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Urban forest structure, ecosystem services and change in Syracuse, NY

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Abstract The tree population within the City of Syracuse was assessed using a random sampling of plots in 1999, 2001 and 2009 to determine how the population and the ecosystem services these trees provide have changed over time. Ecosystem services and values for carbon sequestration, air pollution removal and changes in building energy use were derived using the i-Tree Eco model. In addition, photo interpretation of aerial images was used to determine changes in tree cover between the mid-1990s and 2009. Between the mid-1990s and 2003, tree cover in Syracuse exhibited a decline from 27.5 to 25.9 %, but subsequently increased to 26.9 % by 2009. The total tree population exhibited a similar pattern, dropping from 881,000 trees in 1999 to 862,000 in 2001, and then increasing to 1,087,000 trees in 2009. Most of this increase in the urban tree population is due to invasive or pioneer trees species, particularly *Rhamnus cathartica*, which has more than tripled in population between 2001 and 2009. Insects such as gypsy moth and emerald ash borer pose a substantial risk to altering future urban forest composition. The annual ecosystem services provided by the urban forest in relation to carbon sequestration, air pollution removal and reduction in building energy use are estimated at about $2.4 million per year. An improved understanding of urban forests and how they are changing can facilitate better management plans to sustain ecosystem services and desired forest structure for future generations.

Keywords Urban forest sampling · i-Tree · Urban forest monitoring · Invasive plants · Invasive pests

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Introduction

The urban forest provides a full suite of ecosystem services and values to a city and its residents, but also has economic or environmental costs. Trees provide 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). By understanding the structure of the urban forest (e.g., number of trees, tree size, health, tree location), several ecosystem services and values can be estimated. Also, a better understanding of the relationships between urban forest structure and its services and values can be used to devise management plans to alter urban forest structure to sustain desired services and values for the urban population.

However, urban forests are not static and change through time due to numerous natural (e.g., tree decline and mortality, natural tree regeneration, storms, insects and diseases) and anthropogenic (e.g., development, tree planting, tree removal) forces (Nowak 1993; Nowak et al. 2004; Kong and Nakagoshi 2006; Myeong et al. 2006). By monitoring urban forests through time, amount and rates of change related to numerous structural variables can be determined and help managers understand change and optimize future forest structure and ecosystem services.

Numerous studies (e.g., Nowak et al. 2002b, 2006b; Chaparro and Terradas 2009; City of Toronto 2011; Nowak et al. 2011; Rogers et al. 2011) have analyzed urban forest structure and functions from across the world based on methods employed by the i-Tree Eco model (formerly UFORE model; www.itreetools.org) (Nowak et al. 2008). This study uses similar methodology to assess the urban forest structure and associated ecosystem services and values in the City of Syracuse, NY. The urban forest in Syracuse was originally assessed in 1999 with information used to help develop an urban forest master plan (Nowak and O'Connor 2001). Subsequent re-measurement of the original plots were made in 2001 (Nowak et al. 2008) and 2009. Monitoring of tree cover change in Syracuse between 2003 and 2009 revealed that tree cover increased from 25.9–26.9 %, the only city of 20 cities analyzed that had a statistically significant increase in tree cover (Nowak and Greenfield 2012a).

This current study analyzes long-term changes to the forest structure and services based on plot re-measurements between 1999 and 2009, and from aerial images from c. 1998 to 2009. This study also provides an in-depth analysis of threats to the current urban forest structure from invasive tree species and various insects and diseases. The goals of this paper are to provide an analysis of change in urban forest structure and associated ecosystem services in Syracuse, NY, and its vulnerability to insects, diseases and invasive trees species.

Methods

Overview

The urban forest structure in Syracuse, NY, USA was quantified and monitored using both aerial-based and ground-based approaches. Changes in tree cover were assessed through interpretation of aerial images. Changes in urban forest structure, ecosystem services and values were estimated through field plot re-remeasurements that were analyzed using the i-Tree Eco (formerly UFORE) model (Nowak et al. 2008). Based on the field data and ancillary data, potential risks associated with various insects/diseases and invasive tree species were then assessed. Details of these methods are provided below.

Study area

Syracuse, NY (population=145,170; area=65 km^2; U.S. Census 2012) resides within Onondaga County in Central New York State, which has a fully humid snow climate with a forest potential natural vegetation type (Kottek et al. 2006; Kuchler 1966). This region is within the maple-beech-birch forest type group (USDA Forest Service 1993).

Changes in tree cover (c1998– 2009)

Orthorectified digital aerial photographs of Syracuse from 1994–98 (leaf-off, 1 m resolution, color infrared (CIR)), 1999 (leaf-on, 1 m, CIR), 2003 (leaf-off, 0.3 m, color), 2006 (leaf-off, 0.3 m, color) and 2009 (leaf-off, 0.3 m, color) were photo-interpreted to assess tree cover change in the city. The first set of images did not have specific dates associated with imagery and dates ranged between 1994 and 1998, but the actual date on any specific image was unknown. For each image year, 976 random points were laid in the same geographic position on all sets of temporal images and paired image interpretation was conducted (i.e., interpreter classified each point pair by contrasting and classifying the image points in sequence). In cases of misregistration of the image or point, the interpreter corrected the point location to ensure the exact same location was interpreted. For example, in some instances the points could shift position slightly between images due to issues of image misregistration. In these cases, the interpreter matched the position of the point on the most recent image to the position on the c. 1998 image to make the interpretation of change at the same point on all images. The photo-interpreter could also correct for potential image misclassifications due to image parallax (e.g., tall objects appearing to lean on the image). More details on this method are given in Nowak and Greenfield (2012a).

If changes in cover classes were observed at any point on the image then it is known that cover classes are changing within the city (i.e., no statistical test is needed to determine if change is greater than zero). However, as a cover class can both gain and lose cover through time and space, the McNemar test (Sokal and Rohlf 2003) was used to determine if the net change in cover was statistically different from zero between years of analysis (overall alpha level=0.05).

Ground-based assessment of urban forest structure and ecosystem services/values (1999 – 2009)

In 1999, 2001 and 2009 trees within 198 plots (0.04 ha) within the City of Syracuse were measured with tree location referenced such that individual tree characteristics could be recorded through time. Plot centers were permanent referenced based on triangulation from fixed objects and each tree's location recorded as a distance and azimuth from plot center. Fourteen of the original 212 plots in 1999 sample could not be measured in all 3 years and were excluded from the analyses. The total population estimates for 1999 and 2001 calculated in this paper differ slightly from numbers reported in Nowak and O'Connor (2001) and Nowak et al. (2008) due to the loss of plots as this paper only used plots that had measurements taken in all three years.

Plots were distributed based on a stratified random design proportional to estimated tree cover among the following land use classes as defined in the original 1999 sample: residential (98 plots), vacant (31 plots), greenspace (e.g., parks; 21 plots), multi-family residential (16 plots), institutional (12 plots), transportation/utility (11 plots), and commercial/industrial (9 plots). These tree counts and characteristics were extrapolated to population totals using the i-Tree Eco model (Nowak et al. 2008).

On each plot, woody vegetation with a minimum stem diameter at 1.37 m (dbh – diameter at breast height) of 2.54 cm was measured and recorded as a tree. For multi-stemmed trees, a tree dbh was calculated based on the basal area (cross-sectional area of stem at dbh) of the multiple stems. For each tree, species, dbh, total height, crown width, height to base of crown, percent crown missing, percent dieback and distance and direction to nearest 1–2 story space-conditioned building was recorded (Nowak et al. 2008). Using this basic structural data, other structural attributes (e.g., leaf area, tree and leaf biomass) are estimated (e.g., Nowak 1996; Nowak et al. 2008). These structural data are integrated with local environmental data within the i-Tree Eco model (www.itreetools.org) to estimate several functional attributes and values. Specific methods of assessing these ecosystem services are detailed in various publications, but a general overview of the methods are given below and presented in Nowak et al. (2008). For each species, an importance value was calculated as the sum of the percent of total population plus percent of total basal area.

Air pollution removal by trees is estimated as a pollutant flux (F; in g $m^{-2}s^{-1}$), which is calculated as the product of the deposition velocity (V_d; in m s^{-1}) and the pollutant concentration (C; in g m^{-3}): $F = V_d \times C$. Hourly deposition velocities for trees are estimated based on leaf area estimates and hourly weather data (Nowak et al. 2006a). Hourly pollution concentrations are derived from local or closest air pollutant monitors to the city.

The monetary value of pollution removal by trees is estimated using the median externality values for the United States for each pollutant (Murray et al. 1994) adjusted to 2007 values based on the producer's price index (U.S. Dept. of Labor 2012): NO_2=\$9,906 t^{-1}, PM10=\$6,614 t^{-1}, SO_2=\$2,425 t^{-1}, and CO=\$1,407 mt^{-1}. Externality values for O_3 are set to equal the value for NO_2.

Carbon storage by trees is estimated based on allometric equations that estimate total tree biomass based on measured tree dbh and height (Nowak and Crane 2002; Nowak et al. 2002b, 2008). Carbon storage is estimated as 50 % of dry weight biomass. Length of growing season, tree health and tree competition are used to estimate annual growth and consequently annual carbon sequestration. Carbon value is estimated at \$78.5 t^{-1} based on the estimated social costs of carbon for 2010 with a 3 % discount rate (Interagency Working Group 2010).

Using the tree size, distance and direction to building, climate region, leaf type (deciduous or evergreen) and percent cover of buildings and trees on the plot, the amount of energy use and carbon avoided from power plants due to the presence of trees is calculated based on methods detailed in McPherson and Simpson (1999) and Nowak et al. (2008). To determine the estimated economic impact of the change in building energy use, energy costs were derived from the U.S. Energy Information Administration (US EIA) based on 2009 state average costs for natural gas (US EIA 2012a), 2010/2011 heating season fuel oil costs (US EIA 2012b), 2009 residential electricity costs (US EIA 2012c) and 2008 costs of wood (US EIA 2012d). Average price for heating change due to trees is based on the average distribution of buildings in the region that heat by natural gas, fuel oil, and other (including wood) (McPherson and Simpson 1999).

The compensatory value of the trees (Nowak et al. 2002a) is based on methods from the Council of Tree and Landscape Appraisers (CTLA 1992). These compensatory values represent compensation to owners for the loss of an individual tree and are an approximation based on species, size, condition, and location information.

Change analyses

To estimate changes in urban forest structure and ecosystem services through time, plot data were compared among the sampled years (1999, 2001, 2009). The Wilcoxon signed rank test (alpha=0.05) was used on the paired plots to test for statistically significant differences in total population, population total within land uses, and species population totals between years.

Risk to insects and diseases

Species composition data were used to determine the potential risk of infestation by 29 different insects or diseases (hereafter referred to as pests) that threaten forests in the United States: aspen leafminer (*Phyllocnistis populiella*), Asian longhorned beetle (*Anoplophora glabripennis*), beech bark disease (*Cryptococcus fagisuga*), butternut canker (*Sirococcus clavigignenti-juglandacearum*), chestnut blight (*Cryphonectria parasitica*), dogwood anthracnose (*Discula destructive*), Dutch elm disease (*Ophiostoma novo-ulmi*), douglas-fir beetle (*Dendroctonus pseudotsugae*), emerald ash borer (*Agrilus planipennis*), fir engraver (*Scotylus ventralis*), fusiform rust (*Cronartium fusiforme*), gypsy moth (*Lymantria dispar*), hemlock woolly adelgid (*Adelges tsugae*), jeffrey pine beetle (*Dendroctonus jeffreyi*), large aspen tortrix (*Choristoneura conflictana*), laurel wilt (*Raffaelea lauricola*), mountain pine beetle (*Dendroctonus ponderosae*), oak wilt (*Ceratocystis fagacearum*), Port-Orford-cedar root disease (*Phytophthora lateralis*), pine shoot beetle (*Tomicus piniperda*), spruce beetle (*Dendroctonus rufipennis*), spruce budworm (*Choristoneura fumiferana*), sudden oak death (*Phytophthora ramorum*), southern pine beetle (*Dendroctonus frontalis*), sirex woodwasp (*Sirex noctilio*), thousand cankers disease (*Pityophthorus juglandis* & *Geosmithia* spp.), western pine beetle (*Dendroctonus brevicomis*), white pine blister rust (*Cronartium ribicola*), and western spruce budworm (*Choristoneura occidentalis*).

Tree host species for each of these pests was compiled from numerous sources (McCambridge and Trostle 1970; USDA Forest Service 1985, 2012a, b; Riffle and Peterson 1986; Liebhold et al. 1995; Maclure et al. 2001; Sawyer 2011; Society of America Foresters 2011; FAO North American Forest Commission 2011). In addition, the current pest range within the United States was mapped using data from national forest damage agent range maps (USDA Forest Service 2011). The number of trees and basal area of trees in Syracuse that could be attacked by each pest was calculated based on tree species host list for each pest. In addition, the distance from Onondaga County to the closest county with a pest infestation was calculated using GIS. These results were combined to produce a rating of the potential risk to various pests based on the amount of forest that could be attacked and distance that the pest is from Onondaga County. Only pests within 250 miles of Onondaga County are presented.

Invasive tree species

Tree species found on the New York State invasive plant list (New York State Department of Environmental Conservation 2011) were classified as invasive and percent of the tree population, carbon storage, basal area and leaf area were calculated for the invasive species population in Syracuse.

Results

Tree cover change

Tree cover in Syracuse dropped from 27.5 % in the 1994–1998 time period to a low of 25.9 % in 2003 and then increased to 26.9 % in 2006 and 2009 (Table 1). Statistically significant changes in tree cover occurred between 2003 and 2006 (increase in cover), though overall tree cover change between 1994/98 and 2009 (−0.6 %) was not statistically significant.

Urban forest structure and ecosystem services (2009)

In 2009, there were an estimated 1,088,000 trees in Syracuse, with most of the trees found on residential (28.2 %) and vacant lands (25.6 %). The highest tree densities were found on vacant (497.6 trees ha^{-1}) and green space areas (361.3 trees ha^{-1}) with an overall city tree density of 167.4 trees ha^{-1} (Table 2). The most common tree species in terms of abundance of trees were *Rhamnus cathartica* (19.4 %), *Acer saccharum* (9.1 %), *Prunus serotina* (6.3 %), *Acer negundo* (5.9 %) and *Acer platanoides* (5.8 %) (Table 3). The most dominant species in terms of total leaf area were *Acer platanoides* (13.6 %), *Acer saccharum* (7.8 %), *Acer negundo* (7.5 %), *Juglans nigra* (7.3 %) and *Picea abies* (6.4 %) (Table 3). In terms of importance values, the most important species are *Rhamnus cathartica* (IV=22.7), *Acer saccharum* (17.3), *Acer negundo* (14.1) *Acer platanoides* (14.0) and *Populus deltoides* (11.7) (Table 3).

Syracuse's urban forest stores approximately 165,900 metric tons of carbon ($13.0 million) and annually removes 5,300 metric tons of carbon ($417,000 yr^{-1}) (Table 3). The forest removed approximately 101 metric tons of air pollution in 2009 ($852,000) (Table 4). The estimated annual savings in energy use from trees by residential buildings is $1.1 million yr^{-1} –- $636,000 yr^{-1} in reduced heating and $483,000 yr^{-1} in reduced cooling energy use. The total compensatory value of the urban forest is estimated at $615 million (Table 3).

Urban forest change (1999–2009)

The total tree population in Syracuse had a statistically significant increase between 2001 and 2009 with the population dropping from 881,000 in 1999 to 862,000 in 2001, but then increasing to 1,088,000 trees in 2009 (Table 5). The overall population change between 1999 and 2009 was also statistically significant. Land uses that gained the most trees between 1999 and 2009 were vacant (+69,991), residential (+57,659) and multi-family residential (+34,230). All land uses had statistically significantly increases in trees between 2001 and

Table 1 Change in percent tree cover in Syracuse, NY derived from photo-interpretation

Year	%Tree cover	Alpha
1994–98	27.5	na
1999	26.6	0.0290
2003	25.9	0.1336
2006	26.9	0.0075[a]
2009	26.9	1.0000

[a] indicates significant difference (overall alpha = 0.05; Bonferroni adjustment of alpha – 0.0125 for each individual test) between year and previous year of analysis

Table 2 Total tree population, tree population density, carbon storage and gross carbon sequestration by land use in Syracuse, NY (2009) derived from i-Tree Eco

Land use	Number of trees			Trees per hectare		Carbon storage		Carbon sequestration	
	%Pop	Total	SE	Total	SE	tC	SE	tC yr^{-1}	SE
Residential	28.2	306,579	44,074	109.9	15.8	58,328	8,047	2,368	287
Vacant	25.6	278,183	63,450	497.6	113.5	28,254	6,030	791	165
Green space	24.2	262,997	90,643	361.3	124.5	41,583	10,351	969	206
Institutional	10.1	109,890	54,969	222.4	111.3	19,836	9,842	441	194
Multi-family Res.	6.8	74,165	63,535	160.5	137.5	4,975	2,224	234	101
Trans./Utility	3.6	39,127	16,101	89.9	37.0	4,951	2,365	254	100
Commercial	1.6	17,027	11,260	16.5	10.9	7,930	6,168	258	186
City total	100.0	1,087,968	147,068	167.4	22.6	165,857	18,807	5,315	494

%Pop percent of tree population

tC metric tons of carbon

SE standard error

2009 except for institutional land, which had statistically significant decline (−2,035) and commercial/industrial lands that exhibited no statistically significant change (Table 5). Between 2001 and 2009, there was also a substantial increase in trees less than 6 in. in dbh (Fig. 1).

Most of the recent increase came from invasive or pioneer tree species: *Rhamnus cathartica* (+153,100 trees between 1999 and 2009), *Prunus serotina* (+18,000), *Ailanthus altissma* (+16,800), *Populus deltoides* (+15,800), *Robinia pseudoacacia* (+12,300) and *Acer negundo* (+9,800) (Table 6) and varied by land use (Table 7), with *Rhamnus cathartica* and *Prunus serotina* exhibiting statistically significant increases in population. Species populations that declined the most were: *Acer saccharum* (−17,700), *Thuja occidentalis* (−15,000), *Ostrya virginiana* (−14,400) and *Cornus spp.* (−10,600), with *Acer saccharum* and *Ostrya virginiana* exhibiting statistically significant decreases in population (Table 6).

Carbon storage by Syracuse's urban forest dropped slightly between 1999 (145,000 tC) and 2001 (144,100 tC), but increased to 165,900 tC in 2009. Annual carbon sequestration increased through the years increasing from 4,670 tC yr^{-1} in 1999 to 4,710 tC yr^{-1} in 2001 and 5,320 tC yr^{-1} in 2009. Reductions in building energy use decreased from $1.7 million in 1999 to $1.1 million in 2009 (using 2009 energy costs) due to the loss of the number of trees located near space-conditioned buildings. Air pollution removal decreased from 169.3 t yr^{-1} in 1999 (Nowak and O'Connor 2001) to 101 t yr^{-1} in 2009.

Potential risk to pests

Of the 29 pests that were analyzed, six pests are within 250 miles and can potentially affect greater than five percent (>50,000 trees) of the total tree population (Fig. 2). Four of these pests (gypsy moth: 116,000 trees; sirex woodwasp: 83,600 trees; pine shoot beetle: 71,800 trees; spruce beetle: 59,300 trees) are already located in the Syracuse area and two pests (Asian longhorned beetle: 300,000 trees; southern pine beetle: 113,300 trees) are within 250 miles of the city.

Table 3 Number of trees, carbon storage, gross carbon sequestration, leaf area and compensatory value by species in Syracuse, NY (2009) derived from i-Tree Eco for the 20 most common species

Species	Number of trees			IV[a]	Carbon storage			Carbon sequestration			Leaf area			Compensatory value		
	%	Total	SE		%	tC	SE	%	tC yr^{-1}	SE	%	ha	SE	%	\$ × 1,000	SE
Rhamnus cathartica[b]	19.4	211,491	94,868	22.7	1.8	3,065	1,525	4.9	263.1	104.9	3.1	298.5	126.0	2.8	17,309	6,447
Acer saccharum	9.1	99,228	35,423	17.3	10.8	17,970	6,898	8.8	465.9	163.8	7.8	746.7	233.9	7.4	45,748	14,571
Prunus serotina	6.3	68,051	25,067	9.6	4.0	6,627	3,239	4.2	222.7	92.3	3.7	353.9	163.9	2.1	12,935	4,946
Acer negundo	5.9	64,248	13,397	14.1	8.5	14,136	4,511	8.5	454.4	119.3	7.5	718.8	226.3	4.1	24,969	6,847
Acer platanoides[b]	5.8	63,422	15,471	14.0	7.9	13,122	2,898	10.1	534.2	104.2	13.6	1305.4	278.3	10.4	64,185	13,336
Thuja occidentalis	5.1	55,974	26,428	7.6	0.7	1,170	467	1.6	85.9	37.4	1.5	148.2	57.2	5.5	33,953	15,587
Picea abies	4.4	47,458	22,394	10.8	4.8	7,908	3,454	5.5	290.3	119.3	6.4	613.9	238.1	10.8	66,366	33,067
Rhus typhina	3.5	38,014	16,133	3.9	0.2	296	158	0.9	48.7	26.1	0.3	27.0	12.9	0.6	3,983	2,383
Populus deltoides	3.1	33,358	16,872	11.7	9.0	14,967	7,558	6.6	348.5	191.8	5.3	510.4	219.9	3.6	22,021	11,517
Ostrya virginiana	3.0	32,815	19,571	4.2	0.8	1,249	834	1.2	65.0	41.5	1.7	163.4	88.3	0.8	4,976	3,126
Tsuga canadensis	2.7	29,703	13,277	3.5	0.4	672	499	1.0	54.1	24.5	1.1	106.0	63.1	1.1	6,474	2,984
Ailanthus altissima[b]	2.6	28,795	20,123	4.5	1.8	2,931	2,012	2.1	114.0	70.4	1.8	174.2	129.5	1.4	8,340	5,225
Carya ovata	2.3	24,677	15,381	4.3	2.3	3,740	1,867	2.2	116.0	54.4	1.4	138.7	64.6	1.1	6,670	3,128
Robinia pseudoacacia[b]	2.0	22,157	12,927	4.4	2.4	3,930	2,341	3.3	173.5	108.1	2.9	275.1	166.8	2.6	16,199	10,525
Carya cordiformis	1.9	21,061	16,446	3.7	1.7	2,881	1,982	2.1	113.4	74.8	1.6	149.6	95.8	1.2	7,593	4,788
Juglans nigra	1.7	18,068	5,477	4.7	3.1	5,219	2,057	3.7	198.8	73.5	7.3	697.8	248.7	4.1	25,425	10,011
Prunus virginiana	1.4	15,420	15,411	1.5	0.0	47	47	0.2	9.4	9.4	0.2	17.7	17.7	0.1	332	332
Gleditsia triacanthos	1.2	13,481	6,611	3.5	2.3	3,891	1,904	3.1	164.6	72.5	1.3	120.7	48.8	3.2	19,669	9,069
Malus spp.	1.1	12,445	3,512	1.9	0.6	958	419	1.3	69.2	25.1	1.1	106.9	45.8	1.1	6,997	2,686
Fraxinus americana	1.0	11,010	7,508	1.2	0.1	160	96	0.3	13.6	8.2	0.3	32.0	19.9	0.1	747	458
City Total (all species)		1,087,968	147,068			165,857	18,807		5,315.3	493.9		9,575	830		614,548	64,605

tC metric tons of carbon

SE standard error

[a] Importance value = percent of total population + percent of total basal area

[b] invasive species in New York State

Table 4 Pollution removal by tree and shrub cover and associated value in Syracuse, NY (2009) derived from i-Tree Eco

Pollutant	Annual removal (t)	Annual value ($)
CO	2.2	3.1
NO_2	2.0	19.7
O_3	60.9	603.3
PM_{10}	33.1	219.0
SO_2	2.8	6.8
Total	101.0	851.9

Invasive species

Of the 86 tree species sampled in Syracuse in 2009, five were classified as invasive in New York State: *Rhamnus cathartica* (19.4 % of the total population), *Acer platanoides* (5.8 %), *Ailanthus altissma* (2.6 %), *Robinia pseudoacacia* (2.0 %) and *Elaeagnus angustifolia* (less than 0.05 %). These invasive species comprise 29.8 % of the total tree population, 13.9 % of total carbon stored, 15.7 % of basal area and 21.4 % of the total leaf area in the city (Table 3).

Discussion

Tree cover

Tree cover in Syracuse, NY (26.9 %) is less than both the national average tree cover in urban areas (35.0 %) and urban tree cover in New York State (41.2 %) (Nowak and Greenfield 2012b). However this difference in not unexpected as Syracuse has a fairly high population density (2,233 people km^{-2}) compared to urban New York State (1,600 people km^{-2}) and US urban areas (903 people km^{-2}). Percent tree cover in urban areas is negatively correlated with urban population density (Nowak and Greenfield 2012b). Urban tree cover nationally is less than the New York State average as most of New York is naturally forested while many urban areas nationally area within desert or grassland areas that generally have lower urban tree cover than cities found within naturally forested regions (Nowak and Greenfield 2012b).

Urban forest structure and ecosystem services

There are an estimated 1,088,000 trees in Syracuse, which equates to 167.4 trees ha^{-1} of land or 622 trees ha^{-1} of tree cover. The density of trees per hectare of tree cover is higher than the average from several U.S. states or North American cities (508 trees ha^{-1} of cover; Nowak and Greenfield 2012a). This higher density is partially due to the relatively small diameter structure and dense thickets of *Rhamnus cathartica* that exists within Syracuse. The estimated compensatory value of this forest is $615 million, or about $565 per tree. This value is likely overestimated for invasive small tree/shrub species (*Rhamnus cathartica* and *Elaeagnus angustifolia*) as these species are not specifically addressed in the valuation species list for New York State (genera or family average values are used). However, these two invasive species are valued at $17.4 million or only $82 per tree. If these invasive species are assumed to have no compensatory value, the total compensatory value for the urban forest would drop to $598 million. Though these invasive species provide some

Table 5 Change in city tree population (1999–2009) by land use (1999)

Land use	1999				2001				2009			
	Total	SE	# ha^{-1}	SE	Total	SE	# ha^{-1}	SE	Total	SE	# ha^{-1}	SE
Residential	248,920	35,604	89.3	12.8	251,732	37,481	90.3	13.4	306,579[a]	44,074	109.9[a]	15.8
Green space	231,300	79,398	317.7	109.1	215,880	68,856	296.5	94.6	262,997[a]	90,643	361.3[a]	124.5
Vacant	208,192	49,297	372.4	88.2	198,384	49,020	354.9	87.7	278,183[a]	63,450	497.6[a]	113.5
Institutional	111,925	70,489	226.6	142.7	113,960	69,189	230.7	140.1	109,890[b]	54,969	222.4[b]	111.3
Multi-family	39,935	16,621	86.4	36.0	44,214	20,099	95.7	43.5	74,165[a]	63,535	160.5[a]	137.5
Trans./Utility	26,411	9,098	60.7	20.9	23,476	8,050	54.0	18.5	39,127[b]	16,101	89.9[b]	37.0
Comm/Ind.	14,189	7,507	13.7	7.3	14,189	7,507	13.7	7.3	17,027	11,260	16.5	10.9
City total	880,871	124,040	135.5	19.1	861,835	117,733	132.6	18.1	1,087,968[a]	147,068	167.4[b]	22.6

SE standard error

[a] Statistically significant change from prior measurement period (alpha = 0.01)

[b] Statistically significant change from prior measurement period (alpha = 0.05)

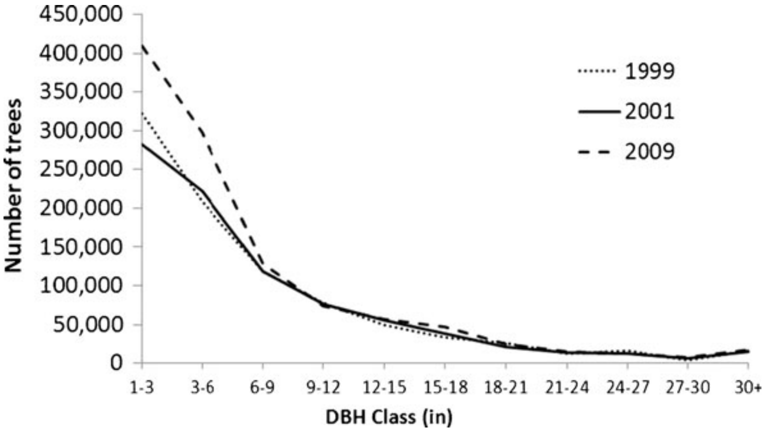

Fig. 1 Diameter (dbh) distribution of urban forest population in 1999, 2001 and 2009

ecosystem services, they also provide disservices by displacing native species and altering local ecosystems (e.g., Pimentel et al. 2000) and can incur costs via management or eradication programs.

Table 6 Population change (1999–2009) for the 20 most common tree species in 1999

Species	1999	Removal (99–09)	Influx (99–09)	2009	Difference
Acer saccharum	116,926	30,459	12,761	99,228	−17,698[a]
Thuja occidentalis	70,998	15,915	892	55,974	−15,024
Acer platanoides	60,588	24,416	27,250	63,422	2,834
Rhamnus cathartica	58,425	17,275	170,340	211,491	153,066[a]
Acer negundo	54,442	21,518	31,324	64,248	9,806[b]
Prunus serotina	50,053	11,236	29,234	68,051	17,998[a]
Picea abies	47,847	2,424	2,035	47,458	−389
Ostrya virginiana	47,247	15,324	892	32,815	−14,432[b]
Rhus typhina	43,313	38,402	33,104	38,014	−5,299
Carya ovata	27,282	2,605	0	24,677	−2,605
Tsuga canadensis	21,385	2,229	10,547	29,703	8,318
Carya cordiformis	18,748	703	3,016	21,061	2,313
Populus deltoides	17,545	1,595	17,408	33,358	15,813
Picea pungens	12,982	2,853	0	10,129	−2,853
Cornus spp.[c]	12,697	11,994	1,406	2,109	−10,588
Ailanthus altissima	12,043	4,081	20,833	28,795	16,752
Juglans nigra	10,996	2,119	9,192	18,068	7,072
Malus spp.	10,662	3,962	5,745	12,445	1,783
Gleditsia triacanthos	10,271	703	3,913	13,481	3,210
Robinia pseudoacacia	9,826	0	12,331	22,157	12,331

[a] Significant difference (alpha = 0.01) in species population between 1999 and 2009

[b] Significant difference (alpha = 0.05) in species population between 1999 and 2009

[c] includes Cornus plants identified to species (C. kousa, C. florida, and C. alternifolia)

Table 7 Species population change (1999–2009) by land use

Species	City	Residential	Vacant	Greenspace	Institutional	Multi-family Res.	Transportation	Comm/Industrial
Acer ginnala	1,017	na	na	na	1,017	na	na	na
Acer negundo	9,806	10,547	4,012	0	−10,175	−1,426	6,847	0
Acer palmatum	703	703	na	na	na	na	na	na
Acer platanoides	2,834	1,406	7,133	0	0	−5,705	0	na
Acer rubrum	−1,149	−703	−445	0	0	na	na	na
Acer saccharinum	−4,494	−3,516	0	na	0	na	−978	na
Acer saccharum	−17,698	0	−7,579	−11,137	1,018	na	na	na
Aesculus hippocastanum	0	0	na	na	na	na	na	na
Ailanthus altissima	16,752	704	16,049	na	0	na	na	na
Amelanchier spp.	2,813	2,813	na	na	na	na	na	na
Betula nigra	0	0	na	na	na	na	na	na
Betula pendula	1,406	1,406	na	na	na	na	na	na
Betula populifolia	−446	0	−446	na	na	na	na	na
Carpinus spp.	703	703	na	na	na	na	na	na
Carpinus betulus	0	na	na	na	0	na	na	na
Carya cordiformis	2,313	−704	446	2,570	na	na	na	na
Carya glabra	−446	0	−446	na	na	na	na	na
Carya ovalis	0	na	0	na	na	na	na	na
Carya ovata	−2,605	na	−892	−1,713	na	na	na	na
Catalpa speciosa	703	703	na	na	na	na	na	na
Chamaecyparis pisifera	−2,675	na	−2,675	na	na	na	na	na
Cornus alternifolia	−857	na	na	−857	na	na	na	na
Cornus florida	703	703	na	na	na	na	na	na
Cornus kousa	0	0	na	na	na	na	na	na
Cornus spp.	−10,434	703	na	−11,137	na	na	na	na

Table 7 (continued)

Species	City	Residential	Vacant	Greenspace	Institutional	Multi-family Res.	Transportation	Comm/Industrial
Crataegus spp.	−978	na	na	0	na	na	−978	na
Crataegus crus-galli	0	na	na	na	na	na	na	na
Elaeagnus angustifolia	446	na	446	na	na	na	na	na
Fraxinus americana	7,673	na	446	0	5,088	2,139	na	na
Fraxinus holotricha	0	0	na	na	na	na	na	na
Fraxinus pennsylvanica	694	1,407	na	na	0	−713	0	na
Ginkgo biloba	703	703	na	na	na	na	na	na
Gleditsia triacanthos	3,210	−703	na	na	na	0	3,912	na
Hibiscus syriacus	2,109	2,109	na	na	na	na	na	na
Juglans cinerea	978	0	0	na	0	na	978	na
Juglans nigra	7,072	4,219	3,566	0	na	−713	0	na
Juniperus virginiana	−3,823	−2,110	na	−1,713	na	na	na	na
Kolkwitzia amabilis	703	703	na	na	na	na	na	na
Lonicera spp.	2,424	1,406	na	na	1,018	na	na	na
Magnolia x soulangiana	0	0	na	na	na	na	na	na
Malus pumila	0	0	na	na	na	na	na	na
Malus spp.	1,783	0	1,784	0	na	0	na	na
Morus alba	−1,664	−2,110	446	na	na	na	na	na
Morus rubra	−960	−1,407	446	0	na	0	na	na
Ostrya virginiana	−14,432	na	−7,578	−6,854	na	na	na	na
Picea abies	−389	−1,406	0	na	1,018	na	na	na
Picea glauca	−704	−703	na	na	na	na	0	na
Picea pungens	−2,853	0	na	na	na	−2,853	0	na
Pinus nigra	−3,541	−703	na	0	na	na	na	−2,838
Pinus ponderosa	0	na	na	0	na	na	na	na

Table 7 (continued)

Species	City	Residential	Vacant	Greenspace	Institutional	Multi-family Res.	Transportation	Comm/Industrial
Pinus resinosa	1,407	1,407	na	na	na	na	na	na
Pinus strobus	0	0	na	na	na	na	na	na
Pinus sylvestris	−446	0	−445	na	na	na	na	na
Pinus thunbergiana	0	na	na	na	na	na	0	na
Platanus hybrida	0	na	na	0	na	na	na	na
Platanus occidentalis	0	0	na	na	na	na	na	na
Populus deltoides	15,813	−703	12,928	2,570	1,017	na	na	0
Prunus spp.	−703	−703	na	na	na	na	na	na
Prunus americana	−4,219	−4,219	na	na	na	na	na	na
Prunus avium	4,646	−703	5,349	na	0	0	na	na
Prunus serotina	17,998	−2,813	−891	2,570	16,280	2,852	na	na
Prunus serrulata	1,406	1,406	na	na	na	na	na	na
Prunus subhirtella	1,406	1,406	na	na	na	na	na	na
Prunus virginiana	13,707	na	na	13,707	na	na	na	na
Prunus x cistena	703	703	na	na	na	na	na	na
Pseudotsuga menziesii	−703	−703	na	na	na	na	na	na
Pyrus communis	1,338	0	1,338	na	na	na	na	na
Quercus alba	−446	0	−446	0	na	na	na	na
Quercus rubra	−2,862	−703	−445	−1,713	na	0	na	na
Quercus velutina	−446	0	−446	0	na	na	na	na
Rhamnus cathartica	153,066	16,173	22,291	48,830	8,140	47,067	4,891	5,676
Rhus typhina	−5,299	11,953	15,603	−3,427	−27,473	na	−1,956	na
Robinia pseudoacacia	12,331	10,548	1,783	na	na	na	na	na
Salix spp.	703	703	na	0	0	na	na	na
Salix nigra	−856	na	na	−856	na	na	na	na

Table 7 (continued)

Species	City	Residential	Vacant	Greenspace	Institutional	Multi-family Res.	Transportation	Comm/Industrial
Sorbus spp.	703	703	na	na	na	na	na	na
Syringa spp.	1,406	1,406	na	na	na	na	na	na
Syringa reticulata	703	703	na	na	na	na	na	na
Syringa vulgaris	3,516	3,516	na	na	na	na	na	na
Taxus spp.	2,109	2,109	na	na	na	na	na	na
Thuja occidentalis	−15,024	−15,470	446	0	na	na	na	na
Tilia americana	411	na	−445	856	na	na	na	na
Tilia cordata	446	0	445	na	na	na	na	na
Tsuga canadensis	8,318	10,548	−2,230	na	na	na	na	na
Ulex spp.	703	703	na	na	na	na	na	na
Ulmus americana	−714	0	0	na	0	−713	na	na
Ulmus glabra	0	0	na	na	na	na	na	na
Ulmus rubra	−1,429	2,813	446	na	1,018	−5,705	na	na

na not applicable: species was not sampled within the land use type

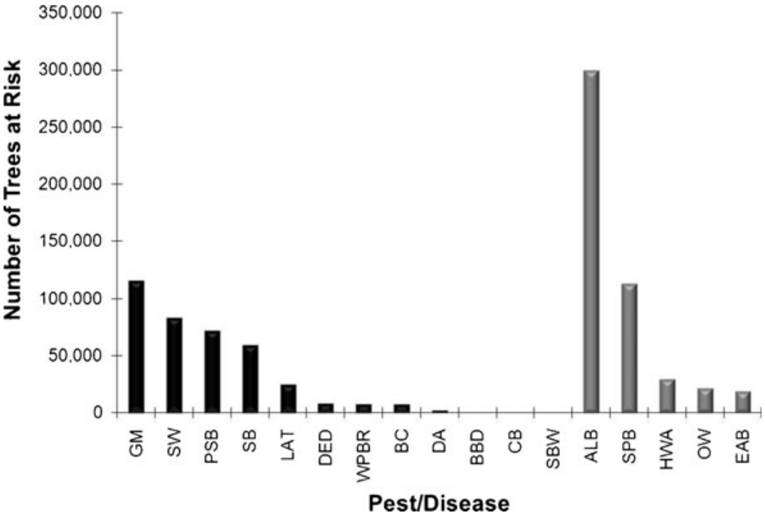

Fig. 2 Potential risk to insects and diseases (pests) in Syracuse, NY. Black bars indicate that pest is within Onondaga County and gray bars indicate pest is within 250 miles of Onondaga County. *ALB* Asian longhorned beetle, *BBD* beech bark disease, *BC* butternut canker, *CB* chestnut blight; *DA* dogwood anthracnose, *DED* Dutch elm disease, *EAB* emerald ash borer, *GM* gypsy moth, *HWA* hemlock woolly adelgid, *LAT*: large aspen tortrix, *OW* oak wilt, *PSB* pine shoot beetle, *SB* spruce beetle, *SBW* spruce budworm, *SPB* southern pine beetle, *SW* sirex woodwasp, *WPBR* white pine blister rust

The annual ecosystem services provided in relation to carbon sequestration, air pollution removal and reduction in building energy use total about \$2.4 million yr^{-1}. These are just a few of the services provided by urban forests, many of which cannot be calculated or monetized at this time (e.g., social benefits, aesthetics, air temperature reduction, wildlife habitat). In addition, the urban forest of Syracuse has various environmental (e.g., VOC emissions, pollen) and monetary costs (e.g., tree maintenance) that are not addressed in this paper. More research is needed to quantify these services and disservices as these services affect the lives and well-being of city residents and can have substantial economic and ecological impacts.

Syracuse's carbon storage per unit of canopy cover (8.59 kgC m^{-2}) and annual sequestration per unit of canopy cover (0.29 kgC m^{-2} yr^{-1}) are greater than the average densities from several U.S. states and cities (7.69 kgC m^{-2} of tree cover and 0.28 kgC m^{-2} yr^{-1} of tree cover, respectively; Nowak et al. 2013a), partially due to above average tree density per unit of tree cover. Syracuse's pollution removal per unit canopy cover is estimated at 5.8 g m^{-2} yr^{-1}, which is less than the average of 10.8 g m^{-2} yr^{-1} from 55 U.S. cities (Nowak et al. 2006a). This lower pollution removal rate per unit canopy cover is likely due to several factors, including: a) general improvements in air quality between the dates of the two studies (original study used pollution data from 1994), b) lower pollution concentrations in the city compared with the other analyzed cities (Syracuse's ozone concentration is near the US average, but is about 60 % of the national average for carbon monoxide and 23 % for sulfur dioxide (U.S. EPA 2013)), c) differences in meteorology, length of growing seasons and percent of forest with deciduous leaves – all of which affect removal rates.

Recently, removal of particulate matter less than 2.5 μm ($PM_{2.5}$) was assessed and revealed that Syracuse's urban forest removes about 4.7 metric tons of $PM_{2.5}$ per year (2010) with an associated value of \$1.1 million (Nowak et al. 2013b). This value is higher than estimated for PM_{10} due to $PM_{2.5}$ values being based on human health costs, not externality values. As $PM_{2.5}$ is a subset of the PM_{10}, these two values cannot be directly added. Adjusting for the overlap, the total value for PM_{10} including this new $PM_{2.5}$ estimate would be $1,286,000. This value is substantially higher than the PM_{10} estimate using just externality costs ($216,600), thus the pollution removal values in this paper using externality values are conservative relative to valuation using human health costs.

The ecosystem services provided by an urban forest are directly related to forest structure (e.g., species composition, tree density, tree cover, tree sizes and health, tree locations) within the context of local environmental conditions (e.g., weather, pollution levels). Thus changing the forest structure, either through natural processes (e.g., natural regeneration, natural tree mortality, insects, diseases, storms) or human-dominated processes (development, tree removal, tree planting), has affected and will affect ecosystem services and values in the future.

Urban forest change

Urban forest populations oscillate through time due to numerous natural and anthropogenic factors. Syracuse's urban forest exhibited a slight, non-significant decline in cover and number of trees between 1999 and the early 2000s, but then exhibited a significant increase between the early 2000s and 2009. The loss of trees between 1999 and 2001 (2.1 % decline), is similar to the population decline exhibit in Baltimore (4.0 % decline) during the same period (Nowak et al. 2004). All land uses in Syracuse except for institutional and commercial/industrial exhibited a significant increase in number of trees between 2001 and 2009. This increase is predominantly due to an influx of young/small invasive or pioneer species regenerating within the city, particularly *Rhamnus cathartica*. Between 2001 and 2009, the number of trees less than 3 in. dbh increased by 88,000 (27 %) with most of this increase on vacant (44,800 trees), residential (23,200) and multi-family residential (14,200) lands. The common species less than 3 in. dbh are: *Rhamnus cathartica* (27.6 % of trees less than 3 in dbh), *Acer saccharum* (12.1 %), *Rhus typhina* (7.6 %), *Prunus serotina* (7.4 %), *Acer negundo* (5.5 %) and *Acer platanoides* (5.4 %). These six species combine for 65 % of all trees less than 3 in. dbh and exclusive of *Acer saccharum*, are invasive or pioneer species. Four of the 14 most common tree species in Syracuse are also classified as invasive plants.

The new tree influx rate in Syracuse between 2001 and 2009 was 8.6 trees ha^{-1} yr^{-1}, of which 7.9 trees ha^{-1} yr^{-1} came from natural regeneration and 0.7 trees ha^{-1} yr^{-1} came from tree planting (Nowak 2012). Thus, over 90 % of new trees established in the city came from natural regeneration, with the greatest density of regeneration occurring on vacant and multi-family residential areas (Nowak 2012). Though humans can and do increase tree populations through planting, the dominant factor affecting tree population increases in Syracuse is natural regeneration. City records on street trees in Syracuse is showing a decline, with 3,980 street trees removed between 2002 and 2009, but only 3,000 street trees planted (Steve Harris, pers. comm., 2013). Street tree plantings are targeted mainly in residential areas.

The most common species in 1999 (*Acer saccharum*: 13.3 % of total population) is on a decline. The fourth to sixth most common species (*Rhamnus cathartica*: 6.6 %, *Acer negundo*: 6.2 %, and *Prunus serotina*: 5.7 %), which are invasive or pioneer species, are significantly increasing. The most substantial increase has been with *Rhamnus cathartica*, which has more than tripled in population since 1999. This increase in population is the result of new trees seeding in, particularly in areas with high buckthorn density. In 1999, 14 of the 198 plots sampled contained *R. cathartica* and by 2009, 23 plots contained this species. Furthermore there were also substantial increases on three plots that had the highest densities of *R. cathartica* in 1999. Plot density of this species on these three plots increased from an average of 461 plants per hectare in 1999 to 1,771 plants ha^{-1} in 2009. The total basal area of *R. cathartica* increased from 386 m^2 (0.9 % of total basal area; IV=7.5) to 1,761 m^2 (3.3 %; IV =22.7) in 2009. Though *R. cathartica* is increasing in number of stems and basal area, it dominance or importance in the overall forest will likely be limited by its small stature. It is unknown as to why this species is increasing, but it likely has to do with the invasive characteristics of the plant (seed distribution) and increases in unmanaged open space due to loss of existing canopy and/or active management (e.g., mowing).

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*. Though native forest species are regenerating, only 35 % of new trees in Syracuse (2001–2009) are native species. In addition, 52 % of the new trees are classified as invasive species in Syracuse (*Rhamnus cathartica*, *Ailanthus altissima*, *Acer platanoides*, *Robinia pseudoacacia*, *Elaeagnus angustifolia)* (Nowak 2012).

The overall increase of new trees between 1999 and 2009 was dominated by, in order: *Rhamnus cathartica, Rhus typhina, Acer negundo, Prunus serotina, Acer platanoides, Ailanthus altissima, Populus deltoides, Acer saccharum, Robinia pseudoacacia,* and *Tsuga canadensis* (Table 6). These species all averaged an increase of at least 1,000 trees per year. However, two of these species (*Rhus typhina, Acer saccharum*) have declined in overall population due to tree removals. Species with the greatest increases in population are: *Rhamnus cathartica, Prunus serotina, Ailanthus altissima, Populus deltoides, Prunus virginiana, Robinia pseudoacacia,* and *Acer negundo,* though only *R. cathartica, P. serotina,* and *A. negundo* had statistically significant increases. Species with the greatest decline in population are: *Acer saccharum*, *Thuja occidentalis, Ostrya virginiana, Cornus* spp., *Rhus hirta* and *Acer saccharinum,* though only *A. saccharum and O. virginiana* had statistically significant decreases.

The change in the amount of tree cover and types of trees between 1999 and 2009 was substantially influenced by the Labor Day Storm of 1998. On September 7, 1998, winds reaching up to 192 km hr^{-1} damaged or killed tens of thousands of trees in the region (NOAA 2012). The death and removal of many trees in Syracuse due to the Labor Day Storm created open space for potential tree regeneration. This storm is perhaps the single most important factor explaining tree cover decline between pre-storm years (27.5 % tree cover) and 2003 (25.9 %). Since 2003, tree cover has increased to around 27 %, mostly due to regeneration of invasive or pioneer species. The City currently has management activities that eradicate invasive plants only in one park (Kirk Park; Steve Harris, pers. comm. 2013). Without tree planting and management, the urban forest composition in Syracuse will shift toward more pioneer or invasive tree species in the near term.

While invasive and pioneer tree species are currently on the rise in Syracuse and are affecting species composition and magnitude of the urban forest, other factors can also have a considerable effect on the future of Syracuse's urban forest. These factors include climate change, urban development, urban forest planning and management, future storms and future insect and disease infestations.

Risks from insects and diseases

In terms of potential insects and diseases, the largest potential threats that are already within the county are gypsy moth, sirex woodwasp, pine shoot beetle, and spruce beetle. The gypsy moth is a defoliator that feeds on many species and can cause widespread defoliation and tree death if outbreak conditions last several years (USDA Forest Service 2005). Gypsy moth could affect about 10.7 % of the tree population and 16.4 % of total basal area (susceptible species; Liebhold et al. (1995)) and gypsy moth defoliation has occurred in this region in the past. Under gypsy moth outbreaks, more trees species may be attacked.

The sirex woodwasp is a wood borer that primarily attacks pine species. It is not native to the United States, but is known to cause a high percentage of tree mortality among North American species that have been planted in countries of the southern hemisphere (Haugen and Hoebeke 2005). The risk to this insect is unclear, but it could kill up to 7.7 % of the city's trees and 14.7 % of the basal area. In New York, the sirex woodwasp appears only to be killing declining and unhealthy scots pine and red pine to date (Schneeberger, pers. comm., 2012). These two species only comprise about 0.4 % of the tree population and 0.8 % of the basal area. However, other stressed pine trees may also be at risk to sirex woodwasp.

The pine shoot beetle is a wood borer that attacks various pine species while the spruce beetle primarily attacks spruce trees (Holsten et al. 1999; Ciesla 2001). These beetles can affect about 6.6 and 5.4 % of the tree population (11.7 and 9.4 % of basal area) respectively. The impact of these beetles will probably be less in Syracuse as the pine shoot beetle seems to prefer smaller trees and most reports of the spruce beetle in the Northeastern United States have been from Maine with no reports of spruce beetle in this region in 2010 or 2011 (Schneeberger pers. comm. 2012).

Insects and diseases that are within 250 miles of Syracuse are Asian longhorned beetle, southern pine beetle, hemlock woolly adelgid, oak wilt and emerald ash borer. The hemlock woolly adelgid, oak wilt and emerald ash borer may be devastating pests elsewhere, but within Syracuse will affect less than 3 % of the population for each pest. However, due to the likelihood of emerald ash borer infesting the Syracuse area in the near future, this pest will quickly pose a significant risk to about 19,000 ash trees in Syracuse (1.7 % of population; 1.2 % of basal area).

Due to their potential impacts, the Asian longhorned beetle and southern pine beetle are of concern, but have a lower probability of reaching Syracuse in the near future than the emerald ash borer. The Asian longhorned beetle is an insect that bores into and kills a wide range of hardwood species (USDA Animal and Plant Health Inspection Service 2010). This beetle was discovered in 1996 in Brooklyn, NY and spread to Long Island, Queens and Manhattan. Beetles have subsequently been found in several other states and Ontario, Canada. This beetle could kill about 27.6 % of the Syracuse tree population (46.7 % of basal area).

Under outbreak conditions, the southern pine beetle will attack most pine species and marginal hosts such as spruce and hemlock (Clarke and Nowak 2009) and could kill about 10.4 % of the urban forest in Syracuse (15.5 % of basal area). However, as the preferred hosts in the Southeastern United States to this pest are loblolly, shortleaf, pitch, pond, and Virginia pines, the actual risk to trees in this city is minimal.

The potential impacts of many of these pests could shift as both pest and host ranges change under future climatic conditions, though the extent to which climate change will affect these pests is unknown. While the most significant insect threats to Syracuse's urban forest appear to gypsy moth and emerald ash borer, a larger impact on forest change may come from invasive tree species.

Given the recent increases in Syracuse's urban forest population and risks to insects and diseases, Syracuse's tree population will continue to shift towards a forest with more pioneer and invasive tree species in the near future, with likely fewer *Fraxinus* spp. due to the impending threat from emerald ash borer. As many of these pioneer or invasive species typically are smaller and have shorter life-spans, the ability of city systems to sustain larger, long-lived tree species may require human intervention through tree planting and maintenance.

The future forest composition will be determined by a combination of natural (e.g., regeneration) and anthropogenic actions (e.g., tree planting and removal, development, mowing). City residents should determine what the desired future forest composition (and ecosystem services) should be and development plans to attain that goal. These plans can use natural regeneration, but also human actions to influence the future forest structure. Humans actions to remove invasive plants or protect trees from insects and diseases will affect forest structure and benefits, but at a cost. Lack of action against invasive plants and insects and disease will also affect forest structure, which will have a cost to society through altered forest structure and ecosystem services. Thus, human actions or inaction in the context of natural forces for change in cities will shape the urban forest of the future. By understanding these potential changes, management actions can instituted to direct the future urban forest composition to a structure that is desirable and beneficial to the residents of the region.

Conclusion

Long-term monitoring of urban forests can provide valuable information on how urban forest structure and ecosystem services are changing through time. Syracuse's urban forest is currently shifting toward an increased dominance of invasive or pioneer tree species. Changes in the urban forest due to such factors as urban development, climate change, urban forest planning and management, storms, invasive plants and insect and disease infestations will continue to affect and alter this resource in the coming years. Better understanding of urban forests and how they are changing can facilitate better management plans to sustain ecosystem services and desired forest structure for future generations.

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