves in the Chettuva estuary and therefore an attempt was made here to study the biomass and carbon stock of two mangrove patches in the estuary.

Material and methods

Two dense patches of mangroves in Chettuva estuary were selected for the study which forms about 50% of the mangrove area of Chettuva. Other patches are scattered along this estuarine system. The selected patches are uninhabited and too dense so that walking through the mangroves is almost impossible. The present study was carried out during December 2017-April 2018. The two patches selected for the study are Islands in the estuary and the sampling stations are shown in Fig. 1.

Patch I is of 2.53 acres and Patch II has an area of 2.33 acres. These two patches are separated by a small canal. Three sampling plots/stations were selected at random from each patch and quadrats of size 10 m x 10 m were laid in each station to determine the species composition of mangroves, tree density and carbon stock by adopting a non-destructive sampling procedure. The geo-location of each sampling site was recorded and is given in Table 1.

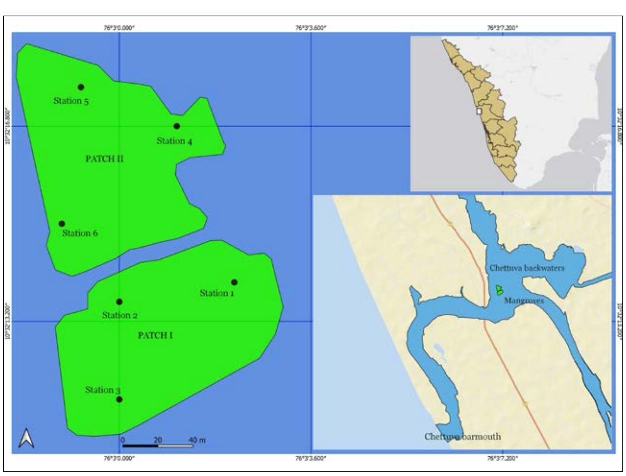

Fig. 1. Map showing sampling stations in Chettuva Estuary

Table 1. Geo-locations of study sites

	Stations	Geolocations
Patch I	1	10°32′14.44″N; 76°03′02.07″E
	2	10°32′13.56″N; 76°02′60″E
	3	10°32′11.76″N; 76°02′60″E
Patch II	4	10°32′16.8″N; 76°03′1.08″E
	5	10°32′17.52″N; 76°02′59.28″E
	6	10°32′15.00″N; 76°02′58.92″E

The mangrove trees in these patches were predominantly *Rhizophora mucronata* except at station 6 of Patch II, where a few trees of *Bruguiera cylindrica* were also present. The mangrove trees in each plot (station) were measured for their girth at breast height (GBH). In the case of *Rhizophora mucronata,* which is characterized by the presence of prop roots, the girth was measured at 30 cm above the highest prop root (Komiyama *et al.*, 2005) while, in the case of *Bruguiera cylindrica,* the GBH was measured at approximately 1.3 m above the ground and by dividing girth at breast height by π, diameter at breast height (DBH) was calculated (Frontier Madagascar, 2005). Then, the above-ground biomass (AGB) and below-ground (root) biomasses were calculated using the allometric equations developed by Komiyama *et al.* (2005):

$$W_{top} = 0.251\rho D^{2.46}$$

$$W_R = 0.199\rho^{0.899}D^{2.22}$$

where, W_{top} is the above-ground biomass in kg,

W_R is the below-ground (root) biomass in kg,

ρ is the wood density of the respective mangrove species and

D is the diameter at breast height (DBH)

The wood density of different mangrove species available in the World Agroforestry Database (WFC, 2019) was used for the above calculations. The above- ground biomass and below-ground biomass were calculated for each station and by adding these two, the total biomass was estimated and the values were converted to tonnes per hectare. The carbon values were estimated as 50% of the biomass (Komiyama *et al.*, 2005).

The soil samples were collected from each sampling station by using a PVC core sampler having a length of 1 m and a diameter of 5 cm. Soil from the surface to 30 cm depth was taken. Two core samples were taken simultaneously from each plot and were stored in separate clean polythene bags. One sample was used for estimating the sediment bulk density and the other for determining organic carbon. The bulk density was calculated by dividing the dry weight (oven dried) of the core sample by the volume of core. The organic carbon was estimated following the method of Walkley and Black (1934). The soil organic carbon per hectare was calculated using the following formula:

Soil organic carbon (tonnes per hectare) = Bulk density (g/cm^3) x Soil depth (cm) x Organic carbon (%)

Results and discussion

The tree density, diameter at breast height (DBH), biomass and carbon stock of mangrove trees along with sediment carbon stock of each sampling station in the two patches of thick mangrove vegetation in the Chettuva estuary were assessed and the same is presented below.

Tree density and diameter at breast height (DBH)

The number of stems varied from 104 per 100 m^2 at station 6 in Patch II to 298 per 100 m^2 at station 3 in Patch I (Fig. 2). The tree density was found to be more in Patch I (237 numbers per 100 m^2) than in Patch II (155 numbers per 100 m^2) and an average of 196 numbers per 100 m^2 (19,600 nos. per ha) was noticed from the study area. A tree density of upto 23,751 trees per ha noticed by Joshi and Ghose (2014) from Lothian Island of Sundarbans and that reported (upto 32,140 trees/ha) by Das *et al.* (2014) from Andaman were very much higher than that of the present work. But the tree density reported from Kadalundi wetland (1,300 trees/ha) by Vinod *et al.* (2018) and that recorded by Rani *et al.* (2016) from Cochin estuary (7680 -11760 trees/ha) were lower than that of the present study. The high tree density in the present study might be due to the presence of thick mangrove vegetation, predominantly by *R. mucronata* in the study area. In mangrove forests where species other than *R. mucronata* are present, the vegetation may not be very dense as the individual trees are found to grow a little apart which would result in lesser tree density. In mangrove areas which are wholly or predominantly occupied by *R. mucronata* trees, it is found that this species forms very dense vegetation, with each individual tree having about five to ten branches or even more. Also, the present study area is uninhabited and a comparatively less human interference has favoured lush growth of mangroves. Also, regular visits of the government officials for periodic monitoring have helped in the protection of these mangroves.

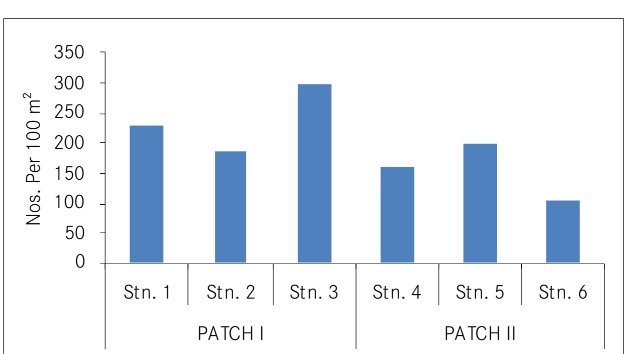

Fig. 2. Station wise tree density in the selected mangrove patches

The station wise mean values of DBH of *R. mucronata* was found to be the minimum at station 1 of Patch I (6.37 cm) and it was maximum (8.81 cm) at both station2 of Patch I and station 5 of patch II (Fig.3). Average diameter at breast height of mangrove trees in patch II (7.81 cm) was higher than that of patch I (7.45 cm) and an overall mean DBH of 7.63 cm was recorded for *R. mucronata* in the study area. The mean DBH of *B. cylindrica* was found to be 6.05 cm which is less than that of *R. mucronata.* The DBH differ greatly in different mangrove areas. Vinod *et al.* (2018) recorded 5.61±2.15 cm for *R.mucronata* in Kadalundi wetlands while the mean DBH observed for the same species was 39.5 cm in Philippines (Azyleah *et al.*, 2014). The variation in DBH for the same species in different geographical locations may be mostly due to the difference in age of the trees.

Biomass and Carbon stock

The biomass and carbon stocks of mangroves in different stations are given in Table 2. The above-ground biomass (AGB) ranged from 353.4 - 923.94 t/ha among different stations with an overall mean of 650.73±108.66 t/ha in the study area. In another study, Azyleah *et al.* (2014) found that the AGB ranged from 210.6 to 1,190.6 t/ha with a mean of 561.2 t/ha from Philippines which is comparable with the values of the present study but on the contrary the values recorded in this study were found much higher than *Rhizophora apiculata* dominated forest (460 t/ha) in Malaysia (Putz and Chan, 1986), mangrove wetland (166.63t/ha) of Kadalundi (Vinod *et al.*, 2018) and

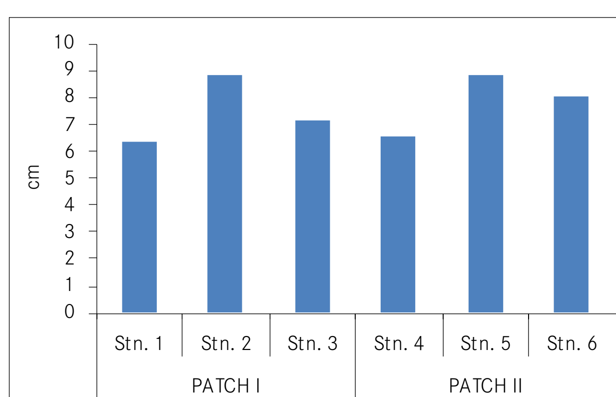

Fig.3. Station wise DBH of *R. mucronata* in the study area

similarly mangroves (159 t/ha) of Thailand (Christisen, 1978). Thus, it is evident that the biomass varies greatly with region. The factors influencing the biomass are tree density, species composition, growth forms, tree height, stem diameter and age of the mangroves (Lugo and Snedaker, 1974; Woodroffe, 1985; Knox, 1986). The mangrove patches in Chettuva are very dense with least anthropogenic interventions. The above-ground carbon stock during the present study varied from 176.7 - 461.97 t/ha with an overall mean of 325.36±54.33 t/ha while a mean of 263.8 t C per ha was reported from Philippines (Azyleah *et al.*, 2014) which is less than that of the present study.

The below-ground (root) biomass of mangroves varied from 171.89 t/ha at station 6 to 438.93 t/ha at station 5, with an overall mean of 316.67±50.81 t/ha in the study area while Azyleah *et al.* (2014) reported root biomass which varied from 80.4 to 388 t/ha from Philippines. Kauffman *et al.* (2011) recorded 312±52 t/ha as the below-ground tree biomass at Yap site of Micronesian mangrove forests which is in agreement with the present study. The below-ground carbon ranged from 85.94 - 219.47 t/ha with an overall mean of 158.33±25.41 t/ha which is more than that of a natural mangrove forest (92.3 t C per ha) in Philippines (Azyleah *et al.*, 2014).

The total biomass in different stations was obtained by adding the above-ground and below-ground biomasses of the respective stations (Table 2). Thus, the total biomass varied from 525.29 t/ha in station 6 to 1,362.87 t/ha in station 5. The mean total biomass and carbon stock of mangroves in the study area were found to be 967.39±159.43 t/ha and 483.7±79.71 t/ha respectively. This was equivalent to 1,775.22 t CO_2 per ha which was sequestered and stored in the mangroves of this area. In Bahile mangrove forest of Philippines, a total biomass of 757.7 t/ha ranging from 291 to 1,578.6 t/ha was recorded (Azyleah *et al.*, 2014). The very high biomass and stored carbon in mangrove patches in the Chettuva estuary can be due to high wood density.

The ratio of the above-ground biomass (T) and below-ground biomass (R), represented as T/R ranged from 1.96 to 2.10 with an overall mean of 2.05. This is consistent with the values reported (varies from 2 to 2.6 with an average of 2.3) by Sahu *et al.* (2016). It is a general feature of mangrove forests to have lower T/R ratio than upland forests for better adaptation to stand upright in wet and soft mud conditions (Sahu *et al.*, 2016). Of the total biomass, 67.27% comprised of above-ground and the rest of 32.73% was below ground or root biomass in the study area, while it was 74% and 26% respectively in mangrove forest of Philippines (Azyleah *et al.*, 2014). The lower percentage of AGB during this study can be due to the lower tree girth when compared to that recorded by Azyleah *et al.* (2014).

Soil Carbon stock

The bulk density and organic carbon of soil in the upper 30 cm depth zone in different stations of the study area is given in Table 3. The mean bulk density and percentage organic carbon of soil were found to be 0.88±0.05 g/cm^3 and 3.30±0.42 respectively. The soil organic carbon varied from 65.66 to 117.82 t/ha in different stations with an overall mean of 85.60±9.15 t/ha in the study area. The mean soil organic carbon values estimated in this study were found much higher than the values (63.87±8.67 t/ha) reported from Kadalundi mangrove wetland by Vinod *et al.* (2018) and by Sahu *et al.* (2016) from Mahanadi mangrove wetland, east coast of India (57.6±11.1 t C per ha). Gnanamoorthy *et al.* (2019) reported an average soil

Table 2. Biomass and carbon stock of mangroves in different stations in the study area

Patches	Stations	Above-ground		Below-ground		Total	
		Biomass (t/ha)	Carbon (t/ha)	Biomass (t/ha)	Carbon (t/ha)	Biomass (t/ha)	Carbon (t/ha)
PATCH I	1	489.16	244.58	249.35	124.67	738.51	369.26
	2	850.81	425.40	405.15	202.58	1255.96	627.98
	3	893.46	446.73	438.15	219.08	1331.61	665.80
Mean		744.47	372.24	364.22	182.11	1108.69	554.35
SE		128.25	64.12	58.22	29.11	186.37	93.19
PATCH II	4	393.60	196.80	196.53	98.27	590.13	295.07
	5	923.94	461.97	438.93	219.47	1362.87	681.44
	6	353.40	176.70	171.89	85.94	525.29	262.65
Mean		556.98	278.49	269.12	134.56	826.10	413.05
SE		183.85	91.92	85.21	42.60	269.04	134.52
Overall mean		650.73	325.36	316.67	158.33	967.39	483.70
Standard Error		108.66	54.33	50.81	25.41	159.43	79.71

Table 3. Soil organic carbon of different stations in the study area

Patches	Stations	Bulk density (g/cm³)	Percentage soil organic carbon	Soil organic carbon (t/ha)
PATCH I	1	0.79	3.05	72.31
	2	1.04	2.49	77.33
	3	0.71	5.14	110.13
Mean		0.85	3.56	86.59
SE		0.10	0.81	11.86
PATCH II	4	1.02	3.85	117.82
	5	0.81	2.69	65.66
	6	0.90	2.60	70.38
Mean		0.91	3.05	84.62
SE		0.06	0.40	16.66
Overall Mean		0.88	3.30	85.60
SE		0.05	0.42	9.15

organic carbon stock in the range of 57.41 - 146.1 t C per ha from Pichavaram mangrove forests in the south-east coast of India which is comparable with that of the present study.

Total Carbon stock

The biomass, C-stock and CO_2 equivalent of above-ground, below-ground (root) and soil are shown in Fig. 4. The total C-stocks in the study area was estimated as 569.3 t C per ha of which above-ground, below-ground (root) and soil were 325.36, 158.33 and 85.6 t C per ha respectively. These C-stocks were equivalent to a total of 2,089.33 t CO_2 per ha of which above-ground was 1,194.08 t CO_2 per ha, below-ground (root) was 581.08 t CO_2 per ha and that of soil was 314.16 t CO_2 per ha which can be sequestered and stored in the selected mangrove patches in Chettuva estuary. Of the total C-stocks in the study area, above-ground contributed to the maximum of 57.15%, followed by below-ground (27.81%) and the minimum of 15.04% was contributed by soil. The overall mean ecosystem C stock in a tropical mangrove forest in Vietnam was reported as 762.2 ± 57.2 t C per ha (Tue *et al*., 2014), in a broad area of mangroves in Indo-Pacific region as 1,023 t C per ha (Donato *et al*., 2011) and that from mangrove forests of Palau (718 t/ha) and Yap (1,062 t/ha) sites of Micronesian mangrove forests (Kauffman *et al*., 2011) are much higher than that of the present study. Yet another study by Azyleah *et al.* (2014) recorded a total C - stock of 529.9 t C per ha which is comparable with the values obtained in the present study but it was found higher than the values estimated by other researchers from different estuaries in Indian coastal waters (Vinod *et al*., 2018, 2019 from Kerala, south west coast of India; Sahu *et al*., 2016 from Mahanadi mangrove wetland, east coast of India).

The mangrove patches in Chettuva estuary cover an area of 1.9668 ha and the carbon sequestration potential of the study area is estimated as 1,119.68 t C. This is equivalent to 4,109.24 t CO_2. The social cost of carbon (SCC) is US dollar 220 per ton of CO_2 (Moore and Diaz, 2015) which is equivalent to ₹ 16,198.6 per ton. Thus, the SCC of the two mangrove patches in Chettuva estuary selected for the study is ₹ 66.56 million. It is therefore assumed that these mangrove patches can store a substantial amount of carbon apart from other ecosystem services and hence it is necessary to preserve this important mangrove ecosystem to mitigate the impacts of climate change.

The enormous carbon sequestration and storage ability of mangrove ecosystems as evident from the present study as well as from the studies carried out elsewhere across the global distributional range of mangroves, signifies the importance of conservation of these blue carbon ecosystems. The reduction in mangrove area would result in loss of potential carbon sinks and the destruction of mangrove forests might lead to greater CO_2 emissions back in the air and ocean, which is more

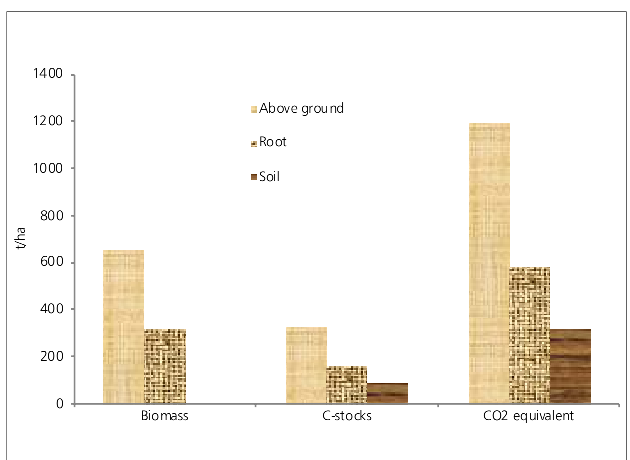

Fig.4. Biomass, C-stocks and CO_2 equivalent potential of the study area

deleterious from the point of global climate change. According to the Intergovernmental Panel on Climate Change (IPCC), carbon sequestration by forests and agriculture can significantly help offset CO_2 emissions that contribute to global warming. Information on carbon sequestration potential of forests including mangroves is pertinent in the present context of carbon trading. India is fast emerging as one of the potential sellers of carbon credits. Therefore, conservation of existing mangroves and rejuvenation of mangroves in degraded areas would help in greater carbon sequestration and storage, which would help in earning more carbon credits.

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References

Azyleah C. Abino, Jose Alan A. Castillo and Young Jin Lee. 2014. Species diversity, biomass and carbon stock assessments of a natural mangrove forest in Palawan, Philippines. *Pak. J. Bot.*, 46 (6): 1955-1962.

Chen, L., X. Zeng, N. F. Y. Tam, W. Lu, Z. Luo, X. Du and J. Wang. 2012. Comparing carbon sequestration and stand structure of monoculture and mixed mangrove plantations of *Sonneratia caseolaris* and *S. apetala* in southern China. *For. Ecol. Manage.*, 284: 222-229.

Christisen, B. 1978. Biomass and primary production of *Rhizophora apiculata* B1. in a mangrove in Southern Thailand. *Aquat. Bot.*, 4: 43-52.

Das, A. K., D. K. Jha, M. Prashanthi Devi, B. K. Sahu, N. V. Vinithkumar, R. Kirubagaran. 2014. Post tsunami mangrove evaluation in coastal vicinity of Andaman Islands, India. *J. Coast. Conserv.*, 18: 249-255. https://doi.org/10.1007/s11852-014-0312-5

Donato, D. C., J. Boone Kauffman, D. Murdiyarso, S. Kurnianto, M. Stidham and M. Kanninen. 2011. Mangroves among the most carbon-rich forests in the tropics. *Nature Geosci.*, 4: 293-297.

Field, C. D. 1995. Impact of expected climate change on mangroves. *Hydrobiologia*, 295:75-81.

Frontier Madagascar. 2005. A field manual for survey methods in tropical marine ecosystems. Biddick, K., Brown, L.F., Markham, K., Mayhew, E.M., Robertson, A. and Smith, V. (eds.). Frontier Madagascar Environmental Research Report 17. Society for Environmental Exploration, UK.

FSI. 2017. *India State of Forest Report 2017.* Forest Survey of India (Ministry of Environment, Forest & Climate Change), Dehradun, India.

FSI. 2019. *India State of Forest Report 2019.* Forest Survey of India (Ministry of Environment, Forest & Climate Change), Dehradun, India.

Giri, C., E. Ochieng, L. L. Tieszen, Z. Zhu, A. Singh, T. Loveland, J. Masek and N. Duke. 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. *Glob. Ecol. Biogeogr.*, 20: 154-159.

Gnanamoorthy, P., V. Selvam, R. Ramasubramanian, S. Chakraborty, D. Pramit and A. Karipot. 2019. Soil organic carbon stock in natural and restored mangrove forests in Pichavaram, south-east coast of India. *Indian J. Mar. Sci.,* 48 (5): 801 - 808.

Grinson George, P. Krishnan, K. G. Mini, S. S. Salim, P. Ragavan, S. Y. Tenjing, R. Muruganandam, S. K. Dubey, A. Gopalakrishnan, R. Purvaja and R. Ramesh. 2019. Structure and regeneration status of mangrove patches along the estuarine and coastal stretches of Kerala, India. *J. For. Res.*, 30 (2): 507 - 518.

Joshi, H. G. and M. Ghose. 2014. Community structure, species diversity and aboveground biomass of the Sundarbans mangrove swamps. *Trop. Ecol.*, 55 (3): 283 - 303.

Kauffman, J. B. and D. C. Donato. 2012. Protocols for the measurement, monitoring and reporting of structure, biomass and carbon stocks in mangrove forests. Working Paper 86, CIFOR, Bogor, Indonesia. 40 pp.

Kauffman, J. B., C. Heider, T. G. Cole, K. A. Dwire and D. C. Donato. 2011. Ecosystem carbon stocks of Micronesian mangrove forests. *Wetlands*, 31: 343-352.

Knox, G. A. 1986. *Estuarine ecosystems: A system approach*. vol. I, CRC Press, Florida.

Komiyama, A., S. Poungparn and S. Kato. 2005. Common allometric equations for estimating the tree height of mangroves. *J. Trop. Ecol.*, 21: 471-477.

Kumudranjan, N. and M. Rathindranath. 1999. Ecology and Biodiversity of Indian Mangroves. Part I-Global Status. Daya Publishing House, Delhi. p. 163-167.

Lugo, A. E. and S. C. Snedaker. 1974. The ecology of mangroves. *Ann. Rev. Ecol. Syst.*, 5: 39-64.

Mohanan, C. N. 1997. Mangroves. In: T. Balachandran, N. M. Nayar and C. S. Nair (Eds.) *The Natural Resources of Kerala.* WWF, Trivandrum, Kerala, India. p. 149-158.

Moore, F. C. and D. B. Diaz. 2015. Temperature impacts on economic growth warrant stringent mitigation policy. *Nat. Clim. Change*, 5: 127-131.

Murdiyarso, D., D. Donato, J. B. Kauffman, S. Kurnianto, M. Stidham and M. Kanninen. 2009. Carbon storage in mangrove and peatland ecosystems in Indonesia - a preliminary account from plots in Indonesia. Working Paper 48, Center for International Forestry Research, Bogor, Indonesia, 35 pp.

Putz, Francis E. and H. T. Chan. 1986. Tree growth, dynamics and productivity in a mature mangrove forest in Malaysia. *Forest Ecol. Manag.*, 17 (2-3): 211-230

Rani, V., S. Sreelekshmi, C. V. Asha and S. Bijoy Nandan. 2016. Forest structure and community composition of Cochin mangroves, south-west coast of India. *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.,* 88 (1). doi: 10.1007/s40011-016-0738-7.

Sahu, S. C., Manish Kumar and N. H. Ravindranath. 2016. Carbon stocks in natural and planted mangrove forests of Mahanadi Mangrove Wetland, East coast of India. *Curr. Sci.*, 110(12): 2253-2260.

Saritha, M. K. and P. P. Tessy. 2011. Mangroves of Poyya backwaters of Thrissur district, Kerala, India. *J. Mar. Biol. Ass. India,* 53 (1): 8-13.

Sreelekshmi S., C. M. Preethy, Rani Varghese, Philomina Joseph, C. V. Asha, S. B. Nandan and C. K. Radhakrishnan. 2018. Diversity, stand structure and zonation pattern of mangroves in southwest coast of India. *J. Asia. Pac. Biodivers.,* 11: 573 - 582.

Tue, N. T., V. D. Luu, T. N. Mai and K. Omori. 2014. Carbon storage of a tropical mangrove forest in Mui Ca Mau National Park, Vietnam. *Catena*, 121: 119 - 126.

Vidyasagaran K. and V. K. Madhusoodanan. 2014. Distribution and plant diversity of mangroves in the west coast of Kerala, India. *J. Bio. & Env. Sci.*, 4(5):38-45.

Vinod, K., A. Anasu Koya, V. A. Kunhi Koya, P. G. Silpa, P. K. Asokan, P. U. Zacharia and K. K. Joshi. 2018. Biomass and carbon stocks in mangrove stands of Kadalundi estuarine wetland, south-west coast of India. *Indian J. Fish.*, 65 (2): 89 - 99.

Vinod, K., P. K. Asokan, P. U. Zacharia, C. P. Ansar, G. Vijayan, A. Anasukoya, V. A. Kunhikoya and M. Nikhiljith. 2019. Assessment of biomass and carbon stocks in mangroves of Thalassery estuarine wetland of Kerala, south west coast of India. *J. Coast. Res.,* 86 (spl.): 209 - 217.

Walkley, A. and I. A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.*, 37: 29-37.

Woodroffe, C. D. 1985. Studies of a mangrove basin, Tuff Crater, New Zealand. I: mangrove biomass and production of detritus. *Estuar. Coast. Shelf. Sci.*, 20: 265-280.

WFC. 2019. World Agroforestry Database. World Agroforestry Centre, Nairobi, Kenya. http://www.worldagroforestrycentre.org/our_products/databases (Accessed 17th September, 2019).