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A study of Bangalore urban forest

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Abstract

The study is aimed to investigate the species assemblage in different land-use categories and the changes in vegetation over the recent years in Bangalore City, India. Forty-six sites of nine different land-use categories were sampled to study species composition, DBH distribution and end-uses of trees. Though species richness is high in all the various land-uses, a few species are dominant accounting for >70% of the tree density. Species richness is high in parks and residential areas. Tree density is high in parks, temples and around lakes, where the land-use is recreational and low in commercial and residential areas, which have high built-up area. Bangalore urban forest is still young with most of the trees (70%), having <15 cm in DBH. The larger trees are in older establishments of institutions, offices, commercial areas and parks. The Kolmogorov–Smirnov test shows that there is a variation in DBH distribution in old and new land-uses of institutions and temples. Among the tree owning households (50%) in residential areas, 40% of the houses have >5 trees and 22% of houses have >5 tree species in their compound.

Trees in residential areas were sampled and studied according to the economic strata of residents and the age of the area. One hundred and sixty-four species were identified in different residential areas, of which 149 species were recorded within compounds and 87 species were avenue trees. The species composition and cluster analysis showed that species choice varied in terms of the economic status of the communities rather than that with time. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The urban forest includes all woody vegetation within the environs of all populated places. In this sense, it includes not only trees within city limits, but also those on associated lands that contribute to the environment of populated places. The vegetation in

urban areas could undergo changes in time due to many factors. Increase in population, demand on land for infrastructure and change in priorities reflect on the life style and surroundings of human settings. Hence, a great diversity of vegetation can be found in cities ranging from natural forests in patches, selected cultivars along avenues, in residential compounds, botanical gardens, parks and landscaped private properties. Information on the structure of urban forest provides an understanding of the functions of urban forest that affect the city and its inhabitants. There are few

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detailed studies (for example, Mitra, 1993 and Madan, 1993 on urban forest of Vishakapatnam City) on the urban forest diversity and structure in India, but none for Bangalore. In other countries, many researchers have evaluated the urban forest structure, for example, Namuta (1980) in Japan; Rowntree, et al. in Chicago (Rowntree et al., 1983); and Miller and Winer in Los Angeles (Miller and Winer, 1984), etc.

Urban vegetation is strongly affected by the type and intensity of human influence. Components of natural and cultural realms interact to determine the mixture of indigenous and introduced vegetation of urbanized areas (Rowntree, 1988). A major challenge in urban ecology would be to understand the factors that determine the structure and composition of species assemblage in urban environment. Such an understanding would greatly enhance our ability to preserve ecological diversity in all kinds of human modified environments. Hence, a preliminary study was taken up to understand the changes in vegetation in the recent years and the species assemblage in different land-use categories in Bangalore.

Bangalore City has the dubious distinction of being one of the fastest growing metropolises in India and Asia. Despite this fast growth, Bangalore is still known as the 'Garden City of India'. Well-planned parks and huge green spaces characterize the city. At the same instance, the city is spreading rapidly with the surrounding villages and towns being engulfed into the city limits. This has led to conversion of agricultural land to urban areas rapidly. In this paper, we make an attempt to understand the attributes of vegetation structure, such as species diversity, density, and basal area and to understand the factors that contribute to variations in these indices from one land-use type to another.

2. The study area

The study area encompasses Bangalore City, the capital of Karnataka, situated in the southeastern corner of the State. It lies between the latitudinal parallels of 12°15'N and 13°35'N and the longitudinal parallels of 77°5'E and 78°E. The area of City Corporation along with its appendages, recognized in the form of Bangalore Development Authority and the numerous suburbs enveloping the city on all its sides,

is about 366 km² with a population nearing 5 million. It has an elevation ranging from around 850 m to around 930 m asl. The vegetation of Bangalore was classified as dry deciduous forest-type (Champion and Seth, 1968) under the *Terminalia-Anogeissus latifolia-Tectona* series (Gausson et al., 1965; Puri et al., 1983). The climate of Bangalore district is salubrious and devoid of extremities.

3. Methodology

Urban forestry can be studied at varied scales depending on the objective of the study. Spatial distribution of trees in the city can be studied through satellite imagery by characterizing land cover and land-use in urban areas; through photography by dividing into classes based on both, land-use and vegetation characterization; and by ground sampling which could be based on multi-criteria.

In this study, several sample transects were laid to study various parameters of urban forestry. Sample localities were chosen within the corporation limits of the city. Forty-six sites under various land-use categories were chosen for field studies. The selection of sites falls into the land-use categories of residential, religious, commercial (offices and industrial), institutional and recreational (parks and lakeside). Further, other criteria for sample selection for the above categories included period of land-use and economic status (for residential areas) of the site.

Undergraduate botany students from four colleges of the city were trained to conduct the field survey. This approach exposed the students to research methodology and also familiarized them with the plant wealth of the city. A training programme was conducted to introduce the students to the concept of ecological methods and train them in conducting field study. During the survey, project staff accompanied the students to assist in species identification.

The locations selected for sampling are given in Table 1. The plot size for sampling varied with land-use type. In residential areas, for instance, about 40 000 m² of two replicates in each location; in large industrial and commercial areas, 10 000 m² in each location; in major parks about 160 000 m²; and in minor parks, offices, temples, small industrial and commercial establishments — 100% sampling was

Table 1
Land-use categories and areas sampled for the urban forest survey in Bangalore

Land category	Status	Area
Parks	large	Krishnarao Park, Bugle Rock Park, Lalbagh, Cubbon Park
	small	Laxmanrao Park, Vivekananda Park, Shamanna Park
Residential area	old	Basavanagudi, Malleshwaram, Gavipuram, Sarakki, Srinagar, Hanumanthnagar, Ramachandrapuram
	new	JP Nagar 2nd Phase, Bank Colony, Sadashivnagar, Rajarajeshwari, Tilaknagar, Manjunathnagar
Commercial area	old	Majestic, K.R. Market, MG. Road
	new	Jayanagar and Banashankari Shopping Complex
Institutions	old	Central College, St. Joseph's College, Christ College.
	new	BMS College, Indian Institute of Management
Temples	old	Bull Temple, Shankar Mutt
	new	Mahalaxmi Layout Temple, Rajarajeshwari Temple, Manjunathaswami Temple
Office	old	Corporation office
	new	General Post Office
Industrial areas	old	Peenya Indl. Area, Mm Indl. area
	new	Morzaria Indl. Area
Lakes		Ulsoor lake, Sankey Tank

done. A walking inventory was adopted to record the location of the tree, name of the tree, height class (as seedling, small, medium, and tall tree), GBH (girth at breast height) measurement, uses of the tree and approximate age of the tree wherever possible.

The residential areas were surveyed in much detail according to economic status of the residents and time of establishment of the layouts. The attributes to designate the economic status of the residential locality are the affluence of the residents, the site dimensions of houses and the land value of the residential area. If the year of establishment of the residential layouts and the construction of the houses dates back about 80–100 years, they are classified as old establishments and layouts formed recently, only about 10–15 years back are considered as new extensions. These details were obtained from the residents through a questionnaire survey. Thirteen different sites falling into the four categories were selected for the survey, which are henceforth referred to as follows:

	Older extension	Newer extension
Higher strata	OHA	NHA
Lower strata	OLA	NLA

Single linkage, Euclidean distance cluster analysis was done to determine the linkages of the samples and investigate its grouping to determine if species preference change with time. A dendrogram of the linkages is shown in Fig. 1. Cluster analysis was done

between species diversity and its relative densities in different samples for the land-uses.

A Kolmogorov–Smirnov (KS) test, which is non-parametric, was also done to estimate the difference between distribution of trees in DBH classes in the older and new land classes (Table 4). The D value given is the maximum unsigned difference between the distributions, whereas D_{∞} is the approximate two tailed critical value for the test statistic D .

4. Results

4.1. Species composition

From the field studies conducted, 374 species were recorded in the different land-use categories. Species richness is highest in parks (291 species), followed by residential areas (164), institutions (126), temples (107) and commercial areas (Table 2). The Shannon–Weiner diversity index shows that species diversity is high in parks (1.697) and residential areas (1.605) followed by commercial areas, institutions and temples (Table 2). Within each land-use, except temples, the older establishments have higher species composition, which is about more than twice, compared to new establishments. (Table 2). The spatial heterogeneity of the vegetation was also measured by calculating the within-site standard deviation of the samples in each land-use. The older land-uses and the

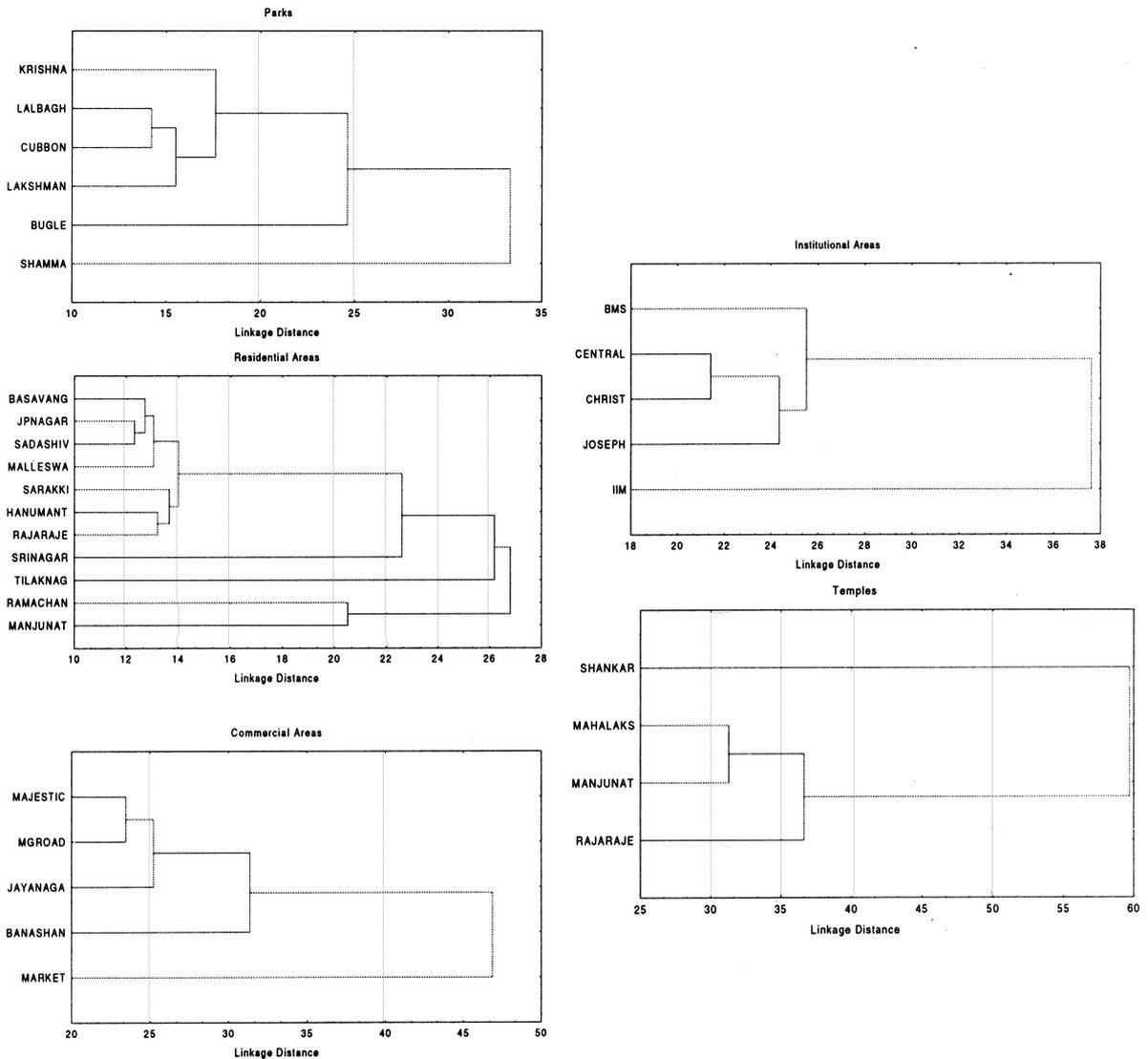


Fig. 1. Dendrogram of the single Euclidean distance cluster analysis to determine the linkages of the samples.

larger parks have a greater standard deviation than the newer land-use and smaller parks, respectively, (Table 2) showing that the vegetation is more homogenous in the newer land-uses and the small parks.

Polyalthia sp. and *Pongamia glabra* are the most dominant species in parks though their relative density is lesser in the larger parks (Table 3). *Polyalthia sp.* is also dominant in institutions and offices to the extent of a relative density of 21 to 34%. In larger parks, the three dominant species account for about 22% of the

trees as compared to 40% in the small parks. In residential areas, irrespective of the length of the land-use, *Cocos nucifera* is the dominant species, though its relative density is higher in the older areas. Including *C. nucifera*, the dominant trees are economically important species, such as Curry leaves tree (*Murraya koenigii*), banana plant (*Musa paradisiaca*) and papaya tree (*Carica papaya*). Institutions are dominated by fast growing species (*Polyalthia longifolia*, *Grevillea robusta*, *Bauhinia variegata*), decora-

Table 2
Species richness in the various land-use category in Bangalore

Land category	Category	No of species	Total no. of species	Mean \pm SD	Shannon–Weiner index	Tree density (No/ha)	Basal area (m ² /ha)
Parks	large	275	291	173 \pm 135	1.697	112	18.00
	small	40		38 \pm 19			
Residential	old	120	164	48 \pm 27	1.605	28	1.97
	new	79		32 \pm 13			
Commercial	old	112	104	61 \pm 43	1.549	18	2.90
	new	43		27 \pm 9			
Institutions	old	94	126	63 \pm 18	1.475	39	4.22
	new	64		37 \pm 18			
Temples	old	29	107	29	1.461	59	3.25
	new	97		51 \pm 14			
Offices	–	–	76	–	1.417	55	10.46
Industrial areas	–	–	72	–	1.333	31	3.75
Lakes	–	–	85	–	0.988	60	20.25

tive trees (*Delonix regia*, *Tabebuia argentea*) and shade-giving trees (*Samanea saman*). Temples are predominated by *Cocos nucifera*, especially in the earlier establishments (80% relative density) compared to newer temples (11%) (Table 3). Many of the other species are fruit-and-flower yielding trees, which are used as offerings to the deity.

The single-linkage Euclidean distance cluster analysis was performed for parks, residential areas, institutions and industrial areas as significant samples were taken in these land-uses for comparison (Fig. 1). It can be seen that Cubbon Park and Lalbagh clustered together which are the large parks. Krishna Rao and Laxman Rao parks, which are moderate sized parks, are clustered together, whereas the smaller parks, Bugle and Shammana parks are clustered together. In residential areas, no discernible clustering occurred among the older and new extensions of residential areas. But clustering in terms of the economic status of the residents was observed. In commercial areas, Majestic and MG Road are clustered together. These two commercial areas have both, residential and commercial establishments. It differed significantly from Jayanagar and Banashankari commercial areas, which have only commercial establishments. K.G. Market, though an old commercial area, has a longer linkage distance to the other samples. Though a similar assemblage of residential and commercial buildings can be seen in this area, it is more cluttered with no discernible green spaces. Few trees, though

present, are near small temples amidst the busy commercial areas. These are also characterized by narrow avenues, small commercial establishments and residential dwellings. Among the institutions, IIM has a wider linkage distance, which is a new establishment as compared to the rest of the institutions. It is also a professionally landscaped establishment. Central, St. Joseph's and Christ colleges are old establishments with large trees.

4.2. Tree density

Parks have the highest tree density (112 trees/ha) followed by lake surroundings and temples (Table 2). Areas surrounding the lakes have a density of 60 trees/ha, which is due to naturally growing vegetation along with the well-maintained parks by the city corporation. Temples, especially the older ones, have a well-maintained garden with trees of different amenity attributes. Since these temples have large areas and the temple gurus and disciples reside within the temple premises, most of the essential flowers for worshipping, fruit- and vegetable-yielding tree species are grown within the temple premises. Commercial areas have low tree density, as the land-use is intense. Trees present in commercial areas are concentrated in small squares and along pedestrian sidewalks. Residential areas also have low tree density as there is less growing space due to a high percentage of built-up space and cemented sidewalks (Table 2).

Table 3
Dominant species and their relative densities in the various land-use categories

<i>Parks</i>			
Large		Small	
<i>Polyalthia longifolia</i>	12.92	<i>Polyalthia longifolia</i>	21.53
<i>Pongamia glabra</i>	4.91	<i>Pongamia glabra</i>	11.16
<i>Millingtonia</i> sp.	4.55	<i>Dolichandrone</i> sp.	7.52
<i>Residential areas</i>			
Old		New	
<i>Cocos nucifera</i>	20.49	<i>Cocos nucifera</i>	15.41
<i>Murraya koenigii</i>	8.74	<i>Musa paradisiaca</i>	12.12
<i>Musa paradisiaca</i>	7.42	<i>Carica papaya</i>	8.92
<i>Institutions</i>			
Old		New	
<i>Polyalthia longifolia</i>	33.74	<i>Polyalthia longifolia</i>	21.49
<i>Peltophorum pterocarpum</i>	6.22	<i>Casuarina equisetifolia</i>	14.02
<i>Delonix regia</i>	4.07	<i>Tectona grandis</i>	8.27
<i>Temples</i>			
Old		New	
<i>Cocos nucifera</i>	80.29	<i>Cocos nucifera</i>	11.42
<i>Polyalthia longifolia</i>	5.44	<i>Polyalthia longifolia</i>	8.75
<i>Mangifera indica</i>	4.35	<i>Grevelia robusta</i>	7.20
<i>Industrial areas</i>			
Old		New	
<i>Ricinus communis</i>	31.81	<i>Cocos nucifera</i>	36.50
<i>Cassia</i> sp.	19.13	<i>Carica papaya</i>	33.33
<i>Polyalthia longifolia</i>	11.48	<i>Mangifera indica</i>	11.11
<i>Offices</i>			
Old		New	
<i>Polyalthia longifolia</i>	26.77	<i>Sentry palm</i>	27.03
<i>Sentry palm</i>	11.93	<i>Thuja</i> sp.	11.07
<i>Swietenia mahagoni</i>	6.12	<i>Musa paradisiaca</i>	8.46

4.3. Size distribution of trees

The urban forest surveyed has most trees (53–82%) with <15 cm DBH (diameter at breast height) in the land-use categories (Fig. 2). The larger trees are more in older establishments of institutions (13% of the trees in the land-use); offices (12%); commercial areas (15%); and parks (14%). In the oldest residential and commercial areas, large trees exist within the compounds and a few along the sidewalks and avenues. The Kolmogorov–Smirnov (KS) test shows that there is a variation in DBH distribution in the old and new land-uses of institutions, temples and parks (large and

small) (Table 4). Institutions have the maximum variation (KS value — 0.48) followed by temples (0.36) and parks (0.26). The distribution is not very distinct in commercial areas with KS value of 0.17 and is insignificant in trees within compounds (0.09) and avenues (0.08). *D* values are significant at a confidence level of 99%.

4.4. Basal area

The basal area of trees in different land-use categories varies from 20.25 m²/ha around lakes to 1.97 m²/ha in residential areas (Table 2). Residential,

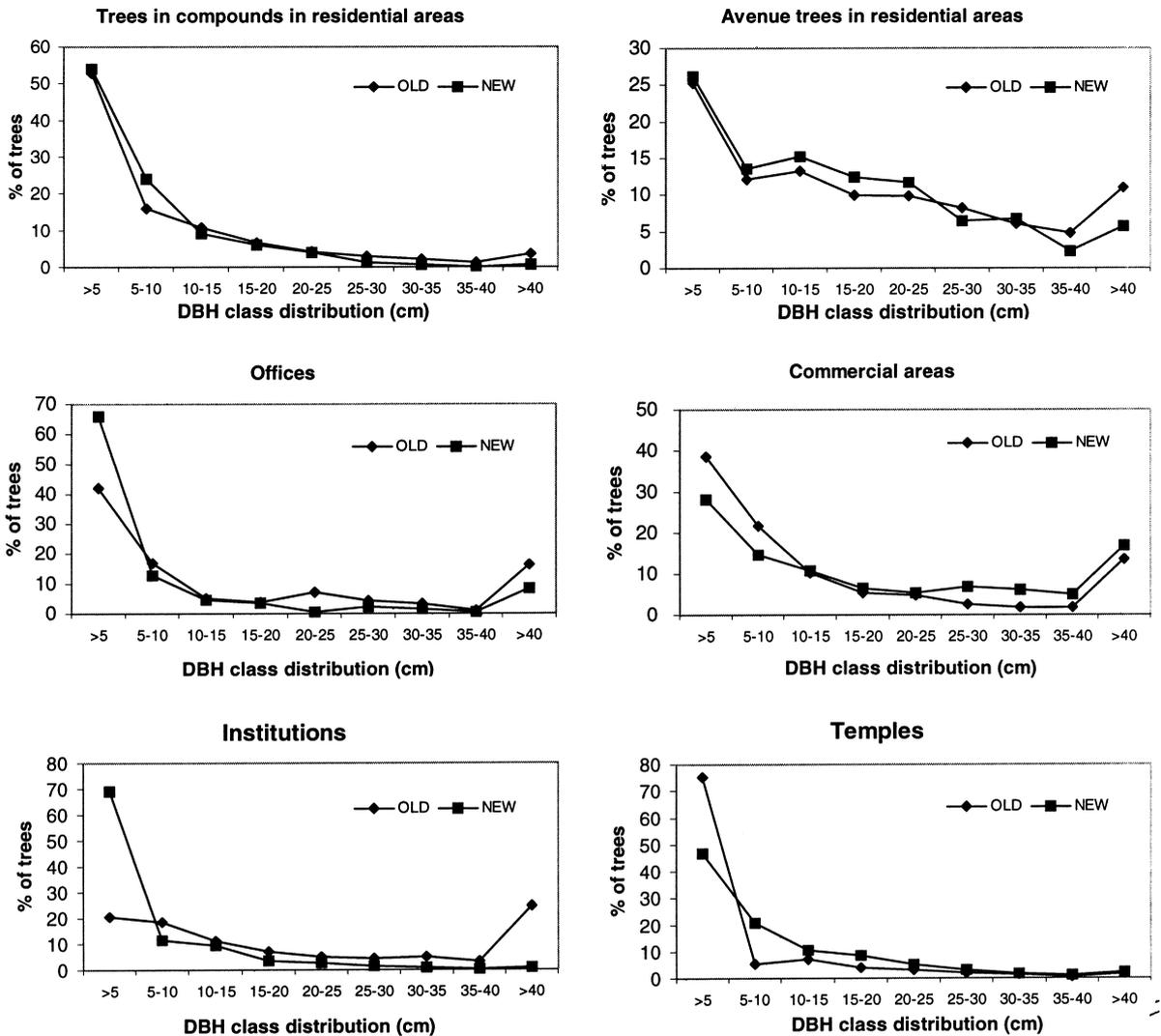


Fig. 2. DBH distribution of trees in the different land-use categories in Bangalore City.

Table 4

Maximum unsigned differences of DBH distribution of trees in the old and new land-use categories determined by the Kolmogorov–Smirnov test

Land category	D value ^a	n_1 and n_2 values	D_∞ value ^b
Parks	0.2655	1609, 2849	15.95
Residential	0.0922 (in compounds) 0.0869 (avenue)	3947, 2359 1062, 666	3.45 1.75
Commercial	0.1774	156, 801	2.02
Institutions	0.4855	1268, 2248	13.82
Temples	0.3570	2478, 900	9.17

^a D value is the maximum unsigned difference.

^b D_∞ is the approximate two-tailed critical values for the test statistic D .

commercial and industrial areas with high built-up area have low basal areas. Parks have high basal area, next only to lakes. In the parks, trees are landscaped with vast expanses of lawns, rose gardens, varieties of herbs and shrubs, and the trees are spaced widely to accommodate tracks for walks. Hence, the well laid-out parks have a relatively lower basal area, in spite of their land-use as horticultural, botanical and recreational centres.

4.5. Trees in residential areas

Residential areas in Bangalore City are a major land-use. This land-use is expanding multi-fold along the fringes of the city limits and occupying the erstwhile agricultural lands. Hence, the expansion of the city due to increasing population is influencing the ever-changing standing vegetation or the urban forest structure. Hence, a detailed study of the dynamics of composition and structure of trees in different residential environs is elucidated in the following. Trees in residential areas include trees inside the residential compounds as well as trees along the avenues.

4.5.1. Species composition in residential areas

A total of 164 species were identified in different residential areas, which accounted for a maximum species richness compared to other land-use (except parks). Of these, 149 species were recorded within compounds and 87 species as avenue trees. Except in NLA, the avenue trees account for 41–46 species in different extensions. The 10 dominant species accounted for 58% of the trees. The species diversity is high in the older strata and 50% of the species recorded are exotic and 50% are of native origin, whereas in the newer extensions the species diversity

is not very diverse and the native species account for 70% of the tree composition. The Shannon-Weiner index also shows that the diversity is higher in the older residential areas (both higher and lower strata) compared to the newer extensions (Table 5). The variation in species richness in different localities is observed due to the trees in residential compounds. Single linkage and Euclidean-distances cluster analysis showed that species choice varied in terms of the economic status of the communities rather than that with time. Hence, the species composition in the higher strata are more similar rather than compared to older and new residential areas. The predominant species in the higher strata are *Cocos nucifera*, *Murraya koenigii*, *Psidium guajava* and *Polyalthia longifolia*. In the lower strata, the dominant species are *C. nucifera*, *Moringa oleifera*, *Musa paradisiaca* and *Mangifera indica* (Table 6).

4.5.2. Tree density

Residential areas have the least tree density compared to other land-uses (Table 2). The higher strata and, especially, the older extensions, contribute the most to tree density. Trees in compounds account for the maximum percentage (55–84%) in residential areas (Table 4). Avenue trees account for only one for every 2–5 trees in these areas. In the NLA, the residential and avenue trees contribute almost equally and record the least tree density.

Though a number of species are present in compounds, a few species are more prevalent. The 15 most dominant species in the different localities account for 67–92%. *Cocos nucifera* is the most prevalent species accounting for 10–20% of the composition (Table 6). In the OHA, of the 15 dominant species, eight are of economic importance and seven of ornamental value.

Table 5
Distribution of trees in different residential areas

	No. of species			Tree density and % contribution			Basal area and % contribution			Shannon-Weiner index
	RESI ^a	AV ^b	Total	RESI ^a	AV ^b	No./ha	RESI ^a	AV ^b	m ² /ha	
Old higher	108	46	117	84	16	43	62	38	2.874	1.554
Old lower	69	48	83	67	33	22	72	28	1.411	1.368
New higher	74	41	84	72	28	34	20	80	2.688	1.363
New lower	29	25	40	55	45	11	38	62	0.940	1.129

^a Residential trees.

^b Avenue trees.

Table 6
Relative density of residential and avenue trees in different localities

Old higher		Old lower		New higher		New lower	
species	RD ^a	Species	RD ^a	Species	RD ^a	Species	RD ^a
<i>Residential trees</i>							
<i>Cocos nucifera</i>	18	<i>Cocos nucifera</i>	20	<i>Cocos nucifera</i>	19	<i>Musa paradisiaca</i>	19
<i>Polyalthia longifolia</i>	9	<i>Moringa oleifera</i>	10	<i>Murraya koenigii</i>	11	<i>Moringa oleifera</i>	19
<i>Murraya koenigii</i>	7	<i>Murraya koenigii</i>	9	<i>Psidium guajava</i>	8	<i>Carica papaya</i>	11
<i>Psidium guajava</i>	4	<i>Musa paradisiaca</i>	8	<i>Polyalthia longifolia</i>	7	<i>Cocos nucifera</i>	10
<i>Mangifera indica</i>	4	<i>Mangifera indica</i>	6	<i>Careya arborea</i>	7	<i>Mangifera indica</i>	7
<i>Avenue trees</i>							
<i>Pongamia glabra</i>	19	<i>Peltophorum</i>	14	<i>Michelia champaca</i>	13	<i>Moringa oleifera</i>	27
<i>Spathodea campanulata</i>	17	<i>Samanea saman</i>	13	<i>Pongamia glabra</i>	8	<i>Delonix regia</i>	20
<i>Bauhinia variegata</i>	8	<i>Spathodea campanulata</i>	11	<i>Spathodea campanulata</i>	7	<i>Michelia champaca</i>	12
<i>Delonix regia</i>	7	<i>Delonix</i>	10	<i>Jacaranda mimosifolia</i>	6	<i>Bauhinia variegata</i>	6
<i>Dolichandrone</i> sp.	6	<i>Millingtonia</i> sp.	9	<i>Cassia</i> sp.	6	<i>Cocos nucifera</i>	3

^a Relative density.

In the OLA, 12 species are of economic importance of which the most prominent species are *C. nucifera*, *Moringa oleifera*, *Murraya koenigii*, *Musa paradisiaca* and *Mangifera indica*. In the NHA, *C. nucifera*, *M. koenigii*, *Psidium guajava*, *Polyalthia longifolia* and *Carica papaya* are the most prominent species, and 11 of the 15 dominant species are of economic importance. In the NLA, of the 15 species, accounting for 92%, 13 are of economic value, the most dominant species being *Musa paradisiaca*, *Moringa oleifera*, *Carica papaya*, *Cocos nucifera* and *Mangifera indica*.

The species planted as avenue trees in the residential areas are *Pongamia glabra*, *Bauhinia variegata*, *Spathodea campanulata*, *Delonix regia*, *Jacaranda mimosifolia*, *Peltophorum pterocarpum* and *Michelia champaca* (Table 6). The ten dominant species account for almost 64–82% of the total avenue trees. Of special interest is the dominance of *Moringa oleifera* as avenue trees in NLA, which accounts for 27% of the total avenue trees. The other dominant species are *Cocos nucifera* and *Carica papaya* in this locality, which are not promoted as avenue trees by the Forest Department.

4.5.3. Biomass structure

The basal area of trees in residential area accounts for 1.97 m²/ha, which is the least compared to other land-use. The higher strata have a better representation of 2.87–2.68 m²/ha compared to lower strata (Table 5). Maximum contribution to the basal area is from

residential trees in older residential areas (62–72%), whereas in the newer areas, avenue trees contribute to a greater extent of 62–80% among the trees (Table 4). Among the trees found in the compounds, the maximum number of huge trees (>40 cm) are encountered in OHA, followed by OLA and the least numbers in the newer extensions. A better representation of huge trees, as avenues trees, lies in the higher strata areas (10–16%) as against the lower strata areas. It is relatively a fewer huge trees which contribute the maximum to basal area. In all areas, it is species such as *Mangifera indica*, *Moringa oleifera*, *Polyalthia longifolia*, *Ficus religiosa* which account for the maximum basal area. Among the avenue trees, *Pongamia glabra*, *Spathodea campanulata*, *Delonix regia*, *Bauhinia variegata*, *Peltophorum pterocarpum* and *Jacaranda mimosifolia* contribute the maximum to basal area of trees.

4.5.4. Trees in house compounds

The top 15 predominant species in compounds of residences account to 77% of the total trees in compounds. *Cocos nucifera* is the predominant species, accounting for 18%, followed by *Murraya koenigii* and *Musa paradisiaca*. In addition, *Moringa oleifera* and *Carica papaya* are abundant. The amenity attributes of most predominant species is economic importance, except for *Polyalthia longifolia* and *Michelia champaca*, which are ornamental. Of these species, nine are fruit-yielding, namely *Cocos nucifera*, *Musa*

Table 7
Relative frequency of residential trees in different localities

Old higher		Old lower		New higher		New lower	
<i>Cocos nucifera</i>	72	<i>Cocos nucifera</i>	35	<i>Cocos nucifera</i>	55	<i>Moringa oleifera</i>	56
<i>Murraya koenigii</i>	30	<i>Moringa oleifera</i>	33	<i>Murraya koenigii</i>	45	<i>Cocos nucifera</i>	33
<i>Psidium guajava</i>	29	<i>Murraya koenigii</i>	25	<i>Psidium guajava</i>	38	<i>Careya arborea</i>	29
<i>Mangifera indica</i>	28	<i>Mangifera indica</i>	23	<i>Carica papaya</i>	30	<i>Mangifera indica</i>	19
<i>Michelia champaca</i>	26	<i>Psidium guajava</i>	21	<i>Polyalthia longifolia</i>	13	<i>Polyalthia longifolia</i>	8

paradisica, *Carica papaya*, *Psidium guajava*, *Mangifera indica*, *Punica granatum*, *Annona squamosa*, *Citrus limon* and *Artocarpus integrifolius*. Two species are used in cooking; *Moringa oleifera* as a vegetable and *Murraya koenigii* leaflets for seasoning. The fibrous seed coat of *Gossypium hirsutum* (cotton) is used to prepare wicks for lighting lamps. *Ricinus communis* grows more as a weed in the compounds of houses of the higher income group, and also in the wastelands around houses in the lower income areas.

The relative distribution of species indicates an overwhelming preference for a small number of species. *Cocos nucifera*, *Murraya koenigii*, and *Psidium guajava* is the most ubiquitous choice by the residents in the higher strata, whereas *Moringa oleifera*, *Cocos nucifera* and *Mangifera indica* have high relative frequency in the lower strata. Highest relative frequency of species is *Cocos nucifera* (35–72%) in OHA, OLA and NHA; followed by *M. oleifera* (33–56%) in NLA and OLA and *M. koenigii* (25–45%) in OHA, OLA and NHA (Table 7). Of the houses surveyed, almost 50% of the houses have no trees in the compound. Of the other 50% of houses considered, 20% have >10 trees in their compounds. Nearly 3.5% of the houses have >35 trees and these houses are concentrated in the older extensions of residential areas of higher economic strata. Sixty percent of the houses have <5 trees in their premises. Majority of the houses have more built-up area, which is more pronounced in the higher income areas of new extensions, as well as houses of lower economic strata where the houses are placed very close to one another and there is hardly any space to plant trees. Considering distribution of trees according to location, it can be seen that, in the OHA, 65% of the houses have <10 trees in the compounds, whereas 25% houses have 11–25 trees, almost 10% of houses have >26 trees and 7%

alone accounted for >35 trees. In the other localities, 90–95% of the houses have <10 trees in their compounds. A negligible percentage of houses (3%) have >35 trees in the NHA (Fig. 3).

When distribution of the number of tree species is considered in houses with trees, 22% of houses have >5 tree species/residence and, further, about 1% of houses have over 20 tree-species/residence. However, the majority of the residences (77%) have 1–5 tree species/residence. Considering locality-wise, most of the houses in all the localities have <10 species except in the OHA, where 14% of the houses have >10

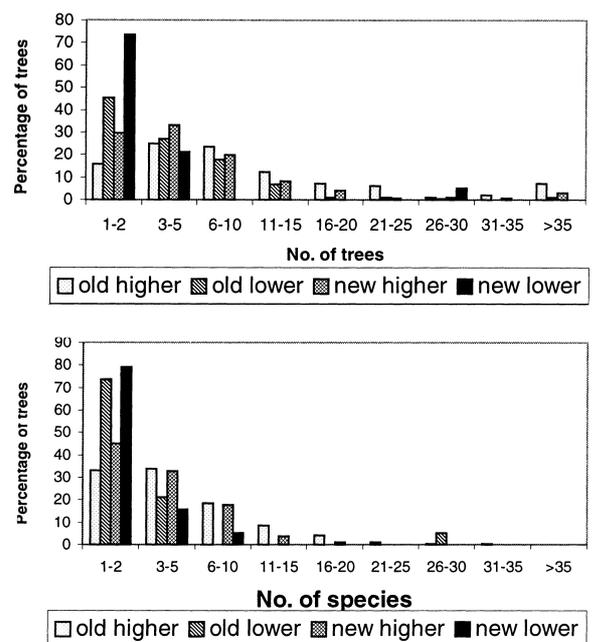


Fig. 3. Percentage of houses with number of trees and species in residential areas.

species. Maximum number of houses have just 1–2 species, of which *Cocos nucifera* and *Murraya koenigii* are most dominant (Fig. 3).

4.5.5. Avenue trees in residential areas

The avenue trees account for 28% of the trees in the residential land-use category. Of the 87 species, the top 15 tree species account for 80% of the total avenue trees. The trees most preferred by the Forest Department authorities are *Michelia champaca*, *Bauhinia variegata*, and *Pongamia glabra*. *Moringa oleifera* is found in abundance in the lower income residential areas along avenues, where these trees are planted in front of the houses by the residents rather than the authorities as these trees are economically important. The long fruits as well as leaves of this fast-growing tree are used as vegetables. The other trees that are significant in number are: *Delonix regia*, *Peltophorum pterocarpum*, *Spathodea campanulata*, *Samanea saman* and *Jacaranda mimosifolia*. When relative density of tree species in residential compounds and avenues in residential areas is compared, it is to be noted that 12 of the top 15 species planted along avenues do not appear in the residential compounds. This clearly shows the difference in the choice of trees by families and urban authorities.

5. Discussion

Bangalore is the fastest growing city in India, which has spread from 2 km² in 1537 to 360 km² in 1994. Before Bangalore was laid out in 1537, a thick jungle covered a part of this city area (Hasan, 1970). According to one theory, the origin of the name Bangalore (benga + uuru) attributes it to *Pterocarpus marsupium*, known to the natives as 'benga', and 'uuru' meaning town in the local language. Groves of mango and taramind existed in Bangalore at least a couple of centuries back in a village named Mavalli (Mango village). The spread of the city has engulfed many of the villages around Bangalore. Human settlements have led to the addition of different habitats to the once existing forests and rocky outcrops. With the growth of these human settlements and the spread of agro-pastoralism, the existing vegetation was cleared for dryland agriculture leading to the formation of scrub and grasslands as well. With agriculture many

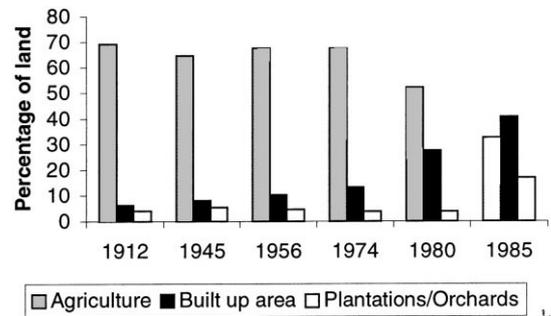


Fig. 4. Changes in land-use pattern in Bangalore City.

tanks and reservoirs were created taking advantage of the undulating terrain of the city. But many of these tanks have now been switched over to other land-uses, such as bus stands, stadiums, playgrounds, etc. due to rapid urbanization and high land pressure.

According to a study conducted by Behera et al., 1985, the percentage area under various urban land-use categories for Bangalore City for the period 1912–1985 was studied based on Remote Sensing Satellite Imagery and Geological Survey of India maps (Fig. 4). Over the years, the urban housing settlements have invaded into the agricultural lands and there has been a considerable decrease in cultivated lands. The built-up area has been constantly increasing since 1912. Most of the built-up area has come up at the cost of agricultural areas and partially from barren areas and scrublands, and a few water bodies. With respect to tree vegetation, tree crown cover of the city has shown a decline from 1912 to 1980. But, during the period 1980–1985, there has been an increase in crown cover from 3.8 to 19.9% of the land area (Behera et al., 1985). It has also been observed from the maps that the green cover within the built-up area has decreased, but has considerably increased in the outskirts of the city which is mainly due to *Eucalyptus* and *Casuarina* plantations in the village commons and agricultural lands. Population is one of the factors contributing to expansion of the built-up area. Population has increased by 47% during the decade 1981–91 and currently stands at about 5 million.

5.1. Factors influencing vegetation patterns

Land-use is one of the most significant factors affecting local vegetation patterns and distribution.

In conjunction with its associated patterns of buildings and other artificial surfaces, land-use influences the space available for trees and to some extent whether these spaces will be filled with trees and, if so, how they will be managed. Vegetation in the city region taken as a whole could be more diverse than any forest stand. Cities are diverse in habitat composition and are also areas of immigration due to hemerichory (Henke and Sukopp, 1986). Maximum tree density is found in parks in Bangalore according to the pilot study. Lake-side plantings, offices and temples contribute significantly to the tree density and basal area. But, in Cook, DuPage, Chicago and Oakland most of the trees are on institutional lands (Nowak, 1993a). Commercial areas and residential areas with high built-up area have low tree density. As Bangalore is still growing rapidly, in the peripherals and also vertically, it is easy to make distinctions between the urbanization levels on the basis of the age of the urbanization. This is more so in the residential areas, as the factors responsible to unit change in these areas are more diverse compared to other land-uses. The urban vegetation is partly composed to original, natural vegetation and exotic species. The older higher strata have many original species occurring among the other urban communities. In the city centre, the vegetation is largely determined by the human activities. The structure and composition of residential trees are less likely to be influenced by urban morphology and other factors, and are more likely to be influenced by site plans. Here, it can be seen that demand for housing seems to be an important variable in site designs. The significance of these decisions determines the initial structure and composition of the population of the residential trees. After the establishment of an area, many other factors, such as socio-economic status of the residents and individual preferences, may become important.

The most common species is the exotic and highly invasive *Polyalthia longifolia*, accounting for 14% of the tree population surveyed in the city. This species is common on all land-use categories, but most common on landscaped and managed lands. Dominance of single species is also reported in Chicago, where buckthorn accounts for 12.76% of the tree population (Nowak, 1994). *Polyalthia longifolia* is a native of Sri Lanka and is now planted throughout India for its graceful appearance, particularly for its evergreen

thick foliage, which extends from the crown to almost ground level, with its drooping branches. It is planted in the periphery of gardens, open grounds and compounds at close distance as it prevents dust, heat and sound pollution. *Cocus nucifera* is common on two land-uses; residential areas and temples and is used in cooking and as offerings to the deity, respectively. The surveyed Bangalore urban forest is composed mostly of small trees <15 cm in DBH (53–82%) as seen in other cities; Shorewood and Oakland, with 67% and 60.9% of the trees with <15 cm in DBH, respectively (Dorney et al., 1984; Nowak, 1993a). In Chicago, small trees comprise 76.9 % of the urban trees (Nowak, 1994). However, the distribution of tree sizes varies among and within land-use types depending on the duration of human habitation. Highly managed areas, particularly those managed for a relatively long period like institutions, major parks and older extensions of residential areas tend to have a higher proportion of large trees. Most of the trees are strategically placed along the compound of the institution or the edge of the playground, or as landscaped locale in case of parks. But a fundamental dichotomy exists between public and private trees in residential areas (Coughlin et al., 1984). The residents govern the nature of the private residential trees. In addition to the capricious human factor that furnishes the main source of variation, site attributes — the space available either as frontyards or backyards or in the sides, also determines the species choice. Private residential trees, therefore, represent the collective product of multiple decisions, which engender a heterogeneous treescape. Avenue trees in the public domain are subject to a constraining management regime. There is always a propensity for the choice of species, planting design and tree care. Hence, tree diversity and quality are often overlooked.

5.1.1. Residential areas

The socio-economic profile of residents and age of a neighborhood are found to be important determinants of the tree landscape (Schmid, 1975; Talarchek, 1990). In the older residential areas, especially the higher strata, due to single residential houses with vast frontyards and backyards, species richness and huge mature trees can be seen in the compounds. Tabata et al. (1983) found that the percentage of private gardens was higher in old residential areas. The higher new

strata, are dominated by high-rise blocks. With rising affluence, most of the housing estates developed are exorbitantly priced. Hence, most of the land is utilized in construction of the building with limited space around the building. But regulations by the Bangalore development authorities require a minimum width in the front, which provides some growing space. Again, due to the limited growing space, not many huge trees are preferred in the front yard. And the small front and back gardens and such small enclaves provide little opportunity for residents to satisfy their horticultural needs. Houses in the lower strata are of smaller dimensions and, most often, adjacent houses have common walls without compounds. A maximum utility of space without value for aesthetics is the need. Hence, few private gardens are maintained. Therefore, houses being close to each other show some degree of spatial clustering of species with streets acting as the basic building blocks for the definition of landscape differences due to which least species richness is observed.

Irrespective of the economic status and age of urbanization, *Cocos nucifera* and *Murraya koenigii* are the most ubiquitous choice of the residents, these being economically important species. *Cocos nucifera* thrives in most compounds as it is of lesser girth and the crown cover is not dense. *Murraya koenigii* is also a weak stemmed small tree which is in array with the limited available space. The leaves of the *Cocos nucifera* tree is used during auspicious occasions as decorative entrances; dried leaves are used as fuel and the dried midrib of the leaf is bundled and used as brooms. The fruit which is a drupe is an important ingredient of Indian cooking. The solid endosperm is used as the cooking ingredient and the watery endosperm has medicinal and nutritive value. The hard, stony endocarp shell is used as fuel along with the fibrous mesocarp of the fruit, which is also used for rope making. *Murraya koenigii* is also most preferred as the leaflets of the tree is used for seasoning Indian dishes and, hence, is a requirement for day-to-day cooking. In the lower income residential area, *Moringa oleifera* and *Musa paradisiaca* are preponderant. The main cause for its dominance is that these trees are fast-growing and do not need much care. And also, the lower strata do not consume *Cocos nucifera* as much as the residents of the higher strata, and it needs lot of care during the initial years of planting. *Moringa*

oleifera is a fast-growing tree and the long legumes are used as vegetables. The leaves are also used as vegetable by the residents. The tree is lopped regularly and the twigs and branches serve as fuel wood. *Musa paradisiaca*¹ is also an economically important plant. The fruits are highly nutritious and wholesome. The core of the stems and flowers are used as vegetable and the leaves are used as plates to serve food. New shoots spring up from old stems, and, hence, the relative density of the tree can be expected to remain high. *Polyalthia longifolia* is also a popular choice by the residents of the higher strata. It is an ornamental variety preferred for its foliage, which is dense, dark and glabrous. Due to its evergreen, thick foliage, which extends from the crown to almost ground level, and its drooping branches, it is planted in the periphery of gardens, and compounds at close distances.

Most of the houses have <5 trees in the compounds, echoing the general shortage of space for planting. Some houses do not plant any trees at all, some keep lawns with or without decorative shrubs and a few have compounds paved entirely with bare concrete. Hence, only houses with trees have been taken into records. Garden size, significantly associated with several variables, is evidently the cardinal concern in tree ecology. The number of trees per house suggests the efforts of the house owners to make adjustments to tree locations, to maximize utilization of the confined growing spaces and to minimize physical disruption to tree growth.

5.1.2. Avenue trees

Avenue trees form an important component of the city. In residential areas, one out of every three trees is along the avenues. Street trees contribute significantly to the street corridor environment (Schroeder and Cannon, 1987). Trees in Chicago constitute one out of every 10 trees overall and one out of every four trees in residential areas. In suburban Cook County, street trees constitute one out of every 37 trees and one of every 10 trees on residential land. Thus, street trees become a more important component of the urban forest in more urbanized areas as artificial surfaces and land-use activities compete for tree space. In Wicomico, Prince George and Anne Arundel, street trees

¹ *Musa paradisiaca* is a non-woody plant and does not contribute to the basal area. But it accounts for the high relative density.

account for 103, 100 and 95 trees/km, respectively (Zipperer et al., 1991). A high percentage of street trees in the Chicago area have >46 cm DBH. In Bangalore, most of the avenue trees are relatively young and not >15 years old as street-tree planting was taken up on a large scale only since 1982. The few mature trees in residential areas are concentrated in older extensions. Avenue trees sampled can also be categorized with similarities in street width and age of urbanization. Narrow streets characterize lower strata, whereas wider streets include the high-income neighbourhoods. The lower strata have the least public growing space and sidewalk width with narrow roads. Few houses with compounds are seen and most houses abut one another. Growing space is minimal outside the residential section. In the oldest residential areas, the large trees persist and new trees have been planted, which account for the mature street trees in this area. Preponderance of *Moringa oleifera*, *Cocos nucifera* and *Carica papaya* as avenue trees in the NLA is seen, though not promoted as avenue trees by the Forest. These trees are mainly planted by the residents in front of the houses on the narrow sidewalks due to lack of compound, and the benefits are reaped by them.

The main aspects of avenue trees are the amenity characteristics, environmental tolerance and landscape roles. *Michelia champaca*, a moderate-sized tree has fragrant flowers with minimal canopy cover and is a fast-growing tree. *Delonix regia*, the most visible species, grows to a moderate height, with crimson red showy flowers and a spread-out canopy. Rows of these trees lining the avenues on either sides is an awesome sight in the flowering season. *Spathodea campanulata* attains a sizable height with limited crown spread and the flowers are bright and showy, providing a picturesque sight. *Bauhinia variegata*, which is a relatively small tree, is represented almost entirely by young trees planted mainly for their attractive flowers. A comparison among tree species between residential compounds and along avenues in residential area showed that families prefer trees yielding edible fruits, flowers, leaves or multiple-use trees. The authorities prefer shade-yielding or flowering trees, largely for their decorative appearance.

There is a tendency to plant more fast-growing species, such as *Bauhinia variegata*, *Pongamia glabra*

and *Spathodea campanulata* in favour of slower growing ones. The urge to provide quick-greening results has led to the negligence of many native species. The increasing preoccupation with exotic species, particularly those with narrow or short stature that can establish rapidly, has reduced the importance of the indigenous stock. Narrow streets and sidewalks necessitate an unresolved search for fast-growing trees with upright growth forms. Recently, environmental pollution has become an important consideration for species selection. The small growing space poses great problem to the longevity of newly planted trees, because narrow streets and sidewalks lead to more serious stresses associated with pedestrian, automobile, and pollution damage. *Azadirachta indica*, a native species is one such example and is not promoted as an avenue tree. *Pongamia glabra* and *Bauhinia variegata* are drought-resistant and have high tolerance level to air pollution, hence thriving well as avenue trees. Trees such as *Samanea saman* and *Albizia lebbek* are found in few old residential areas which is characteristic of wide canopy cover and contributes significantly to the basal area. These are mainly planted on wide roads.

5.2. Urban trees and its potential

Urbanization increases the diversity of the plants in a city. The choice of introduced species, giving us an insight into how human preferences, sequence of occupancy and the available plant materials act to determine the ultimate composition of the urban forest. Urban forest is characterized by acts of removal of whole vegetation associations and introduction of new species giving rise to mixes of residual and introduced vegetation. A proper choice of urban trees could significantly contribute to the development of the city. Properly located trees shade residences in summer, thus reducing air-conditioning energy use (Heisler, 1986). Tree transpiration also reduces local air temperatures, which can affect local energy use. There has been little research on the amount of carbon that urban forests store. Carbon storage by urban trees in the United States has been estimated at 350–750 million t (Rowntree and Nowak, 1991; Nowak, 1993b). In the USA, it has been estimated that the establishment of 10 million urban trees annually over the next 10 years would sequester and offset the

production of 363 million t of carbon over the next 50 years; 77 million t due to direct sequestration and 286 million t due to avoided carbon emissions from power plants (Nowak, 1993b). There is a need for further research in this direction as the basal area in some of the land categories (in turn, the standing biomass or carbon density) is large (parks, banks of lakes and offices).

It is essential to plant trees which contribute most to the basal area, as it helps to sequester atmospheric carbon. The basal area of trees in residential areas in Bangalore is far below the threshold basal area of 5.5 m³/ha as in the eastern US (Considine and Frieswyk, 1982). In the oldest multi-family residential areas of Syracuse, NY, the basal area is 28 m³/ha due to existence of mature street and yard trees. The areal extent of forested areas having basal areas between 5.5 and 28 m²/ha is adequate for influencing wind, temperature runoff and wildlife populations (Rowntree, 1984). In the US, biomass is sufficient, if at least 10% land is stocked with trees of any size (US For. Serv., 1982). In India, with increasing population density, the use of fossil fuel has been increasing several folds. The use of biofuels for cooking is still prevailing in the lower strata, both in the semi-urban and urban areas. This necessitates having a higher percentage of area under tree cover as a mitigation strategy.

Increasing levels of atmospheric carbon dioxide and other greenhouse gases are leading to increase in atmospheric temperatures. This increase in atmospheric carbon dioxide is largely attributed to fossil fuel combustion and deforestation. Properly placed urban trees can have significant impact on atmospheric carbon dioxide buildup through energy conservation and reducing air conditioning (Sampson et al., 1992). From an atmospheric carbon perspective, a properly placed urban tree can be 4–15 times as effective at reducing atmospheric CO₂ as a rural tree, which primarily is only involved in carbon sequestration. First, it makes the quality of human life more healthy and pleasant, though the electricity saving for cooling will be very insignificant. It acts as a windbreak, effects the amelioration of urban noise, influences the air quality and increases fauna diversity. Analysis of urban trees in Oakland, CA, reveals a tree carbon storage level of 11 t/ha (Nowak, 1993b).

5.3. Management of the urban forest

Proper maintenance of the urban forest is critical. Urban trees have short lives, succumbing to many different stresses, such as drought, vandalism, and urban air pollution. Planting must be associated with a programme for tree care. In areas with power lines, the choice of species and tree location is critical to avoid unnecessary damage during storm events. The first priority of planting trees must be energy conservation by proper planting location. Next priority is to provide the maximum shade for parking lots and streets. It should be aimed to plant at least 10% of the residential area with trees and the choice of species should be such that it enhances the basal area. An ideal situation would be to have the sapling planted by the Forest Department and then being taken care of by the residents. The ownership of the tree will be given to the residents. This will encourage the residents to take active participation in greening the city and will also minimize the cost of maintenance by the Forest Department. The rate of survival of the saplings will be better due to daily monitoring by the residents. The Forest Department can also distribute free saplings to be planted in the residential compounds, especially of indigenous species like *Syzygium* sp., *Mangifera indica*, *Phyllanthus* sp., *Artocarpus integrifolius* and *Nyctanthus* sp., etc. that are economically important and also adds significantly to the basal area. The Forest Department can also plan medicinal parks with indigenous medicinal trees, such as *Saraca indica*, *Terminalia bellerica*, *Embllica officinalis*, etc. in residential localities with the involvement of residents. This will not only promote indigenous species and greenery, but will also educate people about the traditional medicinal value of trees.

6. Conclusion

Urban forest planning and management institutions can direct urban forest structure towards a desired outcome. The current pattern of urban vegetation has been formed through past and present human and environmental factors. However, the urban environment presents many constraints on urban forest structure that managers and planners must consider. Majority of the avenue species is exotic, largely

planted for their high growth rate and decorative appearance. It may also be desirable to plant trees that provide multiple benefits, particularly in compounds for providing edible pods, flowers, fruits, leaves, etc. Tree species, such as *Mangifera indica*, *Murraya koenigii*, *Moringa oleifera*, *Tamarindus indica*, *Artocarpus integrifolia*, *Phyllanthus emblica* and *Syzygium cumini*, can be promoted, which along with their economic importance add significantly to the biomass structure.

The density and basal area (standing stock or carbon density) in some categories of lands, such as parks, lake surroundings, institutions, is quite high. The tree-species richness and density within the small residential compounds is large. Many houses in Bangalore could be compared to the famous homestead gardens. Along with the exotics, other multi-purpose local tree species could also be promoted. The shift could be promoted by providing the seedlings of desired tree species at the right time either at commercial or subsidized rates to households, companies, hotels, etc.

More research is needed to get a better understanding of the urban forest. Research, that quantifies growth and mortality rates of urban trees, calculations of urban tree biomass, examination of the tree species and diameter distribution of urban trees, determines which tree species are the best for carbon sequestration, and analyzes through time the carbon production and reduction by urban trees in an urban forest carbon budget. Estimations need to be obtained to take up planting of trees in order to sequester the present levels of atmospheric carbon.

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