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Tree Diversity and Carbon Sequestration Potential of An Urban Forest Patch of Pondicherry, India

Swapna S Khadanga and Shanmuganathan Jayakumar*

Environmental Informatics and Spatial Modeling Lab (EISML), Department of Ecology and Environmental Sciences, School of Life Sciences, Pondicherry University, Puducherry, India
*Email: * s.jkumar1@gmail.com, jayakumar.eco@pondiuni.edu.in*

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ABSTRACT

Urban forests undoubtedly play a foremost role in mitigating the climate change impacts, also contributes to the quality of urban society thereby providing numerous environmental, ecological, psychological and socio-ecological benefits. Particularly knowing any forest's structure, function and value head from its inventory of diversity and richness. So to better understand the above mentioned and their ecosystem service, a work has been conducted in the urban forest patch of Puducherry. Keeping the importance of urban forest patch in a study to access the tree diversity, biomass and carbon stock of the urban forest patch of Puducherry, India has been undertaken. For quantitative assessment, an area of 1 hectare comprising, 25 plots of 20×20m was studied and all trees ≥ 10 cm gbh were enumerated. As a whole, 30 tree species were enumerated belonging to 17 families and 30 genera. Tree number accounted for 586 stems per hectare, the basal area was found to be 34.273 m^2ha^{-1}. The total biomass and carbon stock of the patch were found to be 278.22$Mgha^{-1}$ and 139.11$MgCha^{-1}$ respectively. This baseline study will further be used to analyze its various components and its ecosystem services, inspiring for its better management.

Key Words:

Biomass and Carbon stock; ecosystem services; Puducherry; species diversity; Urban forest.

INTRODUCTION

Large and intact natural habitats are always kept a close eye to preserve their biodiversity. Similarly, there should be an equal effort for preserving isolated small patches of forest in urban areas. The existing remains of urban forest can act similar to our very own “immune system” by conserving biodiversity, removing atmospheric pollutants, generating oxygen, reducing noise, mitigating urban heat island effects, regulating microclimate, stabilizing of soil, recharging ground water, preventing soil erosion, and sequestering carbon (Bolund and Hunhammar 1999). Urban forest is the term mainly given to the floristic life form, within the boundary of a city.

The variation in the composition of trees in different urban areas mainly depends on its topographical location and historical background, land area and its population (Detwyler 1972; Grey and Deneke 1986; Miller 1997). Assessing the forest composition is one of the first steps towards understanding tree resources and formulating accurate management plans. Studies have suggested that urban areas are greater bio-diversified, which disproves the age-old perception of urban areas beingalow level of biodiversity (Balmford et al 2001; Jim & Liu 2001; Araujo 2003; Godefroid and Koedam 2003; Cornelis and Hermy 2004; Kuhn et al 2004). This knowledge of thecomposition of species along with its diversity would not only provide an understanding of the structure of the forest community but also give a robust insight for its management by creating conservation strategies (Malik et al. 2014; Malik and Bhatt 2015). The vegetation in the patches harboring native tree species and structural (size, shape, and age) diversity will provide suitable habitat for thefaunal community (Whitford et al. 2001; Chace et al. 2006).

One among the services provided by the forest ecosystem is their potentiality for sequestering atmospheric carbon dioxide (CO_2). Due to an unprecedented increase in anthropogenic activities, urban areas are the top contributor of the atmospheric CO_2 level (Grimm et al 2008; Luna et al. 2016), and the major driver of anthropogenic climate change (IPCC 2007). Hence crucial role is played by urban forest through carbon cycle by sequestering atmospheric CO_2 for mitigating climate change (Moulton and Richards 1990; Nowak and Crane 2002). To better identify the major sources and the sink and gaining knowledge regarding the drivers of variations in natural systems both temporally and spatially; assessment of carbon stock at global and regional scales is essential (Wofsy 2001; Law et al 2004; Houghton 2005). The key carbon pools in tropical forest ecosystems include the woody biomass of trees, lianas and their standing crop of litter (Gibbs et al 2007). A wide array of sources are presently available on forest biomass (e.g. quantitative inventories, the output of ecological models and with the use of remote sensing satellites).However, the better estimates on forest carbon stocks can be obtained by the destructive sampling method. This can be also calculated by Allometric equation (Brown1997; Chave et al 2005) using variables such as diameter, height and wood specific density.

Trees having better growth, the high potential of biomass and carbon stock would be useful for urban forestry for mitigating the increase in carbon dioxide concentration in the atmosphere. Extensive studies have been done in urban forests for their uniqueness and the ecosystem services they provide. Researchers for example have conducted multidimensional studies in the USA (McPherson et al 1994; Nowak and Crane 2002; Pickett et al 2008); Germany (Strohbach and Haase 2012); China (Yang et al 2005; Chen and Jim 2008); Singapore (Liu 1998; Chow and Roth 2006); Malaysia (Sreetheran et al 2006); Thailand (Thaiutsa et al 2008) and Korea (Jo 2002). William Kwadwo (2013) in his research has focussed on Contingent Valuation Method (CVM) for estimating the economic value ofthenon-market benefit of urban forest; whereas Duffe et al (2014) worked with high-resolution aerial photographs for determining the spatial coverage of urban trees in and around Canada. Carbon sequestration potential in the Southern United Stateswas estimated by Merry et al (2015) through Remote sensing imagery sources in Humberg.

In India, there are few studies on urban biodiversity, tree diversity inventory of metropolitan city Delhi was conducted by Goel and Singh (2006), this study also identified and suggested suitable tree species for green area expansion. Sudha and Ravindranath (2000) and Nagendra and Gopal (2010; 2011) have studied on density, diversity, and richness of urban trees in Bangalore city. Qualitative measurement of plant diversity was accomplished by Udayakumar et al (2011) in an academic institution in Chennai city. Kiran and Kinnary (2011) quantified the diversity and biomass storing capacity of trees in Vadodarawhereinthequantitative assessment of aboveground carbon dynamics in the temperate forest of Shimla district was done by Palchowdhury et al (2016).

Puducherry encompasses an area of 492 sq km with Pondicherry town and its villages covering 293sq.km. It is the capital city of Puducherry union territory, situated 160 km away from Chennai to the south and it is on the Coromandel Coast of Bay of Bengal. Puducherry is the third most densely populated state/UT in India, wherein the district Puducherry contributes the maximum. Although literature survey shows a few important study on urban areas in cities of India, there is no available documentation for the present urban forest patch in Puducherry. So the present study aimed at assessing diversity and computing the carbon storage potential of the trees in this urban forest patch which would further improve our present understanding and encourage strategic planning.

MATERIALS AND METHODS

Study area

The Swadeshi Cotton Mill Forest, located in the heart of the Puducherry town, deserves a special consideration for its pristinity it possesses. According to the historical record from the forest department, it is 125-year-old patch of natural forest and is under the control of forest department, Govt. of Pondicherry. It lies between the latitudinal of 11 ° 46'N& 12 ° 13'N and the longitudinal of 79 ° 36'E & 79 ° 53'E on the back of the court complex, occupying an area of 11.2 ha (Fig. 1). It resembles a remnant of tropical dry evergreen forest. The climate of Pondicherry is tropical wet and dry. The temperature ranges from 37 °C to 43°C and it receives mean annual rainfall of 1254.4 mm per annum. The soil types present here are classified as red soil, red sandy, and clay loam.

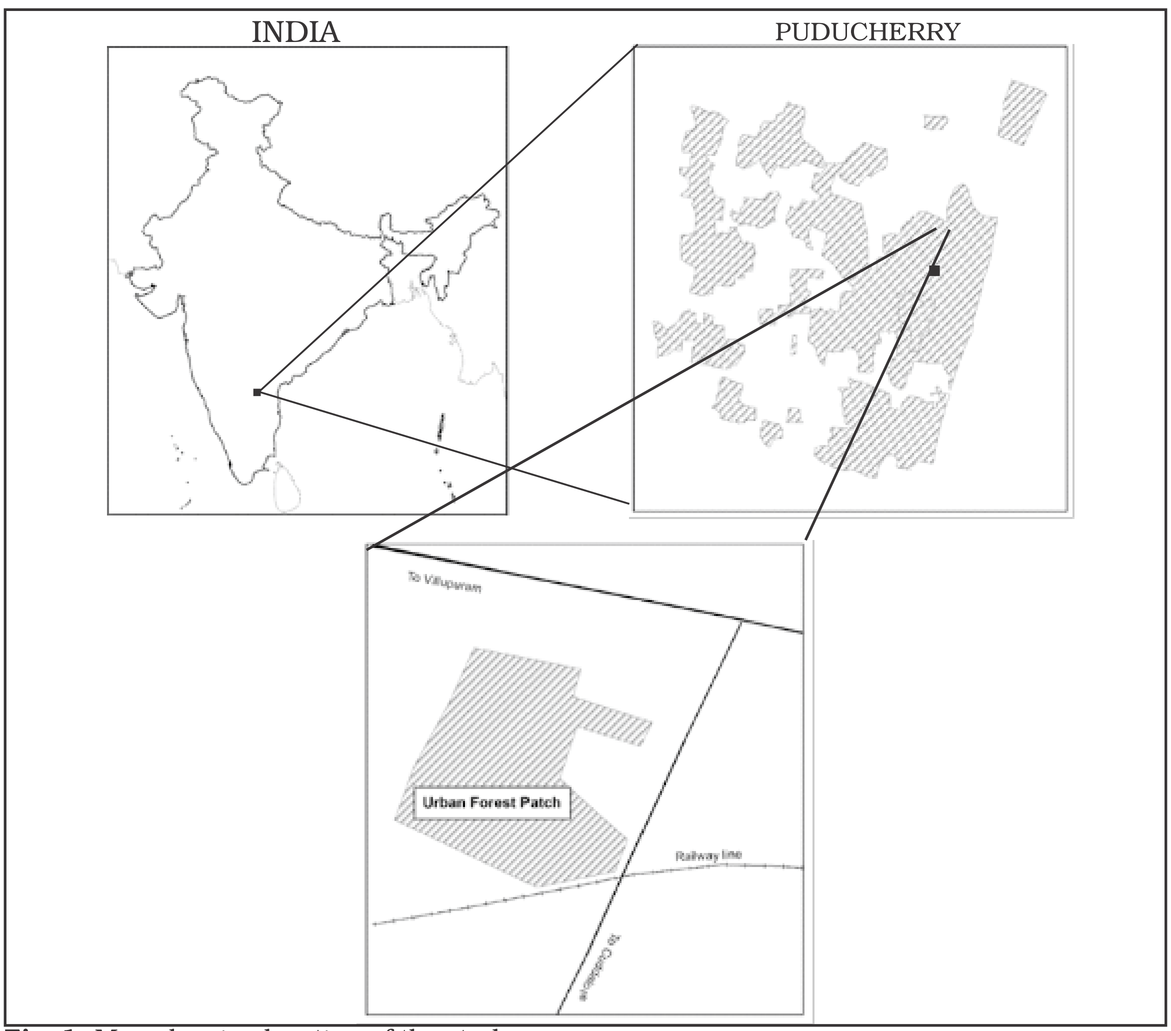

Fig. 1. Map showing location of the study area

Data collection and analysis

For the present study, 25 plots of 20×20 m size were laid randomly throughout the study area. A systematic enumeration of all trees ≥ 10 cm girth at breast height (gbh), measured at 1.3 m height from the ground level was performed. Bole girth was measured separately for themulti-stemmed tree. The tree species were identified to species-level using regional floras (Gamble and Fischer 1915–1935; Matthew 1991). Species diversity indices, Shannon and Simpson were computed (Magurran2004). Basal area was calculated using the formula; $(Dbh)^2 * (\pi/4)$. The various parameters was calculated such as relative density, relative frequency, relative basal area and Important Value Index (IVI).

Biomass estimation was done following the allometric equation of Chave et al (2005). For the estimation of above ground biomass (AGB) and below ground biomass (BGB), diameter and wood specific density were used. The below ground biomass was calculated by multiplying it by 0.26 (Cairns et al 1997 and IPCC 2003). The above ground biomass and below ground biomass were summed up and half of it was taken as the carbon stock (IPCC 2005).

The Allometric equation used is as follow:

$(AGB)_{est}$=p*exp(-0.667+1.784* Ln(D)+0.207*(ln(D))2-0.0281*(ln(D))3)

RESULTS AND DISCUSSION

Tree Diversity

In the present study, a total of 30 tree species were enumerated belonging to 17 families and 30 genera. The list of tree species identified in the present study are given in Table 1 which is comparable to the study conducted in Bhopal (Dwivedi et al 2009), Delhi (Khera 2009), Jaipur (Verma 1985; Dubey and Pandey 1993), Mumbai (Zerah 2007) and Pune (Patwardhan et al 2001), where species diversity were ranged from 30-40 species. Baithalu et al 2012 inventoried 1ha permanent plot of TDEF present in Arasadikuppam, Oorani, Puthupet; India, which resulted in little less species richness (23-29) than from the present site wherein it was found to be lesser than Chennai metropolitan city (Udayakumar and Thangavel 2011). Higher the species diversity, healthier the forest ecosystem is; vice versa also holds true (McPherson and Rowntree 1989; Thaiutsa et al 2008).

Table 1. Tree species diversity and important value index of individual species at urban forest patch of Puducherry, India.

Sl. No.	Species name	Family	No.of Individual	IVI
1	*Adansonia digitata* (L.)	Malvaceae	1	23.56
2	*Albizzia saman* F Muell.	Fabaceae	34	36.63
3	*Allophylus serratus* (Roxb.)Kurz	Sapindacea	29	14.48
4	*Atalantia monophylla* (L.) Correa	Rutaceae	37	11.36
5	*Azadirachta indica*A.Juss.	Meliaceae	39	18.51
6	*Bombax ceiba* (L).	Malvaceae	2	1.51
7	*Butea monosperma* (Lam.) Taubert	Fabaceae	6	1.63
8	*Canthium coromandelicum*Burm.F.	Rubiaceae	3	2.28
9	*Citrus aurantiifolia* (Christm) Swingle	Rutaceae	16	4.51
10	*Cordia oblique* Wild.	Boraginaceae	2	0.93

Sl. No.	Species name	Family	No.of Individual	IVI
11	*Coryphama cropoda* kurt ex Kiden	Arecaeae	5	4.17
12	*Crataeva adansonii* DC.ssp. Odora (Buch.Ham.)M.Jacobs	Capparaceae	5	3.77
13	*Dalbergia paniculate*Roxb.	Fabaceae	1	0.89
14	*Diospyros montana*Roxb.	Ebenaceae	12	5.16
15	*Glyricidia sepium* (Jacq.) Kunth ex Walp	Fabaceae	11	7.03
16	*Ixora pavetta*Andr.	Rubiaceae	7	2.95
17	*Lepisanthestetra phylla* (Vahl.) Radlk.	Sapindacea	20	12.08
18	*Madhuca longifolia* (Koen.)Macbr	Sapotaceaea	14	7.51
19	*Mallotus philippensis*(Lam.) Muell.Arg.	Euphorbiaceae	66	25.26
20	*Millingtonia hortensis*L.f.	Bignoniaceae	4	2.46
21	*Mimus opselengi* L.	Sapotaceaea	15	5.65
22	*Nerium oleander* L.	Apocyanaceae	1	0.76
23	*Peltoforum pterocarpum* (DC.) Baker ex Heyne	Fabaceae	29	19.82
24	*Polyalthia longifolia* (Sonner.)Thw.	Annonaceae	32	11.77
25	*Pongamia pinnata* (L.) Pierre	Fabaceae	21	8.57
26	*Senna siamea* (Lam.) Irwin et Barneby	Fabaceae	25	9.49
27	*Streblus asper* Lour.	Moraceae	104	30.55
28	*Tamarindus indica* L.	Fabaceae	42	24.97
29	*Terminilia chebula* Retz.	Combretaceae	1	0.75
30	*Wrightia tinctoria* (Roxb.) R.Br.	Apocyanaceae	2	0.92

A total of 586 individuals were enumerated which accord with the study conducted by Udayakumar and Sekar (2011) in Chennai metropolitan city where an abundance of 500 individual per hectare was observed. *Streblus asper* was the predominant species with 104 individual. *Mallotus philippensis* was the second dominant species recorded with 66 individual followed by *Tamarindusindica*with 42 individual. These three species together contribute 36.174 % of the total number of individuals. As per Important Value Index is concerned *Albizzias aman* (IVI- 36.63), *Streblus asper*(IVI- 30.55) and *Mallotus philippensis* (IVI- 25.26) were found to be dominant tree species wherein other studies in tropical forests suggest *Terminalia paniculata, Hopea parviflora, Anogeissus latifolia, Lannea coromandelica* and *Tamarindus indica* to have higher IVI (Naidu and Kumar 2016).Present study site possessed common species as of other urban forest in India and other countries. Bangalore urban areas possess *Albizia saman, Cassia fistula, Delonix regia, Polyalthia longifolia, Pongamia pinnata. Peltophorum pterocarpum and Spathodea campanulata* (Nagendra and Gopal 2010, 2011); Delhi recorded *Azadirachta indica, Albizia lebbeck, Bombax ceiba, C. fistula, Ficus religiosa, Mimusopselengi, Tamarindusindica and Ziziphus mauritiana* (Goel and Singh 2006); Aurangabad possess *A. lebbeck, A. indica, C. fistula, D. regia, Ficus. benghalensis, Leucaena latisiliqua, P. pterocarpum, Pithecellobium dulce, P. longifolia, P pinnata and Termanaliaindica* (Chavan and Rasal 2010), which is comparable to the present site. The Shannon Wiener Index(H') value of the study site was computed as 2.96 which is more or less closer to the study conducted in Bangalore (2.68), India (Nagendra and Gopal 2010). Simpson Dominance Index(1-D) value was 0.923 which is well within the range of other tropical dry evergreen forest patch (0.14-3.15) (Anbarashan and Parthasarathy 2013).The Shannon Wiener and Simpson Dominance Index for the present study site showed moderate species diversity and dominance of few species respectively.

The total basal area was estimated to be 34.273 m^2ha^{-1}. The literature available suggests that the basal area of the present site is moderately larger than other urban forests of the world. In present study, *Albizia saman* contributed to the maximum basal area followed by *Adansoniadigitata* (Fig. 2). The stand basal area is more or less comparable to the other Tropical dry evergreen forest of India which ranges from 17.74 to 47.84 m^2 ha^{-1}. (Anbarashan and Parthasarathy 2013). The presence of a good proportion of large trees (*Adansonia digitata and Albizias aman*) along with higher density have resulted in the high basal area in the present site.

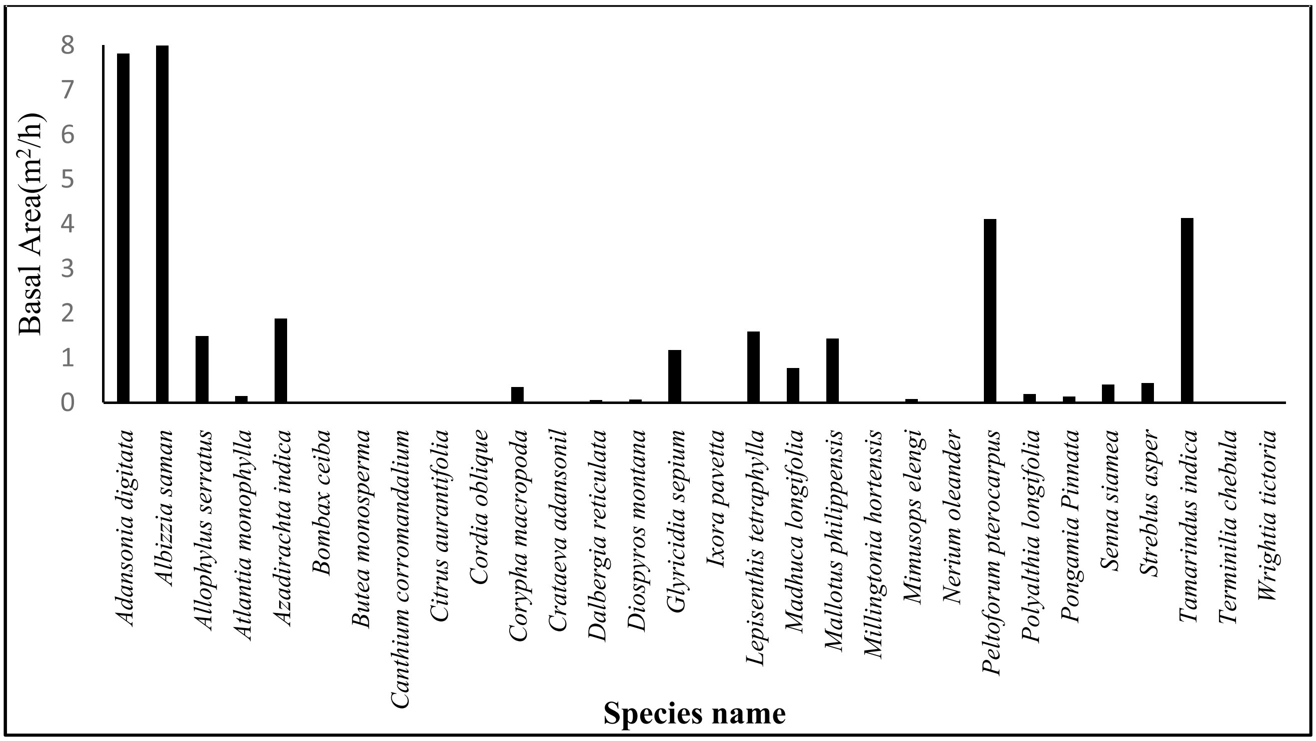

Fig. 2. Comparison of Basal area among individual species at urban forest patch, Puducherry; India.

As similar to other natural forest of Tamil Nadu, urban forest toois dominated by the family Caesalpiniaceae and Fabaceae (Gamble and Fischer 1915–35).The maximum number of species were contributed in our study site is also by Fabaceae (8 species), followed by Bombacaceae, Rutaceae, Rubiaceae, Sapindacea and Sapotaceaea (2 each) and rest of the eleven families contribute 1 species each (Table 1).Whereas studies conducted in ten coastal and inland Tropical Dry Evergreen Forest, India reported Melastomataceae, Sterculiaceae, Rubiaceae, Dipterocarpaceae and Euphorbiaceae as the most specious family (Mani and Part has arathy 2006). Of the 17 families, Fabaceae contributed to the maximum number of individual (169) recorded, followed by Moraceae (14%) representing the maximum basal area (Fig. 3).

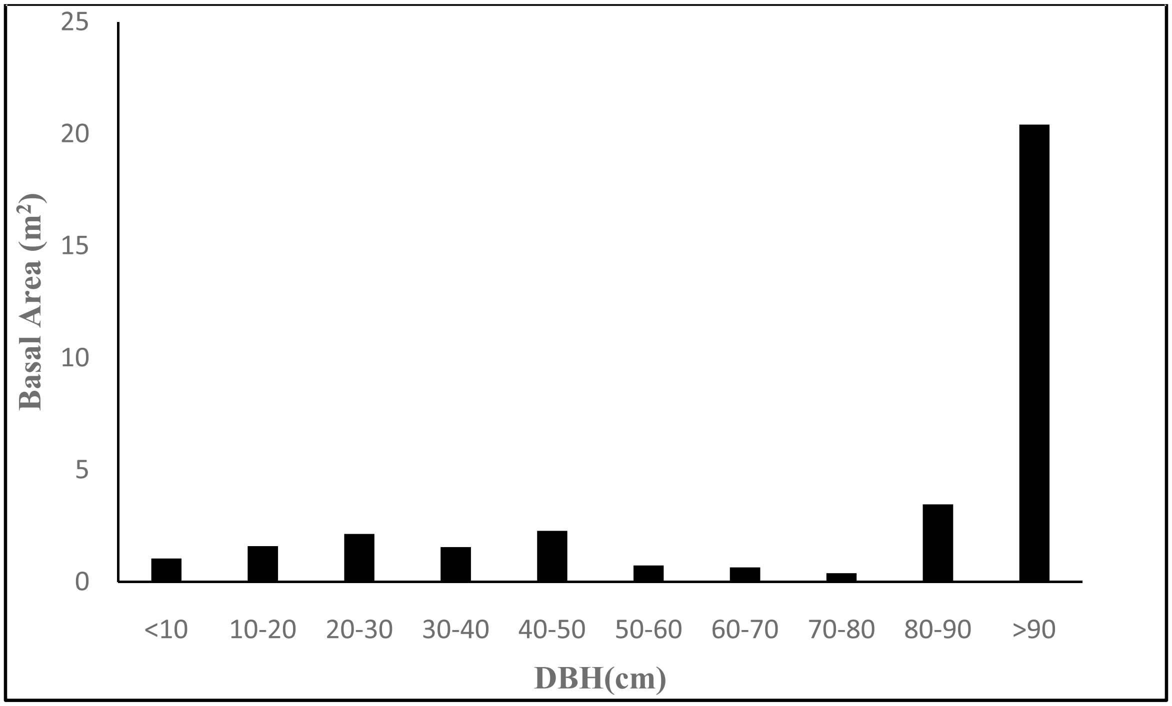

Fig. 3. Contribution of Basal area among family at urban forest patch; Puducherry; India.

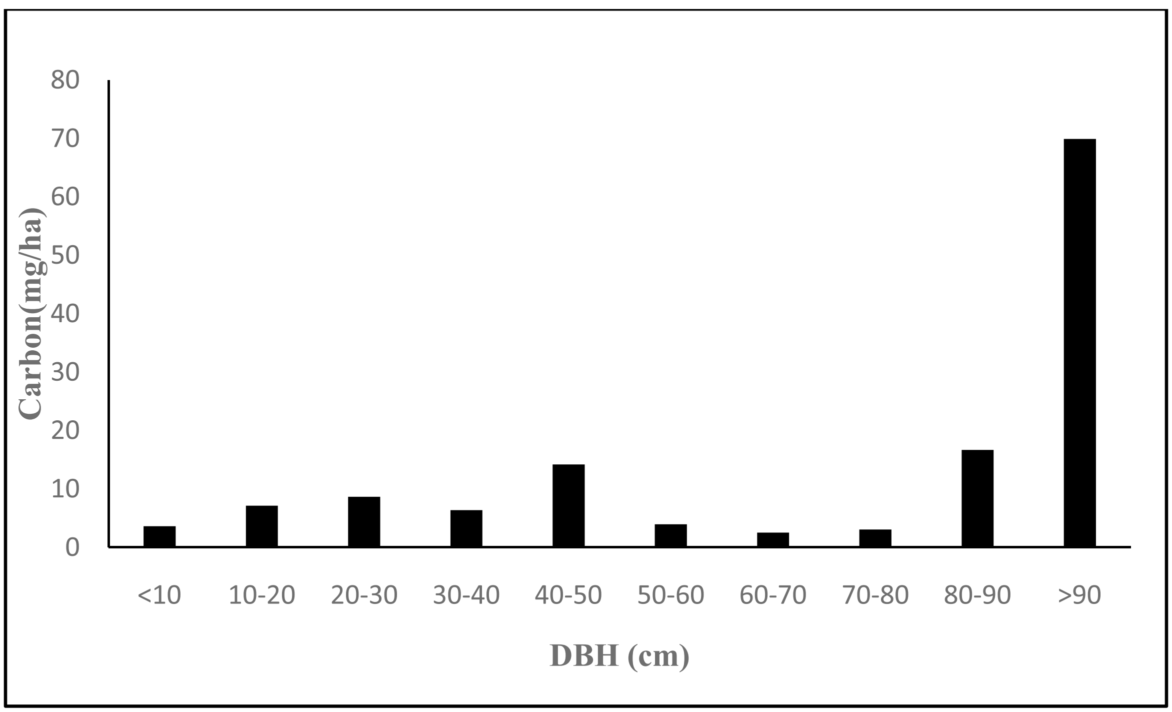

Fig. 4. Number of individuals falling in different diameter size classes in the urban forest patch of Puducherry, India.

Majority of individuals falls under 10-30cm diameter class (384 individual). Our results suggest that more than half (65.52%) of the tree abundance fall in lower diameter class (Figure 4) which accord with the study conducted by many tropical forest researcher (Nagendra and Gopal, 2010). The reason for this may be the frequent cyclones, leading to the uprooting of higher girth trees and quick regeneration rate in case of the present study area which is well protected, restricting any kind of anthropogenic activities. *Adansonia digitata* was recorded with 991 cm is the highest girth sized species represented by only 1 individual. As the obvious higher basal area was contributed by the girth class more than 90cm (Fig. 5).

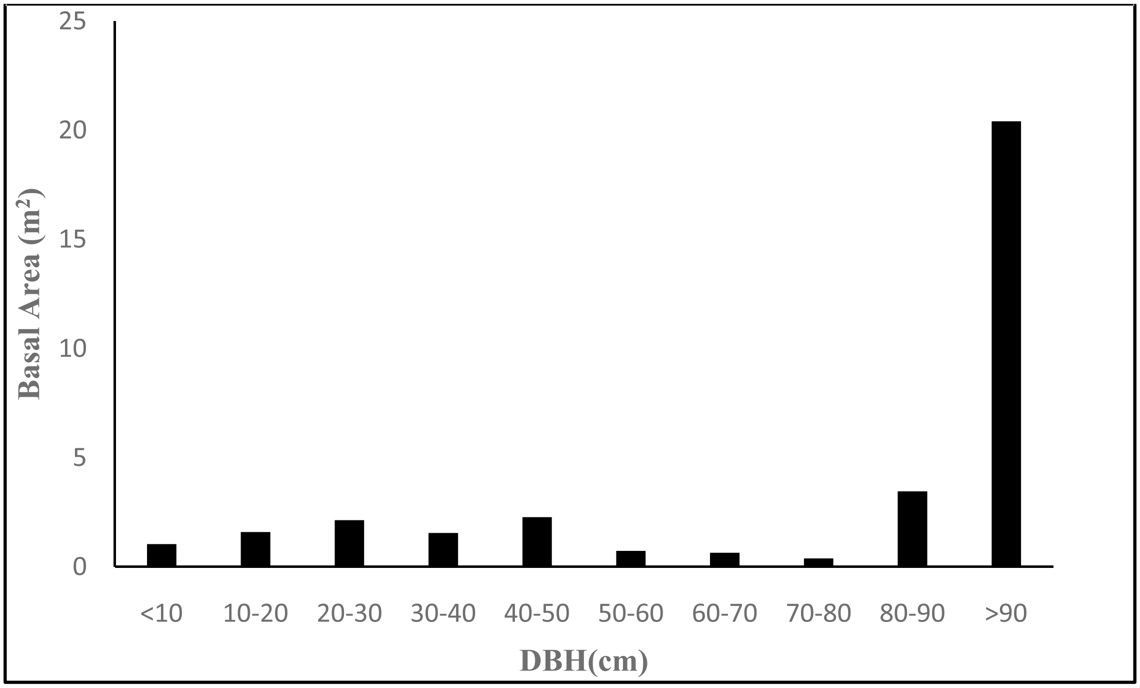

Fig. 5. Basal area contributed by different diameter size classes in the urban forest patch of Puducherry, India.

Biomass and Carbon Stock estimation

The total above ground (220.81) and below ground biomass (57.41) of the present site summed to 278.22Mgha^{-1} and it resulted in a carbon stock of 139.110MgCha^{-1} (Table 2). The total biomass and carbon stock fell well within the range of another study conducted by Parthasarathy and Vivek (2015) 121.71-717.69 Mg ha^{-1}; 60.858-235.5 Mg ha^{-1} respectively where it is found to be more than few other studies like Tiwari and Singh (1987) estimated 68.5–122.5 Mg ha^{-1} biomass carbon, the reason to support this can be the lone (*Adensonia digitata*) which contributes to a maximum biomass. The present study clearly reveals that the urban forest patch being a small undisturbed secondary forest harbor higher percentage of carbon stock. As similar to the basal area, carbon storage was estimated to be highest in the higher girth class (Figure 6). Other workers such as Parendes and Jones (2000); Tikka et al. (2001); Gelbard and Belnap (2003) have also obtained a similar result. Several factors such as climate, type of forest, species variability, native and non-native species and physical and chemical changes in soil (Western and Jurvick 1983, Holzapfel and Schmidt 1990; Parendes and Jones 2000;) have been suggested to be responsible for a higher percentage of carbon stock in forest patches

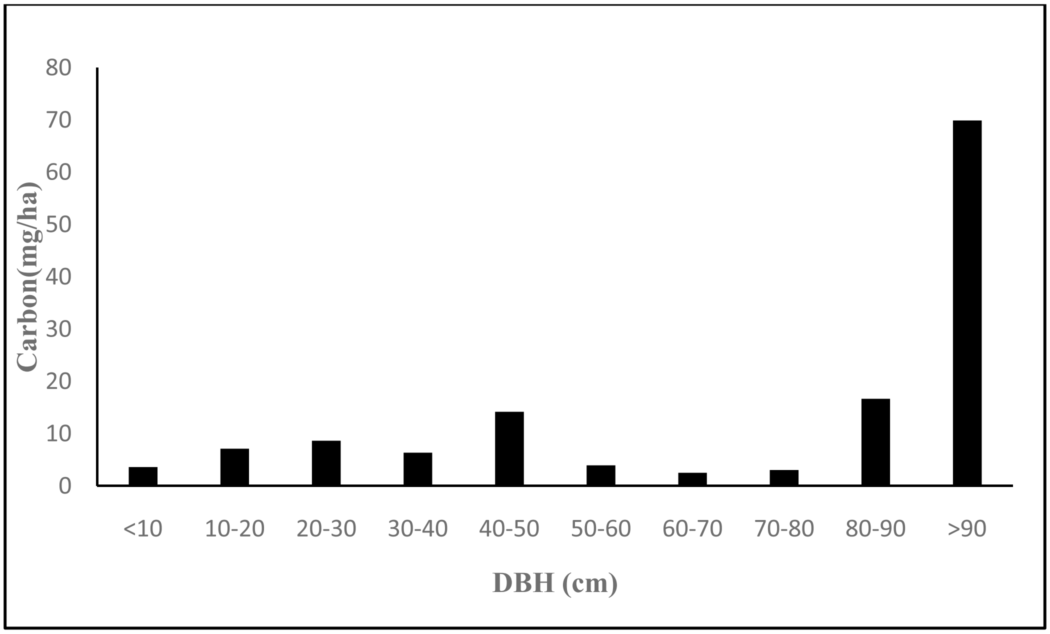

Fig. 6. Carbon stock contributed by different diameter size classes in the urban forest patch of Puducherry, India

Table 2. Above ground biomass (AGB), Below ground biomass (BGB), and Carbon stock of Urban Forest Patch, Puducherry, India.

Sl. No.	Species name	AGB	BGB	TB	Carbon
1	*Adansonia digitata* (L.)	18.246	4.744	22.990	11.495
2	*Albizzia saman* F Muell.	47.367	12.316	59.683	29.841
3	*Allophylus serratus* (Roxb.)Kurz	11.272	2.931	14.203	7.101
4	*Atalantia monophylla* (L.) Correa	1.134	0.295	1.429	0.715
5	*Azadirachta indica*A.Juss.	15.612	4.059	19.671	9.836
6	*Bombax ceiba* (L).	0.014	0.004	0.017	0.009
7	*Butea monosperma* (Lam.) Taubert	0.038	0.010	0.048	0.024
8	*Canthium coromandelicum*Burm.F.	0.070	0.018	0.088	0.044
9	*Citrus aurantiifolia* (Christm) Swingle	0.092	0.024	0.116	0.058
10	*Cordia oblique* Wild.	0.026	0.007	0.032	0.016
11	*Coryphama cropoda* kurt ex Kiden	1.938	0.504	2.441	1.221
12	*Crataeva adansonii* DC.ssp. Odora (Buch.Ham.)M.Jacobs	0.038	0.010	0.047	0.024
13	*Dalbergia paniculate*Roxb.	0.395	0.103	0.497	0.249
14	*Diospyros montana*Roxb.	0.460	0.120	0.580	0.290
15	*Glyricidia sepium* (Jacq.) Kunth ex Walp	4.914	1.278	6.191	3.096
16	*Ixora pavetta*Andr.	0.057	0.015	0.072	0.036
17	*Lepisanthestetra phylla* (Vahl.) Radlk.	17.754	4.616	22.370	11.185

Sl. No.	Species name	AGB	BGB	TB	Carbon
18	*Madhuca longifolia* (Koen.)Macbr	9.003	2.341	11.344	5.672
19	*Mallotus philippensis*(Lam.) Muell.Arg.	11.495	2.989	14.483	7.242
20	*Millingtonia hortensis*L.f.	0.075	0.019	0.094	0.047
21	*Mimus opselengi* L.	0.553	0.144	0.696	0.348
22	*Nerium oleander* L.	0.020	0.005	0.025	0.012
23	*Peltoforum pterocarpum* (DC.) Baker ex Heyne	26.241	6.823	33.063	16.532
24	*Polyalthia longifolia* (Sonner.)Thw.	0.927	0.241	1.168	0.584
25	*Pongamia pinnata* (L.) Pierre	0.668	0.174	0.841	0.421
26	*Senna siamea* (Lam.) Irwin et Barneby	3.930	1.022	4.952	2.476
27	*Streblus asper* Lour.	2.479	0.645	3.124	1.562
28	*Tamarindus indica* L.	45.976	11.954	57.930	28.965
29	*Terminilia chebula* Retz.	0.005	0.001	0.006	0.003
30	*Wrightia tinctoria* (Roxb.) R.Br.	0.014	0.004	0.018	0.009
		220.810	**57.411**	**278.221**	**139.110**

As a remnant patch of tropical dry evergreen forest, Swadeshi Cotton mill forest patch encompasses a fair amount of native species, as well as it has some introduced species which may be due to seed dispersalor plantation. But as per the information obtained by forest department, there was no plantation scheme introduced for that patch, making it a pristine natural forest patch. No doubt there were anthropogenic disturbances, still as compared to other remnant patches of TDEF's the disturbance is less as it is protected by a compound wall and outsider are not allowed. This provides further study insights to a number of other soil micro-macro flora and fauna of the present sights as the present study is exclusively on tree diversity and its carbon stocks. Visual observation on the bat population of the present study site gives way forward for research on bat species, which are restricted to part of the study site. The observation suggests that this patch provides numerous ecosystem services ranging from mitigating climate change to preserving biodiversity.

CONCLUSION

This study shows that the urban forest patch is potent enough for retaining a good number of species, thereby contributing better biomass and also act as a carbon sink. The Urban forest is now decreasing in the elm of industrial grooming, haphazard population growth, increase in settlements and other infrastructure for anthropogenic recreation. Even a small green spaces in cities, when managed properly, can reduce the cost of heating, control flooding, erosion, curb a load of air pollutants and health care *etc*. The present study has revealed the state and importance of the remnant patch. Hence there should be a study conducted in this direction; *i.e.*, how well this small urban forest patch responses to the natural disasters? And also what is its recoverable rate? For this long-term monitoring study should be conducted. A robust study as of Chandigarh and Delhi should be conducted to give a holistic picture of the whole of urban forest patches at Pondicherry.

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