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Contrasting natural regeneration and tree planting in fourteen North American cities

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ABSTRACT

Field data from randomly located plots in 12 cities in the United States and Canada were used to estimate the proportion of the existing tree population that was planted or occurred via natural regeneration. In addition, two cities (Baltimore and Syracuse) were recently re-sampled to estimate the proportion of newly established trees that were planted. Results for the existing tree populations reveal that, on average, about 1 in 3 trees are planted in cities. Land uses and tree species with the highest proportion of trees planted were residential (74.8 percent of trees planted) and commercial/industrial (61.2 percent) lands, and *Gleditsia triacanthos* (95.1 percent) and *Pinus nigra* (91.8 percent). The percentage of the tree population planted is greater in cities developed in grassland areas as compared to cities developed in forests and tends to increase with increased population density and percent impervious cover in cities. New tree influx rates ranged from 4.0 trees/ha/yr in Baltimore to 8.6 trees/ha/yr in Syracuse. About 1 in 20 trees (Baltimore) and 1 in 12 trees (Syracuse) were planted in newly established tree populations. In Syracuse, the recent tree influx has been dominated by *Rhamnus cathartica*, an exotic invasive species. Without tree planting and management, the urban forest composition in some cities will likely shift to more pioneer or invasive tree species in the near term. As these species typically are smaller and have shorter life-spans, the ability of city systems to sustain more large, long-lived tree species may require human intervention through tree planting and maintenance. Data on tree regeneration and planting proportions and rates can be used to help determine tree planting rates necessary to attain desired tree cover and species composition goals.

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Introduction

The quantity of trees within a city can number in the millions (e.g., Barcelona, Spain = 1.4 million (Chaparro and Terradas, 2009); Washington, DC = 1.9 million (Nowak et al., 2006); Philadelphia, PA = 2.1 million (Nowak et al., 2007a); Chicago, IL = 3.6 million (Nowak et al., 2010); New York, NY = 5.2 million (Nowak et al., 2007b); Los Angeles, CA = 6.0 million (Nowak et al., 2011); Toronto = 10.2 million (City of Toronto, 2011)) and nationally in the United States is in the billions (Nowak et al., 2001). The urban forest provides a full suite of ecosystem services and values to a city and its residents, but also various economic or environmental costs. Trees provide various benefits associated with air and water quality, building energy conservation, cooler air temperatures, reductions in ultraviolet radiation, and many other environmental and social benefits (e.g., Dwyer et al., 1992; Kuo and Sullivan, 2001; Westphal, 2003; Wolf, 2003; Nowak and Dwyer, 2007). Costs associated with trees are both economic (e.g., planting and maintenance, increased building energy costs) and environmental (e.g., pollen, volatile organic compound emissions) (Heisler, 1986; Nowak and Dwyer, 2007; Escobedo et al., 2011).

The city tree resource is constantly changing due to various natural and anthropogenic forces (e.g., Nowak, 1993). A recent analysis of U.S. cities reveals that tree cover has declined in recent years (Nowak and Greenfield, 2012). To help sustain tree cover in cities, various city programs are planting large numbers of trees (e.g., City of New York, 2011; City of Los Angeles, 2011), protecting existing trees (e.g., Town of Chapel Hill, 2011; City of Pasadena, 2011) and developing tree canopy goals (e.g., City of Seattle, 2011; Maryland Dept. of Natural Resources, 2011).

Many of these urban tree canopy programs involve tree planting to help sustain tree cover and associated environmental services and values. However, a critical question in developing tree planting goals and appropriate budgets is how much of the city tree population actually is or needs to be planted? If most of the urban forest is planted, then human efforts toward tree planting are critical to sustaining tree cover. If most of the urban forest cover or population derives from natural regeneration, then efforts directed toward tree

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planting might not be the most productive or cost effective means to sustain the city tree population. In this case, efforts to facilitate natural regeneration might be the best option to sustain tree cover.

Various factors that affect tree cover in cities (e.g., Nowak et al., 1996) are likely the same forces that will influence natural regeneration in cities. These forces include natural environmental conditions (e.g., precipitation, air temperatures, surrounding natural vegetation type) and the distribution of land use types in the city. The natural environment can provide a seed source and conditions conducive to regeneration, while land uses often dictate the amount of management or human interventions that can limit natural regeneration (e.g., impervious surfaces, mowing, soil compaction) and may increase tree planting rates.

Unfortunately, to date, there have not been any studies investigating the magnitude of natural regeneration or tree planting across an entire city system. To help remedy this dearth of information, this study uses field data from cities in the United States and Canada that recorded whether a sampled tree was planted or occurred through natural regeneration. Though not a perfect means to assess planting and natural regeneration in cities, these data can provide some essential and basic information on natural regeneration vs. tree planting in cities. The objectives of this paper are to: (a) estimate the percentage of the city tree population that is planted in 14 U.S. and Canadian cities, (b) estimate how the proportion of tree population that is planted varies among land use and species within cities, and (c) discuss the implications of the results for city tree canopy programs.

Methods

Field data were collected in 14 cities in the United States and Canada (Table 1) to assess the ecosystem services provided by the urban forest using the i-Tree model (Nowak et al., 2008). Nine of the cities are from southern Ontario Canada, which has a fully humid snow climate with a forest potential natural vegetation type (Kottek et al., 2006; Kuchler, 1966). These cities include London, Toronto and neighboring Toronto communities (Ajax, Brampton, Markham, Mississauga, Pickering, Richmond Hill and Vaughan). Two of the five U.S. cities are also found in this same climate and potential natural vegetation type (Hartford, Syracuse). The other U.S. cities were located in a fully humid snow climate with a mixed grassland and forest potential natural vegetation type (Chicago); a fully humid, warm temperate climate with a forest potential natural vegetation type (Baltimore); and a warm temperate climate with dry summer with a grassland (California steppe) potential natural vegetation type (Los Angeles).

In each city, randomly located 0.04 ha field plots were measured with all woody vegetation with a diameter at breast height (dbh at 1.37 m) of at least 2.54 cm recorded as a tree. Land use of each plot was also recorded along with basic tree measurements (e.g., species, dbh, height) including a designation as to whether each tree was likely planted or occurred from natural regeneration. As the designation of planting versus natural regeneration can be difficult, field crews were asked to make the best designation possible given the various site conditions around each tree. Site context included maintenance of the tree or the area around the tree site, and location of the tree relative to anthropogenic objects. For example, trees along fence lines or in unmaintained/vacant areas are often classified as naturally regenerated, while trees in maintained lawn areas or street trees would often be classified as planted. No strict rules could be set to make this classification; crews were instructed to use local site clues to make the best designation possible. In a few cases (less than 1 percent), if no designation could be made, the tree planting status was classified as unknown and not included in the analysis.

Two cities (Syracuse and Baltimore) used a stratified random sampling design instead of basic random sampling, with plot distribution pre-stratified by land use (i.e., each land use was sampled with a different plot density). In Syracuse, plots were measured in 2001 and 2009. In Baltimore, plots were measured in 2004 and 2009. As tree ingrowth (newly established trees greater than 2.54 cm dbh since prior measurement) could be determined, only newly established trees were evaluated as to planting status. If no designation could be made, the tree planting status was classified as unknown and not included in the analysis of planting proportion. However, all newly established trees were included in the analysis of total regeneration rates by land use type. The density of newly established trees was calculated by dividing the number of newly established trees by the total area sampled. The density of new trees that were planted or naturally regenerated was calculated by multiplying the total new tree density by the proportion of trees that were classified as planted or natural regeneration. As the remeasurement period was either five (Baltimore) or eight (Syracuse) years, the new tree establishment rate was divided by number of years between measurements to estimate an annual influx rate.

The percentage of trees in each city and within each land use type that were classified as planted was calculated by dividing the number of trees planted by the total number of trees. To estimate the total percent of trees classified as planted in the cities with a stratified random sample, the land use estimates were weighted by land use area. This weighting was not necessary for the cities with simple random sampling. To estimate the percent planted by species or land use, only species or land uses with a minimum sample size of 10 per city were analyzed to avoid potential misleading results due to a small sample size.

The data from the 12 cities were aggregated into common land uses to determine the planting percentage by land use and overall for the entire sample population. Likewise, the species data were

Table 1
Number of plots, year of data collection and data collection group for analyzed cities.

City	No. plots	Year	Data Collection Group
Ajax, Ont.	198	2008	Toronto and Region Conservation Authority
Baltimore, MD	195	2004, 2009	U.S. Forest Service
Brampton, Ont.	196	2008	Toronto and Region Conservation Authority
Chicago, IL	745	2007	City of Chicago, Chicago Park District, U.S. Forest Service
Hartford, CT	200	2007	Knox Parks Foundation
London, Ont.	383	2008	Upper Thames River Conservation Authority
Los Angeles, CA	348	2007/08	U.S Forest Service, University of California, Riverside
Markham, Ont.	213	2009	Toronto and Region Conservation Authority
Mississauga, Ont.	205	2008	Toronto and Region Conservation Authority
Pickering, Ont.	219	2009	Toronto and Region Conservation Authority
Richmond Hill, Ont.	208	2009	Toronto and Region Conservation Authority
Syracuse, NY	198	2001, 2009	U.S. Forest Service
Toronto, Ont.	407	2008	City of Toronto
Vaughan, Ont.	212	2009	Toronto and Region Conservation Authority

Table 2
Percent of city tree population classified as planted, city human population density (#/ha) and city percent tree and impervious cover.

City	%Planted	SE	n	Tree cover		Imp. cover		Year	Pop. density
				%	SE	%	SE		#/ha
Los Angeles, CA	89.0	1.2	683	20.6	1.3	54.0	1.6	2009	31.7
Mississauga, Ont.	57.7	2.0	608	19.0	1.8	49.4	2.2	2009	23.2
Toronto, Ont.	45.9	1.0	2669	26.5	0.4	47.9	0.5	2009	39.3
Chicago, IL	45.0	1.2	1791	18.0	1.2	58.5	1.6	2009	48.1
Markham, Ont.	33.7	1.4	1204	19.3	1.2	26.5	1.4	2009	12.3
Ajax, Ont.	30.0	1.1	1688	18.4	1.2	26.6	1.4	2009	13.4
London, Ont.	29.0	0.9	2445	27.2	1.6	31.9	1.6	2008	14.9
Richmond Hill, Ont.	27.4	1.0	2079	24.5	1.4	31.8	1.5	2011	15.9
Vaughan, Ont.	25.9	1.1	1524	19.5	1.3	24.7	1.7	2009	8.7
Brampton, Ont.	19.9	1.2	1125	15.2	1.6	28.8	2.0	2009	16.1
Pickering, Ont.	18.4	0.7	3060	25.5	1.4	20.4	1.3	2008	18.6
Syracuse, NY[a]	12.8	1.3	675	26.9	1.4	49.5	1.6	2009	21.6
Hartford, CT	11.1	1.1	883	26.2	2.0	44.4	2.2	2011	27.8
Baltimore, MD[a]	7.3	2.1	148	28.5	1.0	45.8	1.1	2009	30.2

SE = standard error, n = number of trees sampled, Year = year of imagery to determine cover percentages via photo-interpretation.
[a] City estimated based on weighted sample estimate of newly planted trees only.

aggregated to determine the overall planting percentage by species for species with a minimum sample of 50 trees that occurred in at least two cities. As data from Baltimore and Syracuse were only for newly planted trees, these data were not included in the overall population summaries.

The percentage of tree and impervious cover was estimated for each city using photo-interpretation of random points on aerial images. The percentage of tree or impervious cover (p) was calculated as the number of sample points (x) hitting the cover attribute divided by the total number of interpretable sample points (n) within the area of analysis ($p = x/n$). The standard error of the estimate (SE) was calculated as $SE = \sqrt{p * (1-p)/n}$ (Lindgren and McElrath, 1969). To explore relationships among percent planted and other urban variables within a city, Pearson product moment correlation was used to test for relationships between percent of population planted and: (a) population density and (b) percent impervious cover in cities.

Results

The overall percentage of trees estimated as being planted within cities averaged 32.7 percent (not including Baltimore or Syracuse), but varied from 7.3 percent in Baltimore to 89.0 percent in Los Angeles (Table 2). The percentage of trees planted by land use varied within the cities (Table 3). Residential (74.8 percent planted) and commercial/industrial (61.2 percent) had the highest proportion of planted trees and park/cemetery/golf (10.7 percent), open space/vacant (7.1 percent), agriculture (2.0 percent) and wetland/water (0.8 percent) had the lowest proportion of planted trees (Table 4).

The percentage of the species population that was planted also varied within the cities (Table 5). Species with the highest proportion of planting were *Gleditsia triacanthos* (95.1 percent), *Pinus nigra* (91.8 percent), *Juniperus virginiana* (89.2 percent), *Picea pungens* (89.1 percent) and *Picea abies* (85.2 percent) (Table 6). The least commonly planted species included *Populus deltoides* (5.8 percent), *Prunus serotina* (5.2 percent), *Ailanthus altissima* (4.4 percent), *Fagus grandifolia* (2.5 percent) and *Rhamnus cathartica* (1.0 percent) (Table 6).

The overall density of tree planting was 0.7 trees/ha/year in Syracuse and 0.2 trees/ha/year in Baltimore. Natural regeneration rates were higher, being 7.9 trees/ha/year in Syracuse and 3.8 trees/ha/year in Baltimore (Table 7). The highest tree influx rates, which were mostly due to natural regeneration, occurred on vacant, multi-family residential, and park/cemetery/golf lands in Syracuse and on forest/open space land in Baltimore (Table 7).

Discussion

Understanding the proportion of the urban forest that is actually planted by land use and species can lead to better planning of resources to sustain urban forest cover and desired species composition. The proportion of planted trees varied by land use type. More managed or human-dominated land uses (i.e., residential, commercial/industrial) had a greater proportion of planted trees than land uses containing less managed or more natural lands (e.g., parks, open space, wetlands). An exception to this generalization is agricultural lands, which are highly managed, but often managed to specifically exclude trees. Thus the proportion of planted vs. naturally regenerated trees depends upon a mix of natural forces and human actions.

One city, Hartford, had a relatively low proportion of planted trees (11.1 percent) compared to existing tree populations in other cities. This low proportion is likely due to a combination of the forest environments in Connecticut and the landscape structure in Hartford. Though the tree cover in Hartford was only 26.2 percent, urban tree cover on average in Connecticut is the highest in the nation, averaging 66.5 percent (unpublished data). This overall conducive environment to tree growth may be a factor in the proportion or amount of natural regeneration occurring in Hartford. Proportion of trees planted would decline if natural regeneration could successfully establish desired tree canopy. Also Hartford contains several natural areas and within residential lands with often small properties, tree regeneration along fences and property boundaries is common.

Overall, only about 1 in 3 trees in urban areas are planted. Thus 2/3 of the existing urban forest is from natural regeneration. These statistics are based on a sample of cities that is heavily dominated by cities occurring within naturally forested areas where natural regeneration can readily occur if not precluded by human actions (e.g., mowing, impervious surfaces). The cities in grassland, or mixed grassland – forest areas, had a greater proportion of trees planted (Los Angeles – 89.1 percent, Chicago – 45.0 percent) indicating that human actions are likely required more in non-forested regions to sustain canopy cover.

As most of the cities (12 out 14; 86 percent) are from forested areas, with most cities from one geographic region (Toronto), the overall averages from the sample do not likely represent the true average for cities in the United States and Canada. However, the distribution of urban land in the United States by potential natural vegetation type is comparable to the sample distribution. Based on classifying States by their dominant potential natural vegetation type, approximately 80 percent of U.S. urban land is classified

Table 3
Percent of tree population planted by land use (minimum sample size = 10).

City	Land use	% Planted	SE	n
Ajax, Ont.	Institutional	100.0	0.0	11
	Residential	97.2	1.0	253
	Agriculture	86.7	9.1	15
	Commercial/Industrial	48.8	7.9	41
	Park/Cemetery/Golf	27.1	2.1	469
	Vacant	10.0	1.0	899
	Total	30.0	1.1	1688
Baltimore, MD[a]	High Density Residential	10.5	7.2	19
	Forest/Open Space	1.9	1.4	104
	Medium/Low Density Residential	0.0	0.0	16
	Total[b]	7.3	2.1	148
Brampton, Ont.	Commercial/Industrial	95.5	4.5	22
	Residential	65.0	3.2	226
	Parks	61.3	8.9	31
	Vacant	4.4	0.8	663
	Golf Course	1.9	1.3	106
	Agriculture	0.0	0.0	60
	Transportation	0.0	0.0	11
	Total[b]	19.9	1.2	1125
Chicago, IL	Institutional	90.6	4.1	53
	Multi-family residential	80.6	4.0	98
	Cemetery	80.0	13.3	10
	Residential	73.9	1.6	714
	Commercial/Industrial	27.0	3.7	141
	Park	17.1	1.7	516
	Vacant	12.0	3.8	75
	Transportation	4.3	1.5	184
	Total	45.0	1.2	1791
Hartford, CT	Right-of-way	35.7	6.5	56
	Multi-family residential	22.5	4.2	102
	Commercial/Industrial	17.4	5.7	46
	Residential	17.1	4.5	70
	Municipal/Govt.	13.2	3.9	76
	Institutional	10.6	2.1	216
	Park	0.6	0.4	317
	Total	11.1	1.1	883
London, Ont.	Residential	77.5	1.6	699
	Commercial/Industrial	70.0	6.0	60
	Transportation	34.3	5.8	67
	Park	20.6	3.1	175
	Institutional/Golf	9.7	3.8	62
	Vacant	3.8	0.5	1349
	Agriculture	0.0	0.0	25
	Total[b]	29.0	0.9	2445
Los Angeles, CA	Medium to High Density Residential	100.0	0.0	71
	Commercial	100.0	0.0	51
	Industrial	100.0	0.0	15
	Transportation & Utilities	100.0	0.0	13
	Low Density Residential	98.0	0.7	446
	Other	50.0	13.9	14
	Vacant	19.2	4.6	73
	Total	89.0	1.2	683
Markham, Ont.	Commercial/Industrial	100.0	0.0	20
	Golf Course	100.0	0.0	10
	Residential	97.9	0.7	380
	Institutional	2.2	1.6	89
	Vacant	0.2	0.2	445
	Agriculture	0.0	0.0	112
	Parks	0.0	0.0	146
	Total[b]	33.7	1.4	1204
Mississauga, Ont.	Commercial/Industrial	98.1	1.9	53
	Residential	83.2	2.2	303
	Transportation	42.9	11.1	21
	Vacant	25.4	5.2	71
	Parks	13.8	3.2	116
	Institutional	9.1	4.4	44
	Total	57.7	2.0	608
Pickering, Ont.	Commercial/Industrial	92.3	7.7	13
	Residential	76.0	1.7	649
	Other	43.5	10.6	23
	Institutional	17.4	8.1	23
	Utility	10.7	3.4	84
	Parks	2.1	0.4	1241
	Vacant	0.8	0.3	991
	Golf Course	0.0	0.0	25
	Transportation	0.0	0.0	11
	Total	18.4	0.7	3060
Richmond Hill, Ont.	Commercial/Industrial	82.7	4.2	81
	Residential	64.8	2.1	522
	Open Space/Natural	20.1	1.5	690
	Other	6.8	1.3	384
	Agriculture	0.0	0.0	368
	Utility/Transportation/ Institutional	0.0	0.0	34
	Total	27.4	0.9	2709
Syracuse, NY[a]	Residential	29.1	3.5	165
	Institutional	2.6	2.6	38
	Vacant	1.4	0.7	292
	Park/Cemetery/Golf	0.0	0.0	86
	Multi-family Residential	0.0	0.0	71
	Utilities/Transportation	0.0	0.0	21
	Total[b]	12.8	1.3	675
Toronto, Ont.	Multi-family Residential	94.4	3.1	54
	Residential	73.5	1.2	1322
	Industrial	44.9	7.2	49
	Institutional	36.5	5.6	74
	Commercial	31.0	5.5	71
	Other	15.2	2.6	191
	Open Space	14.6	3.5	103
	Parks	11.3	1.2	750
	Utility & Transportation	3.6	2.5	55
	Total	45.9	1.0	2669
Vaughan, Ont,	Commercial/Industrial	93.4	3.2	61
	Other	88.2	8.1	17
	Residential	79.5	2.5	259
	Parks	15.0	2.4	227
	Vacant	11.0	1.1	748
	Wetland/Water	0.8	0.8	127
	Agriculture	0.0	0.0	85
	Total	25.9	1.1	1524

SE = standard error, n = number of trees sampled.
[a] City estimated based on weighted sample estimate.
[b] Total includes trees sampled from other land uses with sample size less than 10.

within forested natural vegetation types. To determine the true overall average proportion of tree planting in the United States and Canada, more field data are needed that represent urban tree populations across these nations.

Cities with greater population density (Pearson product moment correlation coefficient (r) = 0.45) and/or higher percent

Table 4
Overall percent of tree population planted by land use within 12 cities (Baltimore and Syracuse data not included).

Land use	% Planted	SE	n
Residential	74.8	0.5	6439
Commercial/Industrial	61.2	1.8	732
Institutional	19.7	1.5	689
Utilities/Transportation	15.1	1.5	557
Other	13.8	1.4	629
Park/Cemetery/Golf	10.7	0.5	4225
Open Space/Vacant	7.1	0.3	6503
Agriculture	2.0	0.5	665
Wetland/Water	0.8	0.8	127

SE = standard error.

Table 5
Percent of species population planted within cities (minimum sample size = 10).

City	Species	% Planted	SE	n
Ajax, Ont.	*Gleditsia triacanthos*	100.0	0.0	16
	Malus sylvestris	100.0	0.0	13
	Pinus nigra	100.0	0.0	13
	Picea glauca	94.4	3.9	36
	Acer platanoides	91.7	5.8	24
	Acer saccharinum	84.6	10.4	13
	Pinus strobus	69.9	5.1	83
	Thuja occidentalis	63.4	2.7	331
	Pinus sylvestris	50.0	16.7	10
	Populus balsamifera	33.3	14.2	12
	Fraxinus pennsylvanica	13.7	4.9	51
	Pinus resinosa	10.0	6.9	20
	Betula papyrifera	7.1	7.1	14
	Prunus virginiana	6.3	6.3	16
	Rhamnus cathartica	4.2	1.8	120
	Populus tremuloides	4.1	2.3	73
	Acer saccharum	3.6	1.3	194
	Fraxinus americana	0.7	0.7	149
	Tsuga canadensis	0.0	0.0	85
	Rhamnus spp.	0.0	0.0	39
	Acer negundo	0.0	0.0	38
	Ulmus americana	0.0	0.0	35
	Tilia americana	0.0	0.0	21
	Crataegus chrysocarpa	0.0	0.0	17
	Crataegus spp.	0.0	0.0	16
	Ostrya virginiana	0.0	0.0	15
	Salix spp.	0.0	0.0	12
	Prunus serotina	0.0	0.0	11
	Robinia pseudoacacia	0.0	0.0	10
Baltimore, MD[a]	*Fagus grandifolia*	0.0	0.0	27
	Ailanthus altissima	0.0	0.0	15
	Morus alba	0.0	0.0	12
	Prunus serotina	0.0	0.0	10
Brampton, Ont.	*Thuja occidentalis*	100.0	0.0	56
	Gleditsia triacanthos	100.0	0.0	11
	Acer platanoides	93.8	4.3	32
	Picea glauca	80.8	7.9	26
	Populus tremuloides	28.6	12.5	14
	Fraxinus americana	17.9	5.2	56
	Pinus resinosa	17.6	6.6	34
	Acer saccharum	16.7	4.9	60
	Fraxinus spp.	5.7	4.0	35
	Rhamnus spp.	0.3	0.3	325
	Crataegus succulenta	0.0	0.0	60
	Acer negundo	0.0	0.0	34
	Ostrya virginiana	0.0	0.0	34
	Fraxinus nigra	0.0	0.0	33
	Tilia americana	0.0	0.0	30
	Crataegus chrysocarpa	0.0	0.0	27
	Fagus grandifolia	0.0	0.0	19
	Ulmus americana	0.0	0.0	16
	Crataegus mollis	0.0	0.0	15
	Carya ovata	0.0	0.0	14
	Crataegus spp.	0.0	0.0	14
	Ulmus rubra	0.0	0.0	11
Chicago, IL	*Thuja occidentalis*	100.0	0.0	55
	Taxus spp.	100.0	0.0	29
	Picea pungens	100.0	0.0	19
	Juniperus spp.	100.0	0.0	16
	Viburnum spp.	100.0	0.0	16
	Syringa spp.	100.0	0.0	15
	Juniperus virginiana	100.0	0.0	14
	Gleditsia triacanthos	94.6	3.0	56
	Acer platanoides	93.1	3.0	72
	Acer rubrum	91.7	8.3	12
	Malus spp.	91.3	6.0	23
	Ulmus pumila	79.3	7.7	29
	Quercus alba	78.6	11.4	14
	Acer saccharinum	69.0	5.1	84
	Celtis occidentalis	54.8	9.1	31
	Fraxinus pennsylvanica	48.9	5.4	88
	Prunus spp.	35.7	9.2	28
	Tilia cordata	34.6	9.5	26
	Acer saccharum	31.6	7.6	38
	Ulmus americana	25.3	4.9	79
	Morus spp.	24.5	4.5	94
	Fraxinus americana	22.9	4.0	109
	Tilia americana	21.4	7.9	28
	Crataegus spp.	17.9	5.2	56
	Tilia spp.	14.3	6.0	35
	Prunus serotina	9.1	6.3	22
	Ulmus spp.	8.3	8.3	12
	Ailanthus altissima	7.6	3.0	79
	Quercus rubra	6.7	4.6	30
	Populus deltoides	3.6	2.5	56
	Acer negundo	3.4	2.4	59
	Rhamnus spp.	2.6	2.6	39
	Rhamnus cathartica	0.0	0.0	71
Hartford, CT	*Pinus strobus*	40.0	16.3	10
	Acer saccharum	27.8	10.9	18
	Malus spp.	26.7	11.8	15
	Acer saccharinum	17.9	7.4	28
	Fraxinus pennsylvanica	16.7	11.2	12
	Quercus palustris	13.3	6.3	30
	Populus deltoides	11.8	8.1	17
	Acer negundo	11.5	6.4	26
	Acer platanoides	9.7	5.4	31
	Morus rubra	7.7	7.7	13
	Acer rubrum	4.0	2.0	100
	Fagus grandifolia	2.9	2.9	34
	Ailanthus altissima	0.0	0.0	63
	Ulmus americana	0.0	0.0	57
	Prunus serotina	0.0	0.0	51
	Quercus rubra	0.0	0.0	40
	Rhamnus frangula	0.0	0.0	26
	Magnolia tripetala	0.0	0.0	20
	Carya ovata	0.0	0.0	19
	Robinia pseudoacacia	0.0	0.0	13
London, Ont.	*Picea pungens*	100.0	0.0	15
	Picea glauca	100.0	0.0	12
	Picea abies	94.1	5.9	17
	Thuja occidentalis	93.2	1.3	385
	Juniperus spp.	90.0	10.0	10
	Tilia cordata	90.0	10.0	10
	Syringa vulgaris	65.0	10.9	20
	Malus sylvestris	64.3	13.3	14
	Ulmus pumila	64.3	13.3	14
	Acer platanoides	62.5	6.1	64
	Acer saccharinum	58.3	10.3	24
	Pinus sylvestris	45.0	11.4	20
	Prunus spp.	40.0	13.1	15
	Morus alba	16.7	11.2	12
	Juglans nigra	12.5	5.9	32
	Celtis spp.	9.1	9.1	11
	Acer negundo	8.1	3.2	74
	Tilia americana	7.7	7.7	13
	Crataegus spp.	7.5	4.2	40
	Populus deltoides	6.5	4.5	31
	Fraxinus pennsylvanica	6.3	2.3	112
	Acer rubrum	4.8	4.8	21
	Ostrya virginiana	4.5	4.5	22
	Acer saccharum	3.8	1.4	182
	Salix spp.	3.1	3.1	32
	Ulmus americana	3.1	3.1	32
	Fraxinus americana	2.2	1.3	134
	Rhamnus cathartica	0.2	0.2	402
	Prunus serotina	0.0	0.0	71
	Crataegus mollis	0.0	0.0	62
	Rhamnus spp.	0.0	0.0	59
	Populus tremuloides	0.0	0.0	34
	Cornus alternifolia	0.0	0.0	30
	Prunus virginiana	0.0	0.0	23
	Carpinus caroliniana	0.0	0.0	17
	Carya cordiformis	0.0	0.0	17
	Populus tremuloides	0.0	0.0	16
	Rhamnus frangula	0.0	0.0	15
	Acer x freemanii	0.0	0.0	12
	Cornus spp.	0.0	0.0	11
	Viburnum lentago	0.0	0.0	10

Table 5 (*Continued*)

City	Species	% Planted	SE	n
Los Angeles, CA	*Cupressus sempervirens*	100.0	0.0	52
	Ficus microcarpa	100.0	0.0	21
	Washingtonia robusta	100.0	0.0	20
	Acacia melanoxylon	100.0	0.0	19
	Syagrus romanzoffiana	100.0	0.0	19
	Magnolia grandiflora	100.0	0.0	18
	Jacaranda mimosifolia	100.0	0.0	17
	Pinus halepensis	100.0	0.0	15
	Syzygium paniculatum	100.0	0.0	14
	Citrus limon	100.0	0.0	11
	Fraxinus uhdei	100.0	0.0	11
	Fraxinus velutina	100.0	0.0	11
	Liquidambar styraciflua	100.0	0.0	11
	Callistemon citrinus	100.0	0.0	10
	Ligustrum lucidum	100.0	0.0	10
	Olea europaea	100.0	0.0	10
	Podocarpus gracilior	100.0	0.0	10
	Juglans californica	25.0	13.1	12
	Quercus berberidifolia	0.0	0.0	27
	Malosma laurina	0.0	0.0	20
Markham, Ont.	*Acer platanoides*	100.0	0.0	24
	Gleditsia triacanthos	100.0	0.0	10
	Picea pungens	93.3	6.7	15
	Picea abies	85.7	9.7	14
	Picea glauca	80.0	13.3	10
	Thuja occidentalis	78.1	2.5	270
	Pinus nigra	75.0	13.1	12
	Pinus resinosa	50.0	15.1	12
	Malus pumila	30.8	13.3	13
	Betula papyrifera	29.4	11.4	17
	Tilia americana	19.0	8.8	21
	Fraxinus pennsylvanica	15.6	6.5	32
	Fagus grandifolia	15.4	10.4	13
	Robinia pseudoacacia	9.1	9.1	11
	Prunus virginiana	8.3	8.3	12
	Acer negundo	7.1	4.0	42
	Ulmus americana	5.0	5.0	20
	Fraxinus americana	3.0	2.1	66
	Tsuga canadensis	2.1	2.1	48
	Rhamnus cathartica	1.6	1.1	128
	Acer saccharum	0.0	0.0	113
	Crataegus spp.	0.0	0.0	50
	Ostrya virginiana	0.0	0.0	36
	Carya cordiformis	0.0	0.0	21
	Carpinus caroliniana	0.0	0.0	14
	Fraxinus nigra	0.0	0.0	13
	Prunus serotina	0.0	0.0	11
Mississauga, Ont.	*Picea pungens*	100.0	0.0	21
	Syringa reticulata	100.0	0.0	16
	Thuja occidentalis	94.1	3.3	51
	Tilia cordata	93.3	6.7	15
	Acer platanoides	88.2	5.6	34
	Picea glauca	88.2	8.1	17
	Fraxinus pennsylvanica	61.5	9.7	26
	Acer negundo	19.4	6.7	36
	Fraxinus americana	16.9	4.9	59
	Populus tremuloides	6.7	6.7	15
	Acer saccharum	1.5	1.5	66
Pickering, Ont.	*Juniperus virginiana*	81.8	8.4	22
	Acer platanoides	76.3	5.6	59
	Lonicera tatarica	72.7	14.1	11
	Syringa vulgaris	64.3	9.2	28
	Picea glauca	57.6	8.7	33
	Thuja occidentalis	39.3	1.8	727
	Pinus sylvestris	36.7	8.9	30
	Fraxinus pennsylvanica	29.5	7.0	44
	Malus sylvestris	27.3	14.1	11
	Prunus virginiana	21.1	9.6	19
	Acer saccharinum	20.4	5.5	54
	Acer negundo	14.3	6.7	28
	Tilia americana	9.4	5.2	32
	Salix spp.	8.3	8.3	12
	Betula papyrifera	7.0	3.4	57
	Pinus strobus	6.8	3.8	44

Table 5 (*Continued*)

City	Species	% Planted	SE	n
	Quercus rubra	6.3	6.3	16
	Fraxinus americana	3.9	1.1	305
	Acer saccharum	1.5	0.7	267
	Acer rubrum	1.4	1.4	72
	Rhamnus cathartica	0.9	0.6	227
	Populus tremuloides	0.7	0.7	145
	Tsuga canadensis	0.0	0.0	177
	Ulmus americana	0.0	0.0	82
	Fraxinus nigra	0.0	0.0	77
	Ostrya virginiana	0.0	0.0	57
	Fagus grandifolia	0.0	0.0	53
	Betula alleghaniensis	0.0	0.0	39
	Crataegus spp.	0.0	0.0	37
	Populus balsamifera	0.0	0.0	30
	Populus grandidentata	0.0	0.0	28
	Amelanchier arborea	0.0	0.0	18
	Abies balsamea	0.0	0.0	16
	Cornus alternifolia	0.0	0.0	16
	Alnus glutinosa	0.0	0.0	15
	Prunus serotina	0.0	0.0	14
Richmond Hill, Ont.	*Morus alba*	100.0	0.0	14
	Acer platanoides	95.0	5.0	20
	Gleditsia triacanthos	94.1	5.9	17
	Syringa vulgaris	93.8	6.3	16
	Pyrus communis	92.3	7.7	13
	Thuja occidentalis	69.4	2.8	268
	Picea pungens	69.0	6.1	58
	Fraxinus pennsylvanica	61.1	11.8	18
	Pinus resinosa	60.0	9.1	30
	Acer negundo	58.8	5.4	85
	Picea glauca	51.1	5.2	92
	Malus sylvestris	44.4	12.1	18
	Betula papyrifera	23.8	9.5	21
	Ostrya virginiana	21.4	7.9	28
	Picea abies	18.8	10.1	16
	Prunus virginiana	15.2	6.3	33
	Salix alba	11.8	8.1	17
	Acer saccharum	10.1	2.6	138
	Populus tremuloides	10.1	2.8	119
	Quercus rubra	7.1	7.1	14
	Fraxinus americana	5.6	1.4	252
	Juglans nigra	5.3	3.7	38
	Tsuga canadensis	3.7	3.7	27
	Crataegus spp.	1.6	1.6	64
	Rhamnus cathartica	0.3	0.3	400
	Hamamelis virginiana	0.0	0.0	35
	Tilia americana	0.0	0.0	34
	Betula alleghaniensis	0.0	0.0	22
	Prunus americana	0.0	0.0	16
	Fagus grandifolia	0.0	0.0	13
	Carya cordiformis	0.0	0.0	10
Syracuse, NY[a]	*Tsuga canadensis*	100.0	0.0	13
	Acer platanoides	2.6	2.6	39
	Rhamnus cathartica	0.0	0.0	229
	Rhus typhina	0.0	0.0	60
	Ailanthus altissima	0.0	0.0	56
	Acer negundo	0.0	0.0	55
	Prunus serotina	0.0	0.0	33
	Populus deltoides	0.0	0.0	25
	Acer saccharum	0.0	0.0	22
	Juglans nigra	0.0	0.0	15
	Prunus avium	0.0	0.0	13
	Prunus virginiana	0.0	0.0	12
	Robinia pseudoacacia	0.0	0.0	11
Toronto, Ont.	*Chamaecyparis lawsoniana*	100.0	0.0	41
	Picea abies	100.0	0.0	32
	Picea pungens	100.0	0.0	16
	Pinus resinosa	96.3	3.7	27
	Gleditsia triacanthos	95.0	3.5	40
	Pyrus communis	94.7	5.3	19
	Pinus nigra	94.4	3.9	36
	Thuja occidentalis	94.4	1.1	429
	Prunus avium	94.1	5.9	17
	Picea glauca	89.0	3.3	91

Table 5 (*Continued*)

City	Species	% Planted	SE	n
	Juniperus virginiana	83.3	9.0	18
	Acer saccharinum	72.0	9.2	25
	Morus alba	53.8	14.4	13
	Acer platanoides	53.1	3.8	177
	Ulmus pumila	50.7	5.8	75
	Malus sylvestris	45.0	6.5	60
	Betula papyrifera	44.7	8.2	38
	Tilia cordata	42.9	11.1	21
	Fraxinus pennsylvanica	41.1	5.1	95
	Quercus alba	34.6	9.5	26
	Prunus virginiana	32.7	6.6	52
	Pinus strobus	22.9	7.2	35
	Ulmus americana	22.5	6.7	40
	Prunus serotina	21.3	5.3	61
	Quercus rubra	20.0	10.7	15
	Tilia americana	16.7	6.3	36
	Pinus sylvestris	12.5	8.5	16
	Populus balsamifera	9.1	9.1	11
	Acer nigrum	7.1	7.1	14
	Acer negundo	6.0	2.1	134
	Acer saccharum	5.7	1.4	263
	Ailanthus altissima	5.6	5.6	18
	Fagus grandifolia	5.6	5.6	18
	Rhamnus cathartica	4.8	3.3	42
	Fraxinus americana	0.7	0.7	142
	Ostrya virginiana	0.0	0.0	82
	Populus tremuloides	0.0	0.0	60
	Crataegus crus-galli	0.0	0.0	25
	Populus grandidentata	0.0	0.0	13
	Amelanchier arborea	0.0	0.0	13
	Alnus incana	0.0	0.0	10
Vaughan, Ont,	*Picea pungens*	100.0	0.0	31
	Picea abies	100.0	0.0	29
	Ulmus pumila	100.0	0.0	22
	Amelanchier laevis	100.0	0.0	14
	Juniperus scopulorum	100.0	0.0	12
	Juniperus virginiana	100.0	0.0	11
	Fraxinus pennsylvanica	87.0	7.2	23
	Gleditsia triacanthos	84.6	10.4	13
	Pinus sylvestris	84.6	10.4	13
	Picea glauca	78.8	5.7	52
	Pinus resinosa	60.0	8.4	35
	Acer platanoides	55.6	9.7	27
	Betula papyrifera	28.6	10.1	21
	Thuja occidentalis	27.6	3.6	152
	Tilia americana	27.3	14.1	11
	Acer rubrum	20.0	10.7	15
	Prunus virginiana	20.0	10.7	15
	Fraxinus americana	12.1	3.3	99
	Ulmus americana	11.8	5.6	34
	Quercus rubra	6.7	6.7	15
	Acer saccharum	2.3	0.9	306
	Pinus strobus	1.9	1.9	53
	Rhamnus cathartica	1.2	1.2	81
	Tsuga canadensis	0.0	0.0	64
	Populus tremuloides	0.0	0.0	56
	Prunus serotina	0.0	0.0	45
	Acer negundo	0.0	0.0	39
	Cornus alternifolia	0.0	0.0	28
	Crataegus spp.	0.0	0.0	16
	Juglans nigra	0.0	0.0	15
	Fagus grandifolia	0.0	0.0	11
	Betula alleghaniensis	0.0	0.0	10

SE = standard error.
[a] Only includes newly established trees.

impervious cover (Pearson $r = 0.67$) also tended to have a greater percentage of their existing tree population planted. This relationship is likely due to the anthropogenic influences associated with greater population densities and more developed land. These anthropogenic influences likely reduce natural regeneration (e.g., increased mowing and impervious surfaces) and increase the probability (i.e., there are more people to plant trees) and need (i.e., there

Table 6
Overall percent of species population that was planted for species present in at least two of the 12 cities (Baltimore and Syracuse data not included) and with a minimum overall sample size of 50 trees.

Species	% Planted	SE	*n*
Gleditsia triacanthos	95.1	1.7	163
Pinus nigra	91.8	3.5	61
Juniperus virginiana	89.2	3.9	65
Picea pungens	89.1	2.4	175
Picea abies	85.2	3.4	108
Picea glauca	75.3	2.2	369
Syringa vulgaris	71.9	5.7	64
Acer platanoides	69.0	1.9	564
Thuja occidentalis	68.2	0.9	2724
Ulmus pumila	65.7	4.0	140
Tilia cordata	56.9	5.9	72
Malus sylvestris	51.7	4.7	116
Acer saccharinum	51.3	3.3	228
Pinus resinosa	50.0	4.0	158
Pinus sylvestris	42.7	5.3	89
Pinus strobus	32.9	3.1	225
Fraxinus pennsylvanica	32.5	2.1	501
Betula papyrifera	22.6	3.2	168
Prunus virginiana	18.2	3.0	170
Acer negundo	13.9	1.4	595
Tilia americana	10.2	2.0	226
Populus balsamifera	9.4	4.0	53
Acer rubrum	9.1	1.9	220
Ulmus americana	8.9	1.4	395
Juglans nigra	7.1	2.8	85
Fraxinus americana	6.6	0.7	1371
Populus deltoides	5.8	2.3	104
Salix spp.	5.5	2.7	73
Prunus serotina	5.2	1.3	286
Acer saccharum	5.0	0.5	1645
Crataegus spp.	4.8	1.3	293
Populus tremuloides	4.4	0.9	472
Ailanthus altissima	4.4	1.6	160
Quercus rubra	4.3	1.9	115
Ostrya virginiana	2.6	1.0	274
Fagus grandifolia	2.5	1.2	161
Rhamnus cathartica	1.0	0.3	1471
Tsuga canadensis	0.5	0.4	401
Rhamnus spp.	0.4	0.3	462
Fraxinus nigra	0.0	0.0	123
Crataegus mollis	0.0	0.0	77
Cornus alternifolia	0.0	0.0	74
Betula alleghaniensis	0.0	0.0	71
Populus tremuloides	0.0	0.0	60

SE = standard error, *n* = sample size.

Table 7
Annual tree influx rates (trees/ha/yr) by natural regeneration and tree planting for Syracuse, NY (2001–2009) and Baltimore, MD (2004–2009).

City	Land use	Total	SE	Regeneration	Planted
Syracuse	Vacant	29.2	10.3	29.2	0.0
	Multi-family Residential	13.7	13.7	13.7	0.0
	Park/Cemetery/Golf	12.9	8.1	12.9	0.0
	Institutional	9.8	5.1	9.5	0.3
	Utilities/Transportation	6.2	3.1	6.2	0.0
	Residential	5.7	1.2	4.0	1.7
	Commercial/Industrial	0.7	0.7	0.7	0.0
	City Total	8.6	1.7	7.9	0.7
Baltimore	Forest/Open Space	13.7	3.4	13.4	0.3
	Institutional	3.0	3.0	3.0	0.0
	High Density Residential	2.7	1.0	2.4	0.3
	Medium to Low Density Residential	2.1	1.2	2.1	0.0
	Commercial/Industrial	1.8	1.1	1.5	0.3
	Barren/Transportation	0.8	0.8	na	na
	City Total	4.0	0.7	3.8	0.2

SE = standard error, na – trees ($n = 3$) could not be clearly determined as to whether they were planted or occurred through natural regeneration.

will be less regeneration) to plant trees to sustain urban tree cover and associated benefits.

Urban tree influx

In Baltimore and Syracuse, natural regeneration dominates the influx of new trees in these cities. The overall influx rates were between 4.0 trees/ha/yr in Baltimore and 8.6 trees/ha/year in Syracuse with the highest natural regeneration rates occurring in areas within land uses that typically have a higher proportion of unmanaged lands (e.g., forest, vacant, multi-family residential). These influx rates may be conservative as some trees may have been established and then subsequently removed within the re-measurement period and would not have been recorded during plot re-measurements.

Tree planting rates in Syracuse were 3–4 times higher than in Baltimore, which is likely an artifact of planting activities by city residents and programs, or possibly that Baltimore has higher new tree mortality rates and many planted trees are not being detected within the 5 year re-measurement period (i.e., planted trees only live a few years). Natural regeneration rates in Syracuse were also more than double the rate in Baltimore, which may be an artifact of proportionally more unmanaged lands in Syracuse to facilitate natural regeneration and/or the more invasive plant characteristics of *Rhamnus cathartica*, which dominated regeneration in Syracuse. Other invasive or pioneer species also dominated regeneration in Syracuse (*Rhus typhina*, *Ailanthus altissma*, *Acer negundo*), but to a much lesser extent than *Rhamnus cathartica*. Natural regeneration in Baltimore was dominated by *Fagus grandifolia* (native forest species) and *Ailanthus altissma*.

For the entire existing tree population of the 12 cities, on average, two trees were naturally regenerated for every one tree planted. However, for the new tree populations, 19 (Baltimore) or 11 (Syracuse) trees were naturally regenerated for every one tree planted. The difference between the new and existing tree ratios is likely due to differences in: (a) size/age classes of the existing and new tree populations, and (b) mortality rates between planted (and presumably maintained) trees and naturally regenerated (and presumably unmaintained) trees. Trees in unmaintained, more natural sites, particularly when young, likely have higher mortality rates than maintained trees due increased competition for light, water and nutrients (e.g., Nowak and McBride, 1991). A lack of sense ownership of street trees has also been shown to lead to increased mortality rates (Sklar and Ames, 1985; Nowak et al., 1990). Due to the likely differences in mortality rates between planted and naturally regenerated trees, the ratio of existing naturally regenerating to planted trees will likely decrease through time as proportionally more planted trees survive. Thus, for new (young) trees, the naturally regenerated to planted tree ratio will typically be much higher than the ratio for the entire existing tree population in cities, particularly within naturally forested areas. More research involving long-term monitoring is needed to help determine actual differences in mortality based on tree planting or tree maintenance vs. natural regeneration in urban areas.

Urban tree cover goals

To help determine the annual tree planting needed to sustain a desired level of tree cover in the future, it is essential to have accurate estimates of tree regeneration and mortality rates. Unfortunately these data do not exist for overall urban forest populations outside of Baltimore (Nowak et al., 2004). Long-term monitoring of urban tree populations across a city are critical to providing the data needed to determine the number of trees a city will need to plant to sustain tree cover. The amount of tree planting needed will vary by region (i.e., surrounding natural vegetation type), development and population intensity, land use type, and the desired level of tree cover to be sustained. Without accurate regeneration and mortality data, planting efforts will be inefficient in sustaining a desired level of tree cover and associated benefits.

In forested regions, natural regeneration may be the most cost-effective means to attain desired tree cover levels and ecosystem services, but at the cost of a potential shift in species composition from current conditions. Many of the plants regenerating in Syracuse and Baltimore are invasive or pioneering small trees/large shrubs (e.g., *Rhamnus cathartica*, *Rhus typhina*) or invasive larger trees (e.g., *Ailanthus altissma*). On some land uses, native forest plant species are also regenerating (e.g., *Fagus grandifolia*, *Prunus serotina*). Without tree planting and management, the urban forest composition in Syracuse will likely shift to more pioneer or invasive tree species in the near term. As these species typically are smaller and have shorter life-spans, the ability of city systems to sustain more large, long-lived tree species may require human intervention through tree planting and maintenance. In addition, the invasive characteristics of some these species pose problems associated with their spreading into the surrounding landscape, displacing native species and altering local ecosystems (e.g., Pimentel et al., 2000).

Native forest species are regenerating with about 58 percent of new trees in Baltimore being native species and only 35 percent of new trees in Syracuse being native species. In addition, 52 percent of the new trees were classified as invasive species in Syracuse (*Rhamnus cathartica*, *Ailanthus altissima*, *Acer platanoides*, *Robinia pseudoacacia*, *Elaeagnus angustifolia*), and 13 percent in Baltimore (*Ailanthus altissima*, *Acer platanoides*, *Pyrus calleryana*) (Maryland Invasive Species Council, 2011; New York State Department of Environmental Conservation, 2011). Tree planting, though more costly than natural regeneration, is required on some sites and will help attain desired tree cover levels with a desired mix of species and tree sizes. Managers need to understand their local conditions to determine the desired mix of natural regeneration and tree planting needed to attain long-term urban forest management goals and optimize benefits at minimum cost.

Though the data in this study have potential limitations related to the ability of the field crews to accurately classify whether a tree was actually planted or not, and that much of the data come from naturally forested areas with similar climates, this study provides reasonable and necessary data needed to advance the understanding of urban forest dynamics and help guide urban forest management in relation to tree planting and natural regeneration. Without constant annual monitoring of urban forests and/or continual social surveys of land owners to determine whether trees are actually planted, there may be no means of precisely determining actual planting rates or proportions. Given the cost limitations of these annual monitoring approaches, the methods used in this study provide a practical means to assess tree influx and planting in cities. Though understanding the proportion of planted versus natural regeneration in a city tree population is important, the most critical information needed is the rate of new tree influx in cities, which can be obtained only through long-term forest monitoring. Urban forest monitoring in cities across the world can help provide critical information needed to better understand changes in urban forests and guide urban forest management.

Conclusion

Tree planting and natural regeneration in cities are influenced by a mix of anthropogenic and natural factors. These factors include the surrounding natural environment (forested regions have a greater proportion of natural regeneration and lower tree planting) and management/development intensity (as indicated by land use type, population density and percent impervious cover) that influence how much space is available for natural regeneration and how many trees will be planted. Natural regeneration varies among and within cities, with natural regeneration a significant force in cities in forested regions. This natural regeneration will have a substantial influence on species composition and tree cover in cities in the future. More long-term data are needed to better understand changes in urban tree populations and how these changes will affect long-term sustainability of urban tree populations and associated ecosystem services, particularly in light of changing environmental conditions associated with urbanization and climate change.

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