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Species composition and structure of regenerated and remnant forest patches within an urban landscape

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Abstract. Regenerated and remnant forest patches were inventoried in Syracuse, New York, USA to determine differences in structure, species composition, human disturbances, and landscape context. Patches had similar mean stem diameter, total stem density, and total basal areas, but differed with respect to diameter distribution, disturbance regime, landscape context, and occurrence of introduced species. In regenerated patches, 23 introduced species were inventoried and they accounted for 48% of relative density. In remnant patches, only seven introduced species were inventoried and they accounted for 17% of the relative density. Cluster analyses identified two community types for remnant patches—sugar maple and black oak—and three for regenerated patches—sugar maple, Norway maple, and boxelder. For remnant patches, *Rhamnus cathartica* dominated the small diameter class in the black oak cluster, and *Acer saccharum* dominated the small diameter class in the sugar maple cluster. For regenerated patches, introduced species—*A. platanoides and R. cathartica*—dominated the small diameter class in the Norway cluster, and a mixture of native and introduced species—*A. negundo, R. cathartica, A. saccharum,* and *Rhus typhina*—dominated the small diameter classes in the sugar maple and boxelder clusters. Functionally, land covers containing remnant and regenerated patches, such as vacant lots and greenspaces, had the highest net rate of carbon sequestration (848.7 mt/ha/yr).

Keywords: patch origin, disturbance, species composition and structure

Introduction

Vegetation cover in an urban landscape represents a continuum of greenspace that ranges from lawns to patches of tree and forest cover (Airola and Buchholz, 1984). Analysis of canopy cover principally has focused on two elements: the interstitial forest and forest patches. The interstitial forest represents planted trees along streets, in yards and parks, and around built structures (Detwyler, 1972). Species composition and structure of the interstitial forest might reflect remnant vegetation (McBride and Jacobs, 1976) and are influenced by social context as defined by census block or tract using indicators such as income, home ownership, and education (Whitney and Adams, 1980). On the other hand, forest patches often represent blocks of contiguous cover and analyses have focused principally on remnant patches—tree-covered sites that have never been cleared for urban use—transportation, recreation, institutional, commercial and residential. Some of these sites may have been cleared at one time for agricultural purposes, but have always existed as a forested patch in the urban landscape. Studies include surveying forests in parks (e.g. Greller, 1975; Profous and Loeb, 1984; Rudnicky and McDonnell, 1989), across urban landscapes (e.g. Hobbs, 1988a), and along gradients of urbanization (e.g. Airola and Buchholz, 1984; Guntenspergen and Levenson, 1997). Findings reveal that the extent of changes to canopy and understory composition and structure depend on the frequency and severity of human activities.

In addition to remnant forest patches, regenerated forest patches also exist within the urban landscape (Forman and Godron, 1981; Zipperer *et al.*, 1997). Regenerated patches are tree-covered sites that once had been cleared of vegetation for urban use and then abandoned. Studies of urban vegetation largely have ignored the composition and structural characteristics of these patches or incorrectly classified them as remnant patches. Like their remnant counterparts, regenerated patches are ecologically and socially important elements of the urban landscape because they influence hydrologic processes through interception and evapotranspiration, improve air and water quality through filtering pollutants, provide critical habitat for wildlife, and offer recreational opportunities.

From a management perspective, forest cover classification by patch origin might seem cumbersome and unnecessary. From an ecological perspective, however, patch origin influences ecological processes by affecting the movement of energy, materials, and organisms (Forman, 1995). If urban forest management objectives are to maintain or enhance ecological benefits from vegetation (Nowak and Dwyer, 2000), understanding how these patch types differ structurally and functionally is the first step toward optimizing their benefits within an urban landscape. In this study, I inventoried regenerated and remnant patches in an urban landscape to identify how they differ compositionally and structurally. In addition, I examined how human disturbances varied by patch type, and used carbon sequestration data for the city of Syracuse to illustrate the functional importance of remnant and regenerated patches for providing ecological benefits.

Methods

Study area

The study was conducted within the city limits of Syracuse, NY (figure 1). The City, located in Onondaga County and incorporated in 1848, is 66.6 km^2 in area and has a population of approximately 150,000 individuals according to the 2000 U.S. Census. The city has a humid, continental climate with mean annual temperature of 9.2°C, a mean annual precipitation of 95 cm, 175 frost-free days, and a mean annual snowfall of 276.8 cm.

Sampling procedures

Patch origin was identified from aerial photographs. Sites without canopy cover in 1939 photos, but with canopy cover on 1978 photos were designated regenerated. Sites with a canopy in the 1938 and 1978 photos were designated remnant. All identified patches on 1978 photos were mapped and numbered. Regenerated patch sizes ranged from 0.08–1.4 ha, and remnant patches ranged from 0.8–89.9 ha. Because of insufficient sample size to stratify by size class, inventoried patches were randomly selected from the pool of potential sites. Each sampled patch satisfied the following criteria: had a closed crown canopy consisting of tree species that developed from natural regeneration; showed no evidence of a recent (< 15 yrs)

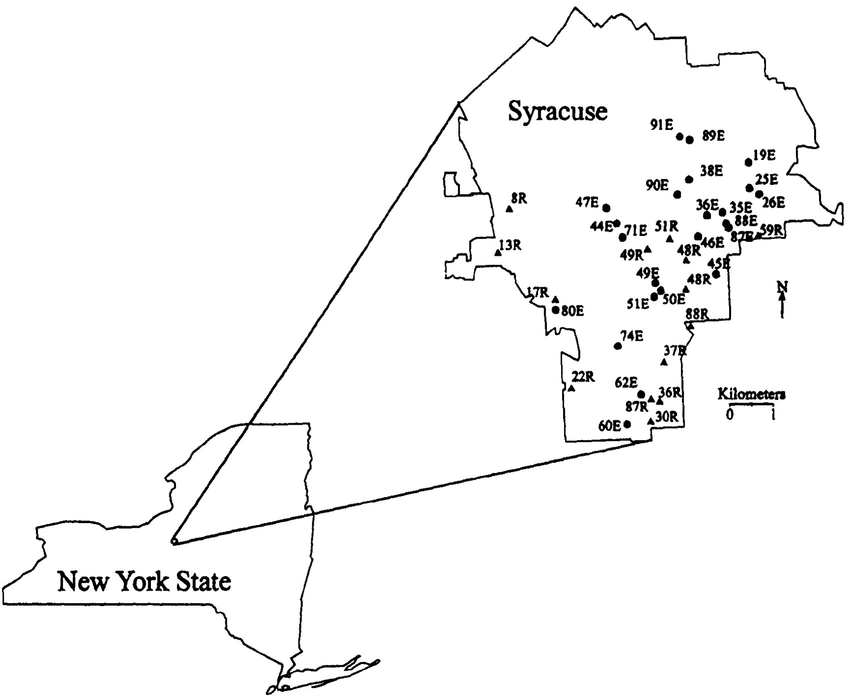

Figure 1. Map of Syracuse, NY indicating the sample location of 12 remnant (▲) and 23 regenerated (●) forest patches.

timber harvesting, grazing or mowing; contained an understory; and were located on well drained sites. Patch histories were obtained by interviewing landowners and neighbors. Patch ages were determined from tree cores. Regenerated patch ages ranged from 30–60 years old. Remnant patch ages ranged from 80–150 years old.

Species and diameter at breast height (dbh) of the tree stratum (woody stems ≥2.5 cm DBH) were tallied on ten 0.12-ha circular plots for patches ≥0.5 ha. (Ten plots yielded a variance-to-mean-density ratio of less than 10%.) Patches <0.5 ha were completely inventoried. Native species were those species whose natural ranges included Onondaga County (Faust, 1961). Introduced species were those species whose natural ranges occurred outside of Onondaga County. Nomenclature followed Gleason and Cronquist (1991).

A disturbance ranking was assigned to each forest patch based on small-scale human activities present on the site. Classification of disturbances were derived from Sharpe *et al.* (1986) and included lawn waste, fire, excavation, vandalism, tree removal, trash present, dumping, trails/soil compaction, and erosion. The severity of each of the nine activities was rated from 0 to 5 with 0 being no disturbance and 5 reflecting severely disturbed. Neighboring land uses surrounding each patch were noted for each patch side and used to characterize landscape context. Land use/cover classifications followed an Anderson level 2 (Anderson *et al.*, 1976) and included: commercial, industrial, institutional, vacant, residential-single family, residential-multiple family, transportation, park, and forest.

Statistical analysis

Stem density, basal area, and dbh were calculated for an entire patch and for each species. In addition, relative density (species density/total density), relative basal area (species basal area/total basal area), and an importance value (relative density + relative basal area) were calculated for each species (Curtis and McIntosh, 1951). A Ward clustering technique, based on relative Euclidean distances (McCune and Mefford, 1999), used species importance values to identify community types. Community types were defined by species composition and dominance. At an alpha level of 5%, paired-sample t test and a general linear model tested differences by patch origin (remnant or regenerated), cluster groups, and species type (introduced or native) for patch structure and species composition (Sokal and Rohlf, 1969).

Results

Patch structure

Field crews inventoried 23 regenerated and 12 remnant patches. Regenerated and remnant patches had similar mean stem densities and basal areas, and dbh (Table 1). Patches, however, differed in density distribution (figure 2). As one might expect, regenerated patches had a greater stem density for smaller trees ($\leq$29.9 cm dbh, $P < 0.01$) and lesser stem density and basal area for larger trees ($\geq$40.0 cm dbh, $P < 0.01$). One patch, 22R, inflated the basal area mean for remnant patches. This patch had a density of 306 stems/ha for larger trees. When this outlier was removed from the analysis, mean basal area for remnant patches was less than regenerated patches (30.14 vs. 32.1 m^2/ha, respectively).

Regenerated and remnant patches differed with respect to landscape context, percentage of patches disturbed, and the severity of human disturbance. Remnant patches occurred more frequently in commercial, industrial, institutional, parks, and forests land use/covers. By

Table 1. Mean site characteristics, and number of species and introduced species sampled in regenerated and remnant patches in Syracuse, NY. Standard errors are in parentheses following the values

Site characteristic	Regenerated	Remnant
Density (stems/ha)	1587.1 (143.2)	1280.3 (96.4)
Basal area (m^2/ha)	32.1 (2.6)	36.5 (6.5)
DBH (cm)	12.0 (0.2)	13.0 (0.2)
Patch size (ha)	0.3 (0.1)	2.2 (0.04)[a]
No. of species sampled	62	42
No. of introduced species	23	7

[a]Mean value does not include patch 22R. Patch 22R is city forest park that is 89 ha.

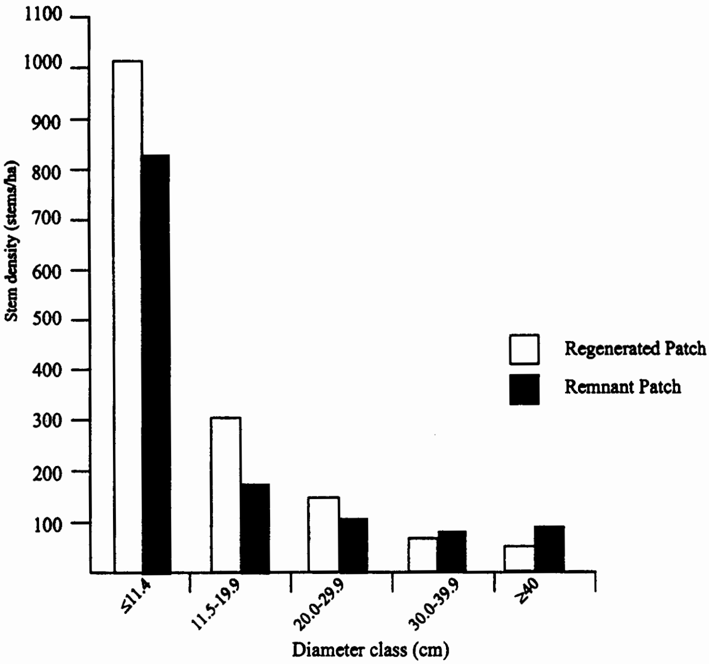

Figure 2. Diameter distribution of trees sampled in remnant and regenerated forest patches in Syracuse, NY.

comparison, regenerated patches were associated with single- and multi-family residential land use.

For each disturbance type, regenerated patches had a larger percentage of patches being affected and at a greater severity than remnant patches. More than 50% of regenerated patches were affected by human disturbances (Table 2). Disturbances included lawn waste, tree removal, trash/litter, dumping, and erosion. The highest mean disturbance ranks were 2.0 for trash/litter and 2.4 for dumping. Small-scale disturbances in remnant patches were similar but less severe.

Another difference between regenerated and remnant patches was the stem distribution of introduced species (Table 3). In both patch types, introduced species occurred primarily in the smaller diameter classes (<20.0 cm dbh). In regenerated patches, introduced species dominated the smallest diameter size class (Table 3). For the larger diameter classes (≥20.0 cm dbh), relative density of introduced species declined from 40 to 24% in regenerated patches and from 3 to 0% in remnant patches.

Compositional differences between patch types

Regenerated and remnant patches differed with respect to the number of species and occurrence of introduced species (Table 1). Regenerated patches had more species (62) and more

Table 2. Percentage of forest patches affected, and mean rank of severity of disturbance in the Syracuse, New York

Disturbance	Percentage affected		Difference	Mean severity rank	
	Remnant	Regenerated	(Rem.-Reg.)	Remnant	Regenerated
Lawn waste	33.3	65.2	−31.9	0.7	1.9
Fire	0.0	4.4	−4.4	0.0	0.1
Excavation	0.0	26.1	−26.1	0.0	0.7
Vandalism	25.0	30.4	−5.4	0.3	0.7
Tree removal	16.7	56.5	−39.8	0.3	1.1
Trash/litter	66.7	78.3	−11.6	1.4	2.0
Dumping	33.3	73.9	−40.6	0.7	2.4
Trails/soil compaction	0.0	17.4	−17.4	0.0	0.7
Erosion	41.7	56.5	−14.9	1.1	1.2

Table 3. Mean stem density by diameter classes of introduced[a] and native[a] species of regenerated and remnant patches in Syracuse, NY

Diameter class (cm)	Introduced species (stems/ha)		Native species (stems/ha)	
	Regenerated	Remnant	Regenerated	Remnant
≤11.4	523.6 (71.1)[b]	200.6 (57.3)	489.8 (88.6)[b]	628.1 (79.4)
11.5–19.9	146.5 (32.5)[b]	13.9 (5.4)	151.3 (23.5)	163.4 (15.3)
20.0–29.9	57.8 (11.7)[b]	3.4 (1.5)	85.7 (13.7)	107.0 (14.3)
30.0–39.9	24.2 (5.0)[b]	0.8 (0.5)	52.5 (12.0)	80.4 (10.2)
≥40.0	11.1 (5.0)[b]	0.0	33.9 (5.7)[b]	81.3 (21.8)
Total	763.2 (100.0)[b]	218.7 (63.0)	813.2 (113.9)	1059.7 (94.9)

Standard errors are in parentheses following the values.
[a]Definition for introduced and native species is given in the text.
[b]Regenerated and remnant patches are significantly different at $P < 0.05$.

introduced species (23). Introduced species on regenerated patches accounted for 48% of the total stem density and 35% of total basal area (Table 3). By contrast, only seven introduced species were surveyed on remnant patches and they accounted for 17% of the total stem density and only 3% of total basal area.

Regenerated and remnant patches shared 30 native and seven introduced species (Appendix 1). Seven native species occurred only on regenerated patches: *Acer saccharinum* (L.), *Celtis occidentalis* (L.), *Morus rubra* (L.), *Populus tremuloides* (Michx.), *Rhus typhina* (L.), *Salix nigra* (Marsh.), and *Ulmus rubra* (Muhl.). Six native species occurred only on remnant patches: *A. rubrum* (L.), *Cercis canadensis* (L.), *Cladrastis lutea* ((Michx.) K. Koch), *Cornus stolonifera* (Michx.), *Hamamelis virginiana* (L.), and *Liriodendron tulipifera* (L.).

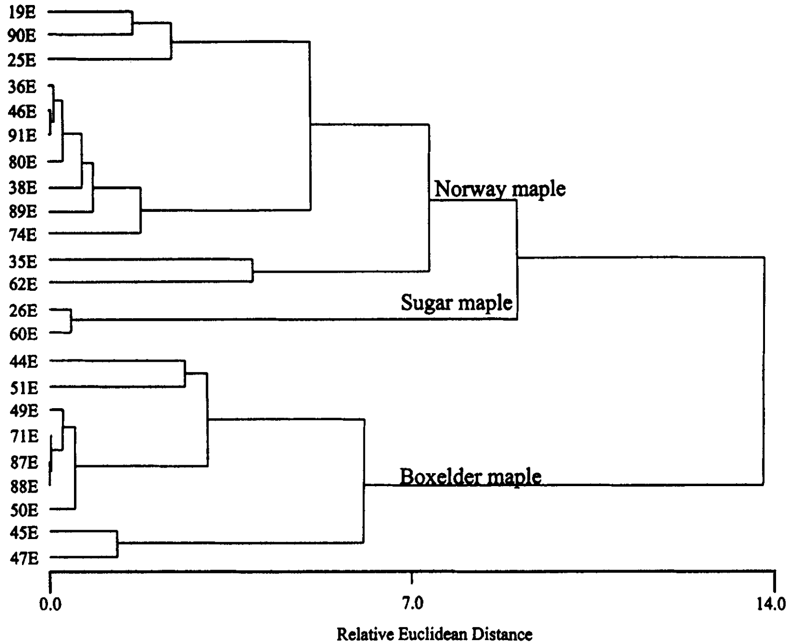

Figure 3. Dendrogram of the cluster analysis for regenerated forest patches based on species importance values.

Community structure and composition within a patch type

Within a patch type, structure and composition varied. Cluster analyses identified three community types in regenerated: sugar maple, Norway maple, and boxelder (figure 3). Two community types were present in remnant patches: sugar maple and black oak (figure 4).

Regenerated community types had similar mean stem density, but the sugar maple community type had a higher mean total basal area and larger stem dbh (Table 4). A comparison of diameter distribution of native and introduced species by community type showed that sugar maple and boxelder had similar distributions (Table 5). For both community types, native species had a greater stem density per diameter class and total stem density than introduced species. The Norway maple community type had more introduced species (23) and those trees dominated the small diameter classes (<20 cm dbh) and total stem density (Table 5).

Compositionally, distinct species patterns were observed between regenerated clusters. The sugar maple cluster contained only two patches whose mean importance value for *A. saccharum* was 56.9%. (Since only two patches defined this cluster group, it was omitted from further statistical analysis.) The patches contained in the sugar maple cluster had relatively low mean importance values for *A. negundo* (IV = 0.20) and *A. platanoides* (IV = 1.58). Other dominant species included *Robinia pseudo-acacia* (L.) (IV = 11.35), *Carya ovata* ((Mill.) K. Koch) (IV = 8.59), and *Rhamnus cathartica* (L.) (IV = 8.18).

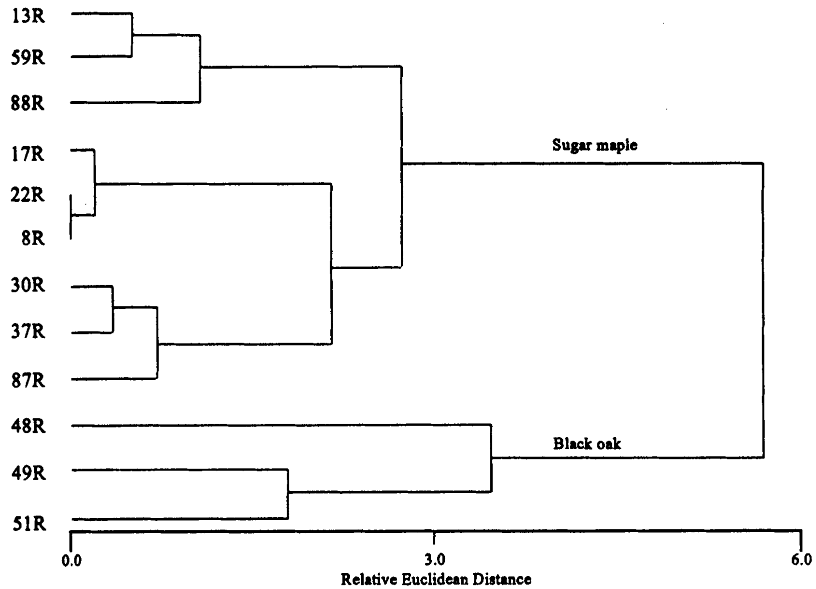

Figure 4. Dendrogram of the cluster analysis for remnant forest patches based on species importance values.

Dominant introduced species in the Norway maple cluster included *A. platanoides* (L.) (IV = 43.39) and *R. cathartica* (IV = 3.09) (Table 6 and figure 5). Important native species include *A. negundo* (L.) (IV = 7.38), *Prunus serotina* (Ehrh.) (IV = 5.41), *A. saccharum* (IV = 5.05), and *Fraxinus americana* (L.) (IV = 3.43). For the boxelder cluster, dominant introduced species included *A. platanoides* (IV = 10.82), *R. cathartica* (IV = 4.94), and

Table 4. Mean site characteristics for regenerated and remnant forest patches by cluster group (NM-Norway maple; BXE-boxelder; SM-sugar maple; BO-black oak) in Syracuse, NY

	Regenerated			Remnant	
Site characteristic	SM ($n = 2$)	NM ($n = 12$)	BXE ($n = 9$)	SM ($n = 9$)	BO ($n = 3$)
Density (stems/ha)	1581.2	1548.6 (185.2)	1612.4 (278.9)	1177.4 (106.8)	1581.6 (85.1)
Basal area (m^2/ha)	36.77	33.94 (4.24)	29.91 (2.84)	39.35 (8.50)	28.49 (2.73)
DBH (cm)	13.4 (0.5)	12.4 (0.2)	11.1 (0.3)	14.3 (0.3)	10.5 (0.3)
	($n = 604$)	($n = 2377$)	($n = 1776$)	($n = 2215$)	($n = 1200$)
No. of species sampled	26	55	35	35	29
No. of introduced species	8	23	12	5	6

Standard errors are in parentheses following the values.

Table 5. Mean stem density (SE) by diameter classes of introduced[a] and native[a] species by regenerated patch cluster groups—sugar maple (SM), Norway maple (NM), and boxelder maple (BXE)

Diameter class (cm)	Introduced (stems/ha)			Native (stems/ha)		
	SM	NM	BXE	SM	NM	BXE
≤11.4	267.3	672.7 (90.3)[b,c]	381.8 (109.5)[c]	704.5	243.7 (54.8)[b]	770.2 (168.5)
11.5–19.9	34.0	221.0 (45.7)[b]	72.1 (40.2)[c]	195.1	130.1 (32.3)	169.7 (41.8)
20.0–29.9	37.0	84.6 (18.3)[b]	26.7 (7.8)[c]	195.8	66.6 (19.3)	86.7 (15.1)
30.0–39.9	43.5	31.7 (6.1)	10.1 (3.1)[c]	56.8	51.9 (20.9)	52.3 (13.4)
≥40.0	10.9	15.9 (9.4)	4.9 (1.8)[c]	36.1	30.5 (7.8)	38.0 (10.4)
Total	392.8	1025.8 (132.6)[b,c]	495.5 (117.1)[c]	1188.5	522.8 (111.5)[b]	1116.9 (197.1)

[a]Definitions for introduced and native species are given in the text.
[b]Significantly different between clusters (rows) at $P < 0.05$.
[c]Significantly different within a cluster (columns) at $P < 0.05$.

Ailanthus altissima ((Mill.) Swingle) (IV = 4.50). Dominant native species include *A. negundo* (IV = 45.51), *Populus deltoides* (Marsh.) (IV = 17.69), *Salix nigra* (IV = 5.38), and *Rhus typhina* (L.) (IV = 4.04) (Table 6 and figure 5). As expected, the differences in importance values between cluster groups were reflective in significant differences in stem density and basal area for *A. negundo*, *A. platanoides*, and *R. typhina* (Table 6). *F. americana* and *S. nigra* mean dbhs also differed between clusters. Diameter distributions indicated that *P. deltoides* and *R. typhina* were predominantly associated with *A. negundo*, and *F. americana* and *F. pennsylvanica* were associated with *A. platanoides* (figure 5).

Remnant patches were divided into two community types: sugar maple and black oak (figure 4). Clusters differed structurally and compositionally. Structurally, the sugar maple cluster had a lesser mean total stem density but greater mean basal area and a larger mean dbh (Table 4). The sugar maple cluster also had a greater total number of species (35) but fewer introduced species (5). The clusters also differed in the diameter distribution of native and introduced species (Table 7). The sugar maple cluster had a lower stem density of introduced species in the smaller diameter classes (<20.0 dbh) and total stem density than the black oak cluster. These differences were significant even with the small sample size for the black oak cluster ($n = 3$). Figure 6 also revealed the relatively low stem density of oak species for both clusters in the smaller diameter classes (<20 cm dbh). *R. cathartica* dominated the small diameter class in the black oak cluster. Other species composing the smaller diameter classes were *Acer rubrum*, *Carya ovata* ((Mill.) K. Koch), *Cornus florida* (L.), *Crataegus* spp. and *A. platanoides*. By comparison, *A. saccharum* dominated in the sugar maple cluster (figure 6). Important species in the black oak community type included *Quercus velutina* (Lam.) (IV = 19.37), *Q. alba* (L.) (IV = 12.61), *R. cathartica* (IV = 11.89), *Carya ovata* (IV = 8.06), *Cornus florida* (IV = 6.18), *A. rubrum* (L.) (IV = 5.27), *Crataegus* spp. (IV = 4.63), *Hamamelis virginiana* (L.) (IV = 4.70), *Q. rubrum* (L.) (IV = 4.55), and *Prunus serotina* (IV = 4.37) (Table 8). For the sugar maple cluster, important species included *A. saccharum* (IV = 33.04), *Q. rubrum* (IV = 10.55), *Ostrya virginiana* ((Mill.) K. Koch) (IV = 10.04), *Carya ovata* (IV = 5.76), and *Tilia americana* (L.) (IV = 5.58).

Table 6. Mean site characteristics of dominant tree species (importance value[a] ≥3.0%) for two community types—Norway maple (NM) and boxelder (BXE)—of regenerated patches in Syracuse, NY

	Mean dbh (cm)		Mean density (stems/ha)		Mean basal area (m^2/ha)		Importance value (%)	
Species	NM	BXE	NM	BXE	NM	BXE	NM	BXE
Acer negundo	13.4 (1.0) (*n* = 130)	13.3 (0.4) (*n* = 684)	127.1 (66.7)[b]	661.5 (152.9)	2.92 (1.24)[b]	14.16 (2.37)	7.38	45.61
Acer platanoides	11.1 (0.2)[b] (*n* = 1241)	8.5 (0.6) (*n* = 220)	740.7 (125.1)[b]	177.1 (82.8)	11.14 (2.16)[b]	2.19 (0.80)	43.39	10.82
Acer saccharum	16.1 (2.7) (*n* = 37)	27.7 (12.3) (*n* = 5)	44.0 (32.8)[b]	4.5 (2.3)	2.13 (1.4)	0.51 (0.41)	5.05	0.81
Ailanthus altissima	12.3 (0.9) (*n* = 90)	11.8 (1.0) (*n* = 69)	37.3 (32.7)	101.3 (84.5)	0.68 (0.53)	1.70 (1.56)	2.72	4.50
Fraxinus americana	21.7 (2.2)[b] (*n* = 34)	9.4 (5.3) (*n* = 2)	30.6 (14.2)	2.2 (1.3)	1.97 (1.09)	<0.01	3.43	0.02
Fraxinus pennsylvanica	24.1 (1.6) (*n* = 89)	12.8 (8.3) (*n* = 3)	64.4 (34.5)	1.8 (1.3)	4.31 (2.62)	0.04 (0.04)	6.04	0.15
Populus deltoides	33.0 (2.1) (*n* = 6)	23.2 (1.8) (*n* = 74)	10.0 (10.0)	76.5 (54.2)	0.69 (0.69)	3.14 (2.10)	0.75	7.69
Prunus serotina	14.6 (1.1) (*n* = 110)	11.8 (1.2) (*n* = 87)	65.3 (29.4)	50.5 (40.9)	1.54 (0.67)	1.07 (0.78)	5.41	3.40
Rhamnus cathartica	5.1 (0.2) (*n* = 155)	4.7 (0.1) (*n* = 248)	120.0 (67.0)	148.0 (66.7)	0.29 (0.17)	0.26 (0.14)	3.89	4.94
Rhus typhina	14.9 (3.5)[b] (*n* = 2)	5.0 (0.2) (*n* = 119)	1.1 (0.7)[b]	132.8 (75.1)	0.02 (0.02)[b]	0.29 (0.11)	0.07	4.04
Salix nigra	25.8 (2.4)[b] (*n* = 9)	47.0 (6.7) (*n* = 21)	11.9 (11.6)	15.4 (10.3)	0.61 (0.59)	2.89 (2.57)	0.86	5.38

Standard errors are in parentheses following the values.
[a]Importance value = (relative density + relative basal area) * 100/2.
[b]Significantly difference from the boxelder cluster at $P < 0.05$.

A comparison of diameter distributions of important species showed distinct compositional patterns between the sugar maple and black oak community types. *A. rubrum*, *Carya ovata*, *Cornus florida*, *Juglans nigra*, and *Crataegus* spp. predominantly occurred in the black oak community types, whereas *T. americana* and *Hamamelis virginiana* predominantly occurred in the sugar maple community type.

Discussion

Disturbance patterns

The observed small-scale disturbances by humans in remnant patches were similar to those observed for remnant patches in southern Wisconsin (Sharpe *et al.*, 1986). Sharpe *et al.*

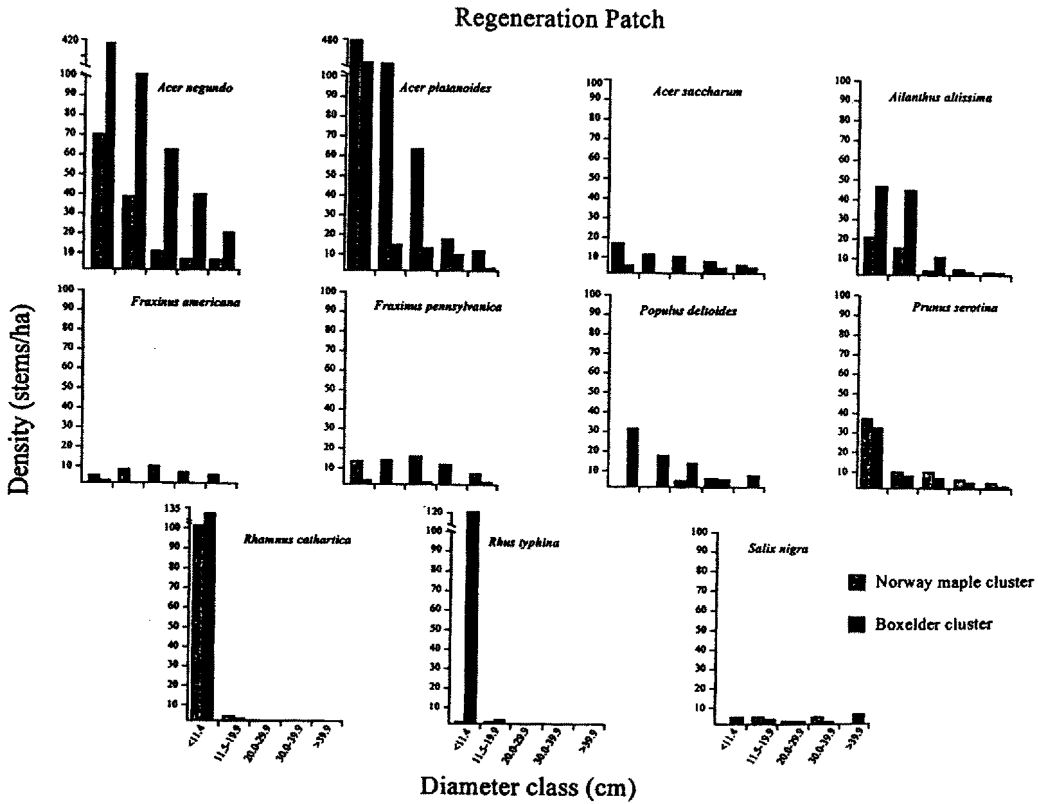

Figure 5. Diameter distributions of selected species with importance values >3.0%, for Norway maple and boxelder types within regenerated forest patches in Syracuse, NY.

Table 7. Mean stem density by diameter classes of introduced[a] and native[a] species for remnant patch cluster groups (SM-sugar maple; and BO-black oak)

	Introduced species (stems/ha)		Native species (stems/ha)	
Diameter class (cm)	SM ($n = 9$)	BO ($n = 3$)	SM ($n = 9$)	BO ($n = 3$)
≤11.4	114.6 (44.2)[b,c]	458.5 (66.6)	600.2 (3.5)	711.7 (170.7)
11.5–19.9	6.3 (3.3)[b,c]	36.6 (13.2)[c]	157.1 (17.9)	182.2 (32.5)
20.0–29.9	2.2 (1.2)[c]	7.1 (4.9)[c]	123.0 (15.1)[b]	59.0 (14.9)
30.0–39.9	1.1 (0.7)[c]	0.0	85.4 (11.7)	65.2 (21.6)
≥40.0	0.0	0.0	87.5 (28.4)	61.3 (24.3)
Total	124.2 (48.1)[b,c]	502.2 (78.3)[c]	1053.1 (119.5)	1079.4 (163.2)

Standard errors are in parentheses following values.
[a]Definitions for introduced and native species are given in the text.
[b]Significantly different between clusters (rows) at $P < 0.05$.
[c]Significantly different within a cluster (columns) at $P < 0.05$.

(1986) reported a high proportion of forest patches in urbanizing landscapes being affected by dumping, footpaths, mowing, and excavation. The study, however, did not provide a severity index. Compared to patterns observed by Sharpe *et al.* (1986), regenerated patches had similar patterns of human disturbances; however, a higher percentage of patches were disturbed. One possible reason for this difference is the age of the residential areas. Sites being evaluated in the Wisconsin study were urbanized only recently, whereas the regenerated patches in this study occurred within established and older neighborhoods, thus having a greater duration of exposure to human disturbances. In addition, social factors such as population and housing density, income, and home ownership also may influence how forest patches in an urban and urbanizing landscape are affected by humans (Grove and Burch, 1997).

The difference in the disturbance patterns between regenerated and remnant patches was likely related to urban context and patch size. Urban context can be viewed from different perspectives: a broad scale perspective (e.g., Anderson level 1) or at a finer scale (e.g., Anderson level 2) (Anderson *et al.*, 1976). At a broad-scale context, Guntenspergen and Levenson (1997) did not observe an influence of land use on community structure of understory species in remnant forest patches along an urban-to-rural gradient in the Milwaukee metropolitan area. At a finer context scale, however, Moran (1984) observed that neighboring land use—transportation, agriculture, and residential (transportation and residential are finer divisions of urban)—influenced community structure of understory vegetation in forest remnants in central New York. She attributed the differences to frequency and type of human disturbances and to the dispersal capabilities of species from the adjacent land use. Within the current study, both remnant and regenerated patches occurred within the same broad-scale context—urban. At a finer context scale, remnant patches were associated principally with institutional, commercial, industrial, park and forest land use/covers. By comparison, regenerated patches were associated principally with single- and multi-family

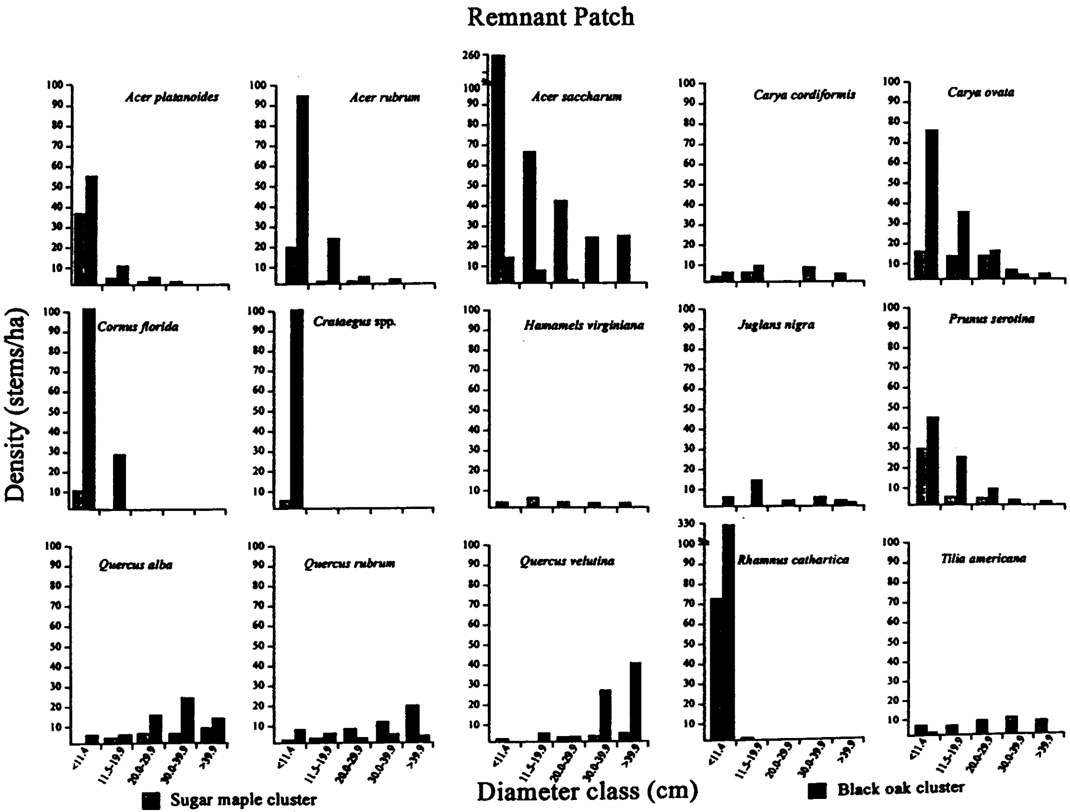

Figure 6. Diameter distributions of selected species with importance values >3.0%, by community within remnant forest patches in Syracuse, NY.

Table 8. Mean site characteristics of dominant tree species (importance value[a] ≥ 3.0%) by cluster group (SM-sugar maple; and BO-black oak) in remnant patches in Syracuse, NY

Species	DBH (cm)		Density (stems/ha)		Basal area (m^2/ha)		Importance value (%)	
	SM	BO	SM ($n = 9$)	BO ($n = 3$)	SM ($n = 9$)	BO ($n = 3$)	SM	BO
Acer platanoides	7.1 (0.7)	8.5 (0.7)	44.4	72.8	0.33	0.62	2.49	3.45
	($n = 74$)	($n = 81$)	(29.0)	(56.0)	(0.42)	(0.42)		
Acer rubrum	5.8 (0.6)[b]	8.4 (0.7)	21.1	124.4	0.08	1.05	0.83	5.27
	($n = 39$)	($n = 84$)	(19.6)	(99.5)	(0.08)[b]	(0.83)		
Acer saccharum	13.2 (0.5)	9.5 (1.7)	418.8	21.4	12.54	0.21	33.04	0.93
	($n = 828$)	($n = 13$)	(75.9)	(21.4)	(2.92)	(0.21)		
Carya cordiformis	28.5 (1.8)[b]	14.8 (1.8)	27.8	21.4	2.32	0.44	4.14	1.64
	($n = 56$)	($n = 13$)	(8.6)	(21.4)	(0.84)	(0.44)		
Carya ovata	18.0 (1.1)[b]	11.6 (0.7)	48.7	129.2	1.62	1.89	5.76	8.06
	($n = 93$)	($n = 94$)	(21.9)	(74.6)	(0.84)	(1.15)		
Cornus florida	6.0 (0.7)[b]	8.4 (0.3)	11.8	141.1	0.04	0.91	0.56	6.18
	($n = 24$)	($n = 143$)	(6.8)[b]	(108.4)	(0.03)[b]	(0.74)		
Crataegus spp.	4.8 (0.7)	6.4 (0.3)	4.3	112.9	0.01	0.43	0.17	4.63
	($n = 8$)	($n = 69$)	(2.2)	(111.6)	(0.01)	(0.43)		
Hamamelis virginiana	3.3 (0.1)	3.5 (0.1)	29.5	155.2	0.03	0.17	1.34	4.70
	($n = 62$)	($n = 96$)	(22.6)	(149.7)	(0.02)	(0.16)		
Juglans nigra	47. 6 (0.8)[b]	20.0 (3.3)	2.1	29.8	0.39	1.41	0.32	3.95
	($n = 4$)	($n = 19$)	(1.2)	(24.6)	(0.21)	(1.24)		
Ostrya virginiana	11.8 (0.5)	0.0	146.5	0.0	2.38	0.0	10.04	0.00
	($n = 272$)		(47.3)		(1.30)			
Prunus serotina	12.2 (1.4)	9.4 (0.9)	41 5	80.7	0.93	0.98	3.14	4.37
	($n = 78$)	($n = 61$)	(18.3)	(4.4)	(0.29)	(0.39)		
Quercus alba	36.0 (2.9)	32.5 (1.6)	20.4	62.1	2.67	6.11	3.41	12.61
	($n = 60$)	($n = 60$)	(6.7)	(37.6)	(1.12)	(3.07)		
Quercus rubrum	39.9 (1.8)[b]	25.3 (5.0)	43.5	23.4	6.51	1.85	10.55	4.55
	($n = 83$)	($n = 16$)	(13.5)	(10.6)	(2.03)	(1.34)		
Quercus velutina	42.6 (3.7)	41.0 (1.3)	10.3	75.4	1.78	10.55	3.68	19.37
	($n = 20$)	($n = 56$)	(5.9)[b]	(30.6)	(0.92)[b]	(5.52)		
Rhamnus cathartica	4.1 (0.1)	4.4 (0.1)	70.7	330.0	0.11	0.58	3.29	11.89
	($n = 130$)	($n = 255$)	(26.4)[b]	(102.8)	(0.05)[b]	(0.25)		
Tilia americana	27.7 (1.7)	9.2	34.5	0.9	2.58	0.01	5.58	0.04
	($n = 66$)	($n = 1$)	(10.1)	(0.9)	(0.81)	(0.06)		

Standard errors are in parentheses following the values.

[a]Importance value = (relative density + relative basal area) * 100/2.

[b]Significantly difference from the boxelder cluster at $P < 0.05$.

land use. Because of the proximity of residential areas, humans may have had a greater accessibility to regenerated than remnant patches resulting in the higher frequency of sites being disturbed and the greater disturbance severity.

The larger percentage of regenerated patches being disturbed and the severity of the disturbance also might be related to patch size. Because smaller patches have greater edge effect, they may have a greater exposure to human disturbances, thus possibly increasing the frequency and severity of a disturbance. Regenerated patch mean size was 0.3 ha resulting in a greater edge-to-area ratio than remnant patches, which had a mean size of 2.2 ha.

The observed disturbance patterns differed from those observed by Airola and Buchholz (1984) who studied forest patches along the Palisade Interstate Parkway. Airola and Buchholz (1984) observed that an increase in urban disturbances resulted in a more open canopy. They had no canopy limitation, and probably inventoried patches more severely disturbed than surveyed in this study. In this study, severely disturbed patches still had closed canopies.

Species composition/vegetation dynamics

Together, remnant and regenerated patches have a high species richness of both native and introduced species. The density of introduced species, however, appears to be related to community type. In the remnant patch type, the black oak cluster had a greater stem density of introduced species than the sugar maple cluster. Disturbance may be one factor attributing to the higher stem density. When compared to the sugar maple cluster, the black oak cluster were more severely disturbed.

Another factor influencing structure and composition is species performance. The data indicated that oak species lacked recruitment into the smaller diameter classes. The absence of oak species in the smaller diameter classes has been observed in remnant forest patches in other urban landscapes (Greller, 1975; Rudnicky and McDonnell, 1989; Guldin *et al.*, 1990). Rudnicky and McDonnell (1989) examined how tree species composition and structure of the New York Botanical Garden forest changed between 1937 and 1985. Although no native species were lost, shifts in the canopy structure occurred. In 1937, *Tsuga canadensis*, *Quercus* spp. and *Betula lenta* (L.) dominated the canopy and the midsize diameter classes (15–45 cm dbh). By 1985, *T. canadensis*, *Quercus* spp. and *Betula lenta* still occurred in the canopy, but the composition of the midsize diameter class has shifted towards *A. rubrum*, *P. serotina*, and *Liriodendron tulipifera* (L.). Rudnicky and McDonnell (1989) attributed the shift to early successional species colonizing canopy gaps created from storms and inability of *T. canadensis* seedlings to survive human trampling A similar process might be occurring in black oak community type. As gaps are formed, *A. rubrum P. serotina*, and *R. cathartica* seem to be colonizing available sites.

The lack of oak regeneration is not unique to urban landscapes. Silviculturally, oaks are a difficult group of species to regenerate (Lorimer, 1993). Current silvicultural research focuses on the role of fire and site availability for regenerating oak. Without fire, oaks may not be able to regenerate successively because of dense understory vegetation (Lorimer, 1993; Van Lear and Watt, 1993). In urban landscapes, fire suppression occurs for obvious reasons. In addition to fire suppression, other urban effects, such as soil hydrophobicity (White and McDonnell, 1988), heavy metal concentrations (Pouyat and McDonnell, 1991), and atmospheric pollution (Lovett *et al.*, 2000) can compound the effects of site conditions on oak regeneration and survival.

In contrast to the oaks, the sugar maple cluster appears to be self-regenerating with recruitment occurring throughout the diameter classes. This observation is contrary to the findings by Guntenspergen and Levenson (1997) who observed a decline in *A. saccharum* importance value as landscapes became increasingly more urban. Although a number of factors can contribute to this difference, climate may be an important contributing factor. The drier climate of the Milwaukee metropolitan area and an urban heat island effect may combine to create drier soil conditions that are unsuitable for regeneration and survival of *A. saccharum*, a mesic species. By comparison, the more mesic environment of central New York might offset the drying effect of the urban heat island and soil hydrophobicity, thus creating conditions favorable for regeneration and survival of *A. saccharum*.

Compositional differences between community types in remnant patches were attributed to site conditions. The black oak community type occurred on drumlins glacial formations that are excessively well drained. The sugar maple community type, on the other hand, occurred on mid- to lower slopes that are moderate to well drained (Hutton and Rice, 1977).

Previous studies of forest patches in urban and urbanizing landscapes generally have ignored regenerated forest patches with closed canopy and an understory, or the studies did not distinguish them from other forest patches. Regenerated patches have a high species richness consisting of both native and introduced species that is reflective of the interstitial and remnant forest. Of particular interest is the pervasive occurrence of *A. platanoides* and *R. cathartica*. No other species occurred more frequently in regenerated and remnant sites (present on 87 and 78% of regenerated sites, respectively; 50 and 100% on remnant sites, respectively). The occurrence of *A. platanoides* in Syracuse is related directly to its plantings as street, yard, and park trees. Introduced from Europe, *A. platanoides* was planted extensively as a street tree during the 1950s and 60s to replace dying and dead *Ulmus americana* (L.) (Nowak and Rowntree, 1990). By 1978, *A. platanoides* represented 31% of the total street tree population in Syracuse (Richards and Stevens, 1979). These public trees, as well as those planted on private lands, served as the seed source for *A. platanoides*. Hobbs (1988b) observed a high stem density of *R. cathartica* and attributed its occurrence to the loss of *U. amerianca* and fire suppression. Species and site availability (through small-scale human disturbances and loss of *U. americana*) may have created favorable conditions for *A. platanoides* and *R. cathartica* to colonize and grow in regenerated and remnant patches. Because of their invasiveness, these species are creating new forest communities in urban landscapes. Understory composition and structure indicated a long-term dominance by *A. platanoides* and *R. cathartica*.

Community types within regenerated patches indicate different pathways for vegetation development. Two community types—sugar maple and boxelder—were composed and dominated by native species. The third type—Norway maple—was composed and dominated by introduced species. Community types and composition of forest and tree-covered patches in St Paul, MN was related to moisture preferences and disturbances—principally mowing (Hobbs, 1988b). In her study, Hobbs sampled both upland and lowland sites that varied from very dry to very wet. In the current study, only well drained sites were sampled. Although patches were on well-drained sites, variation in local drainage patterns caused by topography and urban morphology, may have created moisture gradients at a fine scale. These microsite conditions might explain the presence of *A. negundo*, *Populus deltoides*, and *Salix nigra*, species usually associated in lowland sites, in the boxelder cluster. Such microsite factors could play a critical role in species performance and survival when forest patches are too small to create a mesic environment (sensu Levenson, 1981). Additional research is needed to determine how microsite conditions influence forest patch dynamics by counteracting effects from the urban heat island and soil hydrophobicity.

Another aspect of the species richness in regenerated patches is the large number of introduced species that occur only once or twice and generally are not considered invasive. Examples include *Abies balsamea* ((L.) Miller), *Catalpa bignonioides* (Walt.), *Picea abies* ((L.) Karsten), and *Syringa vulgaris* (L.). The occurrence of these species may reflect previous site legacy. Many of the sites occupied by regenerated patches were managed once as greenspaces during the 1920s and 30s, but subsequently abandoned. Any plantings that survived would have been tallied during the current survey. Because of their inability to self-regenerate, these species likely will die and will not be a component of regenerated patches in the future.

Management implications and conclusions

This study points to the importance of regenerated patches within an urban landscape. Regenerated forest patches occupy sites previously cleared for urban use and subsequently abandoned or left vacant. In an urban classification system, these sites would be labeled vacant or greenspace. During the past 50 years, regenerated patches have developed rapidly, nearly equaling the basal area of remnant patches. Introduced and shade intolerant native species contributed to the rapid growth and to the ecological services provided by trees in urban landscapes. A comparison of Syracuse land uses shows that vacant lands had the highest total and net rate of carbon sequestration per hectare (Table 9) (Nowak and Crane, 2000; Nowak *et al.*, 2001). Likewise, vacant land and greenspace also had the largest leaf area of land use/covers in Syracuse. This large leaf area would increase air pollution removal, evapotranspiration, and interception of rainfall. Unlike planted and maintained vegetation, such as streetside trees and parklands, regenerated, and remnant forest patches provide these services without the expenditure of energy and financial resources. Consequently, remnant and regenerated patches may provide a greater net benefit to urban residents than managed trees. Unfortunately, through in-filling, regenerated patches are being cleared, again, for urban uses. With land clearing, the ecological benefits of forest patches are lost. These losses depend on the amount of land cleared and the newly established land use. For example, the conversion of regeneration patches to commercial land use results in a significant reduction in net carbon sequestered (Table 9). We are only beginning to understand how remnant patches function and their benefits (McDonnell *et al.*, 1997) but know little about how regenerated patches function and their benefits.

Table 9. Estimated total carbon, carbon sequestration, net carbon sequestration*, and leaf area of trees ≥2.5 cm dbh by land use in Syracuse, NY, (adapted from Nowak *et al.*, 2001)

Land use	Total carbon (mt/ha)	Carbon sequestration (mt/ha/yr)	Net carbon sequestration (mt/ha/yr)	Leaf area (m^2/ha)
Commercial	5787.0 (4670.5)	207.3 (141.6)	183.2 (123.9)	3232.1 (1896.6)
Greenspace	45903.8 (12281.0)	1119.7 (267.9)	671.0 (336.3)	20166.6 (5442.0)
Institutions	32530.5 (16424.3)	760.2 (346.3)	575.2 (250.1)	14202.0 (6523.8)
Multi-family residential	8339.8 (37.2)	396.0 (188.4)	299.6 (92.8)	6793.5 (2152.6)
Single-family residential	21180.8 (12.6)	819.1 (86.5)	654.6 (75.7)	11351.8 (1227.3)
Transportation/Utilities	5060.5 (3018.9)	327.1 (140.9)	263.2 (96.2)	3017.0 (1563.2)
Vacant land	49593.4 (11188.0)	1257.6 (260.9)	848.7 (382.0)	30250.8 (8412.5)
Entire city	22817.3 (2490.9)	725.7 (64.3)	540.7 (66.2)	12008.5 (1242.4)

Standard errors are in parentheses following the values.
*Gross uptake minus estimated amount of carbon lost to mortality and resulting decomposition.

Appendix 1

Species sampled on regenerated and remnant patches, regenerated patches only, and remnant patches only

Regenerated and remnant	Regenerated only	Remnant only
Acer negundo (L.)	*Abies balsamea* (L.) Miller	*Acer rubrum* (L.)
Acer platanoides (L.)	*Acer saccharinum* (L.)	*Cercis canadensis* (L.)
Acer saccharum (Marsh.)	*Aesculus hippocastanum* (L.)	*Cladrastis lutea* (Michx.) K. Koch
Ailanthus altissima (Mill.) Swingle	*Catalpa bignonioides* (Walt.)	*Cornus stolonifera* (Michx.)
Calocedrus decurrens (Torr.) Florin	*Celtis occidentalis* (L.)	*Hamamelis virginiana* (L.)
Carpinus caroliniana Walt.	*Gleditsia triacanthos* (L.)	*Liriodendron tulipifera* (L.)
Carya cordiformis (Wang.) K. Koch	*Gymnocladus dioicus* (L.) K. Koch	
Carya ovata (Mill.) K. Koch	*Ligustrum vulgare* (L.)	
Cornus alternifolia (L.)	*Maclura pomifera* (Raf.) Schneid.	
Cornus florida (L.)	*Morus rubra* (L.)	
Cornus racemosa (Lam.)	*Philadelphus* spp.	
Crataegus spp.	*Picea abies* (L.) Karsten	
Fagus grandifolia (Ehrh.)	*Picea pungens* (Engelm.)	
Fraxinus americana (L.)	*Populus tremuloides* (Michx.)	
Fraxinus pennsylvanica (Marsh.)	*Prunus pennsylvanica* (L.)	
Juglans nigra (L.)	*Pyrus communis* (L.)	
Juglans cinerea (L.)	*Pyrus malus* (L.)	
Lonicera spp.	*Rhus typhina* (L.)	
Ostrya virginiana (Mill.)K. Koch	*Salix nigra* (Marsh.)	

(Continued on next page.)

(*Continued.*)

Regenerated and remnant	Regenerated only	Remnant only
Pinus strobus (L.)	*Sorbus americana* (Marsh.)	
Populus deltoides (Marsh.)	*Syringa vulgaris* (L.)	
Prunus avium (L.)	*Ulmus pumila* (L.)	
Prunus serotina (Ehrh.)	*Ulmus rubra* (Muhl.)	
Prunus virginiana (L.)	*Viburnum cassinoides* (L.)	
Quercus alba (L.)	*Viburnum americanum* (Ait.)	
Quercus rubra (L.)		
Quercus velutina (Lam.)		
Rhamnus cathartica (L.)		
Robina pseudoacacia (L.)		
Sassafras albidum (Nutt.) Nees		
Tilia americana (L.)		
Tsuga canadensis (L.) Carr.		
Ulmus americana (L.)		
Viburnum lentago (L.)		
Vitis spp.		

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