Plant diversity in cities: call for assessment and conservation

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Urbanization destroys natural habitats, displaces native ecosystems and results in regional extinction of native species. Urbanization is also argued to cause homogenization during which native species are replaced with non-native species. Negative impact of urbanization on ecosystems and biodiversity is usually focused upon while the fact that high levels of biodiversity may flourish inside cities are frequently ignored. Cities comprise a mixture of remnants of the pre-existing urban habitats and new urban habitats. The remaining fragments of natural landscapes, and other vegetation areas constitute the green infrastructure supporting the biological diversity of cities. Several biotopes such as lawns, hedges, parklands and street trees occur in the cities. In the cities ambient temperatures are higher than those of the surrounding rural areas, exhibiting the phenomenon of urban heat island. Urban vegetation experiences longer growing seasons and exhibits earlier greening than vegetation in the surrounding rural areas. Trees comprise the natural capital assets for cities as they provide immense benefits and ecosystem services for the wellbeing of city dwellers, although there are some disservices also. Studies on urban vegetation are very few in the tropics and particularly in India. In this article we review several aspects of plant diversity in cities in order to sensitize scientists, city managers and lay public to the need for more research on socio-economic benefits and costs of city vegetation and to augment the vegetation within cities through conservation.

Keywords: Benefits and cost of city trees, non-native species, plant diversity, urbanization.

CITIES are usually founded in species-rich areas where environment is congenial to life. Urbanization, however, destroys natural habitats, displaces native ecosystems[1,2] and results in regional extinction of rare native species. In cities, roads, buildings and other impervious surfaces occupy a substantial amount of space that could otherwise support vegetation. Research is usually focused on the adverse impact of urbanization on ecosystems, biodiversity hotspots and protected areas[3], but it is also true that high levels of biodiversity may occur within cities[4]. After all, humans have created landscapes and novel habitats in cities that are now occupied by native as well as novel plant communities[5,6]. The fact that urbanization can promote biodiversity in several instances is now drawing substantial interest.

Crowther *et al.*[7] mapped tree density on a global scale and found an inverse relationship between tree density and anthropogenic land use and stated 'The negative relationships between tree density and anthropogenic land use exemplify how humans contend directly with natural forest ecosystems for space.' Inverse relationship has been reported between density of the human population and tree cover in cities such as Baltimore, MD[8], Tampa, FL[9] and Montreal[10] and positive correlation between population density and residential tree cover in Raleigh, NC[11]. Thus density of human population may not be the sole factor driving the spatial distribution of vegetation, particularly tree canopy in cities, warranting consideration of other potential drivers (e.g. Troy *et al.*[8]). There has been a growing interest in examining the mechanisms which lead to the abundance and distribution of city vegetation[12]. Apart from population density, research now focuses on social stratification (e.g. spatial mobility and neighbourhood turnover, access to power and the luxury effect), lifestyle and reference group behaviour to explain the differential abundance of vegetation. The importance of time lags and landscape history is also being recognized[13].

Studies on urban vegetation are limited in the tropics[14,15], generally, and particularly in India[16–18]. In this article we review several aspects of plant diversity in cities to sensitize scientists, city managers and lay public to the need for more research on benefits and costs and to augment the vegetation within cities.

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City climate

Climate is among the primary determinants of plant diversity. Cities are characterized by their own specific microclimate, although they remain connected to the regional climates through the radiation balance and greenhouse gas emissions[19]. Cities experience higher ambient temperatures than non-urban areas; this phenomenon is called urban heat island (UHI). UHI occurs because of the modification of energy balance on account of the presence of urban canyons[20], thermal properties of the building materials[21], presence of impervious surfaces[22,23] and reduced albedo[24]. Zhang *et al.*[25] studied the onset dates for phenology and 'land surface temperatures for urban areas larger than 10 sq. km in eastern North America' and found that 'the vegetation in urban areas experienced longer growing seasons' and 'exhibited lower canopy density relative to rural areas'. White *et al.*[26] also reported earlier greening of vegetation in urban areas. Several authors have reported 'that the onset of flowering dates in urban areas of Europe occurs about 4–17 days earlier'[27,28]. Zhang *et al.*[25] concluded that 'the net effect of urban climate footprint is an increase in the growing season by about 15 days in urban areas relative to adjacent unaffected rural areas.' It is argued that in addition to increasing the amount of vegetation, roofs which account for up to 20–25% of the urban surface[29] can be converted into green roofs to reduce UHI effect, and to enhance air quality, storm-water management and biodiversity[30]. UHI intensities in tropical cities are generally lower compared to temperate cities and exhibit a seasonal variation (lower intensities during the wet and higher intensities during the dry season). In the dry season UHI intensities are the largest. Measurements in a tropical city (the city of Gaborone, in Botswana) indicated a weak night-time heat island (2–3°C) during the clear and calm nights. The densely vegetated areas in this city at noon were up to 2°C cooler than rural sites, while parts of the city having sparse vegetation were warmer.

Tropical cities differ from temperate cities in climate, ecology, demography, economic development and lifestyle, and are generally warmer and experience heavier rainfall[15]. According to the Koppen classification, which considers seasonality as an important factor[31,32], '(i) a tropical wet climate is characterized by significant year-round rainfall (e.g. Singapore and Salvador), (ii) tropical wet/dry (savanna) climate is characterized by pronounced dry season (e.g. Mumbai, Miami), (iii) tropical monsoonal climate experiences relative dryness for 1–3 months (e.g. Monrovia, Jakarta) and (iv) a tropical highland climate, where in absence of high altitude the climate would be tropical wet/dry (e.g. Bogota, Mexico City)[19]. 'Within the tropics near the equator, the climate is dominated by uniformly high temperatures throughout the year and the seasonal movement of the Hadley cells.'[19] The surroundings of cities (i.e. rural areas) in tropical wet climates support tall, 'lush vegetation, swamps, paddy fields or other forms of intensive agriculture' and are characterized by higher moisture availability and lower albedo, while those of the hot and dry climates contain denuded or sparsely vegetated land, sandy or rocky areas, scattered trees and shrubs[19]. Vegetation reduces the storage and uptake of heat in the day and thus could effectively mitigate the night-time UHI. Tropical cities are major producers of greenhouse gases responsible for global warming and emit vast amounts of other pollutants, and these processes are likely to be significantly impacted by changes in global climate[19].

Urban habitats

Cities comprise a mixture of remnants of the pre-existing habitats and new urban habitats. 'A city can be viewed as a complex habitat mosaic.'[33] McKinney[34] pointed out that urbanization drastically alters habitats, devegetating large areas, leading to paved and otherwise extensively modified areas such that the intensity of alteration exceeds the 'habitat changes that occur from logging, or traditional farming'[35].

Various studies have recognized different types of habitats in cities. Ignatieva *et al.*[36] identified seven biotopes (habitat types with plant) in Christchurch (New Zealand), viz. 'lawns, wastelands, herbaceous (flower) borders, shrubberies and hedges, parklands and street trees, and pavement cracks and walls', and argued that the English settlers in the city tried to create plant communities of their home countries. Zerbe *et al.*[37] gave a comprehensive habitat classification, with per cent area occupied by different habitats, for the city of Chonju (southwest Korea): '(i) built-up areas with mixed land-use including closely built-up and intensively sealed areas in the city centre and inner city; (ii) historically old residential areas including rural residential areas in the plains and rural residential areas in hills; (iii) green space and parks including city nature parks laid out in the 1980s with more than 10 ha. Parks laid out in the 1980s with 1–3 ha and parks laid out in the 1990s with 1–3 ha; (iv) commercial areas; (v) agricultural land-use, such as paddy fields, dry fields and orchards; (vi) rivers, lakes, ponds and their banks; (vii) traffic areas (railways and roadways); (viii) public facility areas, viz. university campus, hospitals, museums and schools; (viii) historical buildings and (ix) forests, such as 'natural forests dominated by broad-leaved trees, mixed natural forests, natural forests dominated by coniferous trees and anthropogenous forests dominated by broad-leaved trees or coniferous trees'.

Gardens have been treated as a major habitat type in cities because they are repositories of plants and support different kinds of human uses. For example, Mathieu *et al.*[38] recognized three types of gardens in Dunedin city (New Zealand): 'garden 1: mature and dense gardens with more than 70% of the area comprising trees and shrubs; garden 2: open gardens with mixed vegetation (trees, shrubs, hedges, and lawn), >30% and <70% of the area comprising trees and shrubs; and garden 3: Gardens dominated by lawns and less than 30% of the area comprising trees and shrubs.' In this city about 46% of the residential area constitutes vegetated garden.

The role of private gardens in supporting biodiversity in cities is now being increasingly stressed[38]. Private gardens provide food and sheter for wildlife, seed sources for regeneration, and connectivity between green spaces and green refuges in the otherwise harsh artificial environment[39]. City planners have started encouraging the establishment of private gardens. For example, in Sheffield (UK), '23% of the built-up area is private domestic garden (an estimated total of 175,000 private domestic gardens)'[38]. Another important city habitat is a corridor connecting two other habitats. Beninde *et al.*[3] underlined the importance of corridors for understanding and conservation of urban biodiversity. Corridors together with the patch area have by far the strongest positive effects over vegetation structure and plant diversity, as they increase the urban species richness and habitat quality.Werner[40] defined habitat patches as 'remnants of natural and semi-natural landscapes, parks, green spaces, waste lands, and other vegetation areas' which constitute the green infrastructure of the cities. Werner[40] also introduced the term urban matrix, for 'everything outside patches', and it is 'composed of areas with high-low-density building clusters and parts with high and low level of disturbances'. Walls, particularly in old cities, are another unique habitat that get colonized by plants which exhibit successional changes with the age of the walls[41,42].

Plant diversity

'Plant diversity is an important determinant of overall ecosystem biodiversity'[43]. Urbanization is considered a leading cause of species extinction[34], and therefore, it is often associated with negative impact on plant diversity. Urbanization, more often than not, results in replacing native species with more widely distributed non-native species and thus promotes biotic homogenization[44–46]. Heterogeneity in resource availability results in marked spatial variation in plant diversity[47]. Studies have frequently noted high species richness in cities because the spaces are extremely heterogeneous and frequently include habitat types which are rare or absent in the surrounding areas[48,49]. Aronson *et al.*[4] compiled data on plants from '110 cities and found that the majority of urban plant species are native in the world's cities', although, on an average, the number of species per km^2 markedly declined, with only 25% of native plant species currently present in the urban areas as compared to the non-urban species density. The species density was positively related to the cover of intact vegetation within cities as well as the city age. Thus greater the proportions of intact vegetation within cities, as in the older cities, greater the plant diversity[4].

'Cities are novel ecosystems, characterized by (i) fragmented and disturbed environments, (ii) high densities of fabricated structures and impervious surfaces with strong heat-retaining abilities, and (iii) elevated levels of some resources.'[4] In urban areas all habitats are created by humans and therefore, plant diversity in and around cities, usually reflects social, economic and cultural influences. The construction of cities and expansion of urban areas promote the replacement of native species by non-native species[34]. The native plant species richness declined within 50–150 years by 3–46% in 13 towns and cities representing several continents[50]. DeCandido *et al.*[51] reported that 'New York City has lost 578 native species (i.e. 43% of the original native species) but gained 411 non-native species.' McKinney[34] cites many such examples to show that the increasing intensity of urban activity has resulted in an increase in abundance and species richness of non-native species while native species have declined. According to Kowarik[52], 'the proportion of non-native plant species increases from 6% in nature preserves outside the city of Berlin, to 25% in the suburbs and 54% in the intensively urbanized central areas'. Two basic factors related to urbanization increase species richness of non-natives: (1) increased import of non-natives by humans and (2) presence of favourable habitat conditions provided by human settlements for establishment of the imported non-native species[34]. Urbanization leads to biological homogenization because the same exotic species are established in many cities and therefore, cities may have more similar plant communities than natural areas. However, if different non-native species are imported and they subsequently colonize different cities, then, as opposed to homogenization, biological differentiation can occur[46,53]. Through a massive data analysis, Aronson *et al.*[4] found that 'although some exotic species are shared across many cities, urban biotas have not yet become taxonomically homogenized at the global scale and continue to reflect their regional biogeographic species pool'. Cities could very well be a source of non-native species for the adjoining rural areas.

Compared to rural areas, urban habitats are characterized by lower species diversity, and a vegetation exhibiting low stability, increased patchiness and dominated by non-native species[42,54–56]. According to Lundholm *et al.*[42], urban vegetation is 'mainly dominated by weedy species which are adapted to human disturbance', for example, the wall flora of some of the cities are 'dominated by species from rocky habitats such as cliffs, talus'. The urban plants are mainly ruderals[42] and have been frequently defined as 'synanthropic (associated with man or human dwellings), anthropophytes (whose existence is

Table 1. Street trees statistics for six climatic zones in California[75]

	Inland Empire	Inland Valley	North California coast	South California coast	Southwest desert	Interior West	Total
Street length (km)	32,940	52872	35150	33607	16,766	4032	195,845
Area (km^2)	5074	8275	4431	6028	3643	1049	28,499
Mean density (trees/km)	50.74	38.64	56.75	51.09	37.64	6.58	46.62
Total street trees (1000s)	1671.4	204.7	1994.8	2763.3	631.1	26.5	9129.8
Trees per capita	0.29	0.28	0.30	0.21	0.50	0.13	0.26

related to human activities)[57], or hemerobes (being associated with areas of human impact)'[58]. As urbanization increases, the same 'urban-adaptable' species become widely distributed and locally abundant in all cities bringing about homogenization. Species frequency in urban area depends on species affinity to urban land use. The loss of native species[59,60] 'and the successful establishment of exotic species[61] is a dynamic process within urban plant communities'. Extinction due to urbanization may be species-specific. For example, urbanization increases the extinction risk of geophytes or hemicryptophytes and those dispersed by wind or ants[62]. In the urban areas of Germany, plant species that preferred moderately warm habitats[63] were most frequent, whereas those which preferred 'very warm habitats were less frequent than species preferring cool habitats'; this observation conforms with other studies[64,65]. The warmth-preferring species are more frequent because of higher temperatures of urban areas than the surrounding non-urban areas. Many urban habitats have alkaline soils and support greater frequency of 'species that occur in alkaline habitats; high alkalinity results partly from the use of alkaline building materials'[66].

The species richness along the rural–urban gradient is reported to depend on the species concerned[67], for example, while animal species richness declines from rural to more urban areas[68,69], that of plants often increases towards the city centre[68]. Studies report that rapid loss of area-sensitive species can be prevented if sites are larger than 50 ha (ref. 3). Just one University campus (Banaras Hindu University) in otherwise highly crowded Varanasi city, comprising 526.09 ha, yielded 574 species belonging to 426 genera and 111 families of Angiosperms[70]. They argued that 'increasing the area of habitat patches and creating a network of corridors is the most important strategy to maintain high levels of urban biodiversity'. They further pointed out that the positive-effect vegetation factors, such as herb density, herb cover, herb structure, shrub structure, shrub cover, tree structure, tree cover, and corridor 'could be utilized in conservation practice to enhance species richness in those urban landscapes where extending the size of green spaces is not an option'. Vegetation cover <10% causes rapid decline in species richness[71] and 20–30% of a specific habitat has to be protected to prevent the loss of species or populations[72]. Establishment of urban nature reserves to create space for biodiversity to flourish and to promote wellbeing of city dwellers[73] needs to be made mandatory while planning a city.

City trees

Willis and Petrokofsky[74] have forcefully argued that trees are indeed natural capital assets for cities as they provide immense benefits and ecosystem services for the wellbeing of city dwellers. Street trees hold a prominent position in the city vegetation. Trees growing along public streets, account for only a small proportion of the urban forest, but have a prominent impact on the quality of urban life[75]. Different parts of a city may experience different environment and hence may host variable number of street trees. Table 1 records statistics on street trees of six climatic zones of California.

City trees take up substantial amounts of carbon dioxide, cause local cooling, ameliorate the UHI effect, and reduce pollution and improve human health[74]. However, these beneficial effects depend upon the species of the trees. Willis and Petrokofsky[74] show that vegetation acts 'as a natural filter, by removing particulate matter from the air through the interception of airborne particles or the uptake of gaseous air pollutants through stomata. Foliage cover, physical shape of the species, deciduousness, and height are important tree characteristics'. Shorter trees remove particulate matter more effectively than tall trees. Willis and Petrokofsky[74] cite studies to show the positive effects of city trees on physical and mental health of city dwellers. But some studies also show that some tree species release air-borne pollen allergic to humans (often causing asthma), and some other tree species also emit inimical biogenic volatile organic compounds associated with ozone formation in the troposphere. The trees can also cause hazards, for example, through wind throw and other 'ecosystem disservices' which include negative impacts on human well-being, such as nuisance, health risks, aesthetic problems and different types of pollution[76]. Therefore, selection of tree species to be planted within city boundary is important.

Street trees exhibit spatial continuity in the city vegetation[77]. McPherson and Rowntree[78] 'identified three patterns of age structure in street tree populations in California: youthful populations having >40% of individuals in the

Table 2. Annual monetary value (USD) per tree of services from street tree populations in six US cities[88]

Services	Modesto[92]	Santa monica[92]	Berkeley[93]	Indiana[94]	Missouri[95]	California
Energy	10.89	4.82	15.16	6.83	32.71	11.08
Carbondioxide	3.42	1.67	1.28	0.82	2.75	1.13
Air quality	5.9	6.01	–0.04	1.99	3.68	1.99
Storm water	6.75	3.78	5.42	17	29.91	4.55
Property value/other	26.11	64.82	69.63	28.88	33.44	91.89
Total	53.07	81.1	91.44	55.52	102.48	110.63

Table 3. Annual benefit and cost (disservices) of trees for five cities (USD)[88]

City name	Lisbon	Albuquerque	Berkeley	Charlotte	Santa Monica
Total trees	41,247	21,519	36,485	85,146	29,229
City population	564,657	484,246	104,000	597,308	92,578
Tree/capita	0.07	0.01	0.3	0.14	0.28
Annual benefit ($)					
Energy	254,185	170,422	553,061	914,001	141,032
CO_2	13,701	15,389	49,588	198,548	48,812
Air quality	222,738	23,855	–20,635	–36,270	171,782
Storm water	1,973,613	55,830	215,645	2,077,392	110,486
Property value	5,968,592	295,282	2,449,884	2,757,217	1,894,758
Total benefits	8,432,779	560,778	3,247,543	5,910,888	23,66,870
Total costs	1,882,323	428,500	2,372,000	1,819,460	15,44,000
Net benefits	6,550,456	132,278	875,543	4,091,428	822,870
Benefits-cost ratio	4	1	1.37	3	2

smallest diameter at breast height (dbh); maturing populations having more individuals in the 16–45 cm dbh class than in the 0–15 cm class', and mature populations with relatively even proportions of trees in all dbh classes. A greater proportion of small dbh trees offset establishment related mortality. According to Richards[79], 'A target age distribution for population stability would be 40% of all trees under 20 cm dbh; 30%, 20–40 cm; 20%, 40–60 cm and 10%, >60 cm'. Over a 15-year period planting of small, short-lived species increased in California due to lack of space and the diversity declined. The average number of trees per km street length also declined from 65.6 in 1988 to 64.3 in 1993 (ref. 75).

Trees change the urban environment in several ways: (i) evapotranspiration cools the leaf surface and the surrounding air[80,81]; (ii) provide shade to avoid heating up of the ground[82], affect the movement of air current and heat exchange[83]; (iii) in winters, trees modify the wind speed and reduce the heat loss from urban structures[84]. In addition, trees: (i) reduce carbon dioxide emission and produce oxygen, (ii) reduce noise pollution, (iii) reduce storm water runoff, (iv) mitigate the intensity of heat and ease the temperature, (v) reduce air pollution, and (vi) help maintain biodiversity of urban vegetation[85]. For example, 9.1 million street trees in California are estimated to remove 567,748 tonne CO_2 annually, store 7.78 million metric tonnes of CO_2, and intercept 26.19 million m^3 $year^{-1}$ of rainfall annually. 'Annual air pollutant uptake by 9.1 million street trees of California totals 2658 tonnes $year^{-1}$' (ref. 75).

Urban trees provide habitat for urban wildlife[76], and diverse social, economic, psychological, medical, aesthetic benefits, in addition to storm-water related and energy related ecosystem services[76,86,87]. Annual monetary value of ecosystem services per tree from street tree population in six US cities is given in Table 2. However, as stated earlier, urban trees also impose some costs which can be considered 'ecosystem disservices'[76]. In urban ecology literature, ecosystem disservices have been defined as negative impacts on human well-being, such as nuisance, fear, threat of physical harm, health risks, aesthetic problems and different types of pollution[76], thus the ecosystem disservices would include impacts that degrade the quality of life of city dwellers and impose financial, health and maintenance burdens upon urban residents and municipal land managers. Table 3 includes estimates for monetary value of annual benefit and cost of trees for five cities[88]. Three researches were conducted in India on this topic[89–91]. Nagendra and Gopal[89] studied Bangalore's street tree populations and reported that the streets are being selectively denuded of its largest trees. These authors also found that older trees had a more diverse distribution with several large-sized species, while young trees were from a less diverse species set, and were largely 'dominated by small statured species with narrow canopies, which have a lower capacity to absorb atmospheric pollutants, mitigate urban heat island effects, stabilize soil, prevent ground water runoff, and sequester carbon'. Manzoor Shah *et al.*[90] found mostly negative relationships between the invasive *Conyza canadensis* 'abundance and native species richness in non-native ranges, but either positive or no relationships in its native North American range'. Also in glasshouse experiments,' the total biomass of *Conyza* was suppressed more by species from its native range than by species from regions where it is non-native'. Hiremath and Sundaram[91] reviewed literature on invasive species and their impact on protected areas of India and found that invasive species management needs to move beyond just invasive plant removal and 'needs to include an ecosystem approach that also considers drivers of invasion'.

As cities provide important repositories of plant wealth which has enormous benefits for humans, plant diversity in cities, particularly in the tropics, needs to be assessed and conserved.

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