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Urbanization and riparian forest woody communities: Diversity, composition, and structure within a metropolitan landscape

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ABSTRACT

Understanding how urban land-use structure contributes to the abundance and diversity of riparian woody species can inform management and conservation efforts. Yet, previous studies have focused on broad-scale (e.g., urban to exurban) land-use types and have not examined more local-scale changes in land use (e.g., the variation within "urban"), which could be important in urban areas. In this paper we examine how local-scale characteristics or fine-scale urban heterogeneity affect(s) the diversity, composition, and structure of temperate woody riparian vegetation communities in the highly urbanized area of Cincinnati, Ohio, USA. We use an information-theoretic approach to compare vegetation models and canonical correspondence analyses to compare species responses to urban variables. We found that urban riparian areas can harbor a high diversity of native canopy and shrub species (38 and 41, respectively); however, native and exotic woody plant species responded differently to urbanization. Exotic canopy species increased with the level of urbanization while native canopy and understory species declined. Understory species diversity displayed a greater response to urbanization than did canopy diversity, suggesting temporal lags in canopy response to disturbances associated with present and recent land-use changes. Certain native and exotic woody species represent ecological indicators of different levels of urbanization. Native species characteristic of pre-European settlement conditions were restricted to the wide riparian forests with little urban encroachment. Several native early-successional species appear tolerant to urbanization. Two exotic species, the tree Ailanthus altissima and the shrub Lonicera maackii, were the most abundant and ubiquitous woody species and appear to exploit urban disturbances. These exotic species invasions have the potential to modify forest composition and ecological function of urban riparian systems. In addition, altered hydrology may be a contributing factor as canopy and understory stem density of high-moisture-requiring species decreased with an increase in impervious surface and grass cover and with proximity to roads and railroads. In the face of urbanization, maintaining wide riparian forests and limiting building, road and railroad development within these areas may help reduce the invasion of exotic species and benefit hydrological function in temperate riparian areas.

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1. Introduction

Urbanization, the "city building process" (Gottdiener and Hutchinson, 2006), has substantially influenced vegetation on a global scale (Rebele, 1994; Vitousek et al., 1997; McKinney, 2002). Urbanization directly impacts ecosystems through the replacement of vegetation with urban infrastructure (e.g. buildings, roads, utilities) and indirectly by altering vegetation composition and structure through fragmentation and degradation (e.g., altered hydrology), which reduces habitat quality for certain native species and increases the opportunity for early colonizers and some non-native species (McKinney, 2002). Studies of urban forests that identify specific factors of urbanization that affect the structure and function of urban ecosystems will improve our understanding of these unique systems and inform conservation and restoration decisions (Bernhardt and Palmer, 2007; Pickett and Cadenasso, 2008).

To study the effects of urbanization on ecosystem structure and function, researchers have employed urban-rural gradient methodology (McDonnell and Pickett, 1990). Urban-rural gradients are generally conducted at large spatial scales and have in some



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cases been conceived of as a linear transect radiating out from a city center to less-altered or more "natural" landscapes. Studies employing this method have documented changes along urbanrural gradients for stream hydrology (Nilsson and Berggren, 2000; Groffman et al., 2003), degradation in stream habitat (Miltner et al., 2004), changes in both aquatic and terrestrial species abundance and diversity (McKinney, 2002; Morley and Karr, 2002; Price et al., 2006; Pennington and Blair, 2009), and biogeochemical processes (Pouyat et al., 2002; Groffman et al., 2006). Gradient studies have documented declines in plant species diversity, basal area, and native species density (Porter et al., 2001; Moffatt et al., 2004; Godefroid and Koedam, 2007) and an increase in the presence of non-native species (Burton et al., 2005; Duguay et al., 2007) as sites become more urbanized.

Previous large-scale urban-rural gradient studies have documented that urban riparian forests are more impaired than their "natural" or rural counterparts (Paul and Meyer, 2001); and consequently, their conclusions often diminish the perceived ecological value of small remnant vegetation within highly modified landscapes. Yet, it is increasingly vital for researchers, managers, planners, and citizens to understand the potential ecological and societal value of remnant urban vegetation (Miller and Hobbs, 2002; Turner et al., 2004). Given that over 60% of the world's population will reside in urban areas by 2030 (UNPD, 2003), these "less than pristine" forests could provide critical ecosystem services for both people and other species (Miller and Hobbs, 2002; Bernhardt and Palmer, 2007).

Large-scale gradient analyses often assume a single urban-rural gradient that views urban areas as a dense, highly developed urban core, surrounded by irregular rings of declining development (McDonnell and Pickett, 1990). In reality this "gradient" is a complex mosaic of patches representing small gradients associated with each patch (Alberti et al., 2001). Urbanized landscapes contain numerous gradients that range in intensity and scale over land area and land-cover/land-use types (Cadenasso et al., 2007). Few studies have explicitly examined more local-scale changes in a particular land-use category along this gradient (Pickett and Cadenasso, 1995). For this study, we examine the variation within a complex and spatially heterogeneous urban area to identify the important gradients for woody riparian vegetation.

Understanding how urban structure influences riparian forests is important because these vegetation communities provide a variety of critical ecosystem services and harbor a high diversity of species (Naiman et al., 1993; Richardson et al., 2007). Fundamentally, people have been drawn to the areas adjacent to rivers and streams for transportation, power production, food, and waste disposal needs (Hedeen, 1994; Naiman and Decamps, 1997). The collective effect of these activities has resulted in the "urban stream syndrome," typified by a flashy hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology, and reduced species diversity, with increased dominance of disturbance tolerant species (Walsh et al., 2005).

In addition to the ecosystem services provided to people, urban riparian areas also function as a dispersal route for aquatic organisms and plant propagules (vegetative or seed), provide habitat for aquatic and terrestrial resident and migrant animal species (Rottenborn, 1999; Pennington et al., 2008), and buffer sediment and nutrient runoff into the stream channel (Tabacchi et al., 2000). Further, riparian forests function as important habitat in urban systems by connecting adjacent natural areas, such as parks to contiguous vegetation communities for wildlife mobility and overall habitat enhancement (Botkin and Beveridge, 1997; Savard et al., 2000; Sinclair et al., 2005).

The integrity of riparian forest communities is vulnerable to the intense land-use modification associated with urbanization (Richardson et al., 2007). Significant changes in species composition of

riparian forests along urban-rural gradients have been reported for Columbus, Georgia (Burton et al., 2005), Baltimore, Maryland (Groffman et al., 2003), and Winnipeg, Manitoba (Moffatt et al., 2004). Species diversity, tree basal area, and native plant density were shown to decrease near urban areas (Porter et al., 2001; Moffatt et al., 2004) and invasive exotic richness and density increased with development in the southeastern United States (Burton et al., 2005). These studies applied an urban-to-rural gradient approach to study sites located across a large geographical region from a densely populated urban landscape to a relatively unpopulated rural landscape and did not examine fine-scale responses.

For our study, we characterize riparian forests along a gradient of urban land-use types (commercial, industrial, residential and parklands) in the highly urbanized landscape of Cincinnati, Ohio, USA. Our purpose is twofold: (1) to determine whether canopy and understory woody plant community composition and structure respond differently to fine-scale land use and land cover factors (vegetation, surfaces, and infrastructure) used to describe urbanization; in particular, to determine how urbanization influences the prevalence of exotic species; and (2) to identify potential indicator species of eastern deciduous riparian vegetative communities in densely urbanized areas. By addressing these objectives we seek to improve our understanding of the potential processes influencing urban ecosystem functioning and the conservation and management of vegetation in urban areas.

2. Methods

2.1. Study area/ site selection

The Mill Creek watershed covers 42,994 hectares and is located in Butler and Hamilton Counties in Southwestern Ohio (Fig. 1). Within this watershed, we selected a 4243 ha study area comprised of a portion of the Mill Creek and sections of two tributaries, Sharon Creek and West Fork Mill Creek (Fig. 1). This area is located on the geologically homogeneous Pre-Wisconsinan Drift Plains ecoregion within the urbanizing greater Cincinnati metropolitan area (39.2°N 84.5°W). The selected sub-watersheds represent some of the fastest growing areas in Ohio, with more than half a million people living and working in the Mill Creek watershed (US Census Bureau, 2000). At least three continental glacial events shaped the terrain, removing accumulated soil and influencing regional riverine systems (USDA, 1992). The pre-settlement vegetation of the area was predominately Beech forests (Fagus grandifolia, Acer saccharum, Plantanus occidentalis, Populous deltoides; authorities cited in Appendix A) and mixed mesophytic forests (Gordon, 1966). The climate of the region is temperate with cold winters and hot summers and an annual precipitation of approximately 100 cm with over 50% from April to September (USDA, 1992). The Mill Creek has been designated as one of the most threatened urban rivers in the United States (American Rivers, 1997) because of the various effects of human settlement common to many urban rivers.

Along Mill Creek, West Fork Mill Creek and Sharon Creek, we identified 71 study plots systemically from a random starting point using ArcView[®] Geographic Information Systems (GIS) version 8.2 and the 2002 Cincinnati Area Geographic Information System (CA-GIS) dataset (using high-resolution color aerial photos taken in 2001 that distinguish physical and surface features including topography, waterways, buildings, and roads). All plot centers were located along the streamside edge and separated by a minimum distance of 150 m. Stream channel width was similar across plots (~10 m). The elevation among plots ranges from 200 to 300 m above sea level. Permission was obtained from commercial and residential landowners prior to data collection. These selected waterways traverse various metropolitan land-use types:



Fig. 1. Location of the 71 study plots used to examine woody riparian plant communities in the Mill Creek watershed in the greater Cincinnati metropolitan area Hamilton county, Ohio, USA. Land use/land cover map derived from IKONOS satellite imagery area shows land-use classes and survey plots.

commercial, industrial, residential and parkland (Fig. 1). Each waterway has been directly altered by people in the past: Mill Creek has some channelized sections; Sharon Creek has an unregulated dam upstream of study sites; West Fork Mill Creek has a regulated dam upstream of study sites. Given the scope of our study, we were not able to directly examine the role of hydrologic disturbances via dam regulation on riparian vegetation.

2.2. Landscape parameters

To examine varying levels of urbanization within our study area, we used classified land-cover data derived from 2000 IKONOS satellite imagery for Hamilton County, Ohio. IKONOS imagery produces 1 m high-resolution color images that can be directly used for land-use classification and surface feature data (Dial et al., 2003). Land-cover data were previously classified into categories, including trees, grass, impervious surfaces, agriculture/soil and water (Fig. 1). We verified the accuracy of land-cover classification data for each plot by visually comparing IKONOS data to high-resolution (0.5 m) color aerial photos taken in 2002, which was the same year vegetation data was collected.

From IKONOS-based land-cover data, we calculated three landscape variables to serve as components of urbanization: percent impervious surface (pavement and rooftops), percent tree cover, and percent grass (agricultural fields, meadows, and lawns) within 250 m of each plot origin (Table 1). We calculated five additional landscape variables using the CAGIS dataset: distance to nearest road and railroad from plot center, road density, building density, and building area within a 250 m radius of the plot center (Table 1). We chose to include distance to nearest road and railroad because of the potential influence of these factors on seed dispersal (Tikka et al., 2001).

2.3. Woody plant sampling

Trees and shrubs were sampled mid-August to October 2002. For each site, we located one 70 m diameter circular sampling plot (3848.5 m²) on the stream bank to capture vegetation data from both sides of the waterway (see Fig 2). The plot center was located as close to the edge of the stream as possible. We identified all trees >10 cm diameter at breast height (dbh) and recorded dbh within the plot. We sampled woody plants with stems <10 cm diameter in five 10 m diameter subplots (78.5 m² per subplot; 392.5 m² total), one along each of five 35 m radial transects from the circular plot origin. The compass bearing of the first radial

Table 1

Variable codes for landscape measures and riparian plots in the Mill Creek watershed located within the Cincinnati Metropolitan area, Ohio, USA.

Variable code	Description
Landscape variables	
Imp 250	Percent impervious surface in a 250 m radius from plot
1 - 1	center
T-250	Percent trees in a 250 m radius from plot center
G_250	Percent grass in a 250 m radius from plot center
RD_D	Distance to nearest road from plot center in meters
BDEN_250	Total number of buildings in a 250 m radius from plot
	center divided by the area
RR_D	Distance to nearest railroad from plot center
B_250	Total building area in a 250 m radius from plot center
Woody vogetation var	iablas
Total capopy BA	Absolute basal area of native capony trees
Native canopy_BA	Total absolute basal area of canopy trees
Exotic canopy_BA	Absolute basal area of exotic capopy trees
Total canopy DFN	Total absolute density of canopy trees
Native canopy_DEN	Absolute density of native canopy trees
Exotic canopy DEN	Absolute density of native canopy trees
H canopy	Shannon–Weiner index of diversity for canopy plants
D' canopy	Simpson index of diversity for canopy plants
E canopy	Evenness or distribution of individuals among species
FJ	for canopy plants
S_native_canopy	Species richness of native woody canopy species
S_exotic_canopy	Species richness of exotic woody canopy species
Total	Total absolute stem density of understory woody
understory_DEN	plants
Native	Absolute stem density of understory native woody
understory_DEN	plants
Exotic	Absolute stem density of understory exotic woody
understory_DEN	plants
H_understory	Shannon-Weiner index of diversity for understory
	plants
D'_understory	Simpson index of diversity for understory plants
E_understory	Evenness or distribution of individuals among species
	for understory plants
S_native_understory	Species richness of native woody understory species
S_exotic_understory	Species richness of exotic woody understory species



Fig. 2. Example of a typical vegetation sampling strategy for each study plot. Data for all trees >10 cm dbh was collected in the large 70 m diameter circular site. Woody plant density of plants <10 cm and clinometer data ware collected in each of the randomly selected five 10 m subplots. Subplot location was restricted to terrestrial areas with no overlap. See Section 2 for further details.

transect was randomly selected. Subsequent transects were equidistantly spaced with a 72° interval between each transect. Along each transect one point was randomly selected 5–35 m from the plot origin; this served as the center of the subplot. If a subplot included the stream, the radial transect was reselected or shifted in 10° increments so no part of the subplot was located in the waterway. In each 78.5 m² subplot, every woody stem <10 cm dbh was identified and total stem density calculated.

2.4. Composition and structure measures

We calculated several diversity and composition measures of woody plant communities for each plot (Table 1). For canopy and understory species, we calculated Shannon-Weiner's index (H), Simpson's index (D') and evenness (E), using the multivariate ecological software package PC-ORD version 4.14 (McCune and Mefford, 1999; Magurran, 2004). We also calculated species richness for native and exotic species separately. Exotic or non-native species were defined as those absent from the study area prior to European settlement (Braun, 1989). We used importance values for canopy and understory species to describe woody species composition of riparian plant communities. We calculated importance values for each plot for canopy stems (>10 cm dbh) by summing relative density and relative basal area and dividing by two (Barbour et al., 1987). For understory stems (<10 cm dbh), relative frequency and relative stem density were summed and divided by two to calculate importance values for each plot.

We characterized canopy forest structure using basal area and stem densities. For stems >10 cm dbh, absolute basal area of canopy species was calculated for both native and exotic species, as well as total absolute basal area. Canopy absolute native tree density, absolute exotic tree density and total absolute density were also calculated for stems >10 cm dbh. For stems <10 cm dbh, absolute stem density values were calculated for understory native, exotic and total species.

	T_250	G_250	Imp_250	RDEN_250	RR_D	RD_D	BDEN_250	B_250
T_250	1.00							
G_250	-0.15	1.00						
Imp_250	-0.87	-0.32	1.00					
RDen_250	-0.34	-0.15	0.44	1.00				
RR_D	0.64	0.17	-0.70	-0.40	1.00			
RD_D	-0.01	0.28	-0.21	-0.61	0.25	1.00		
BDEN_250	-0.28	-0.08	0.36	0.85	-0.32	-0.56	1.00	
B_250	-0.60	-0.26	0.72	0.65	-0.46	-0.39	0.63	1.00

Correlations among landscape variables across 71 riparian study plots in the Mill Creek watershed (see Table 1 for codes).

To explore the importance of altered hydrology on the riparian woody community in the study area, we first categorized species based on moisture requirement using Burns and Honkala (1990) and USDA-NRCS (2006) (Appendix A), then analyzed vegetation structure and diversity measures separately for each category.

2.5. Statistical analysis

Vegetation data were log-transformed to down weight the contribution of highly abundant or rare species on community structure. We examined multicollinearity among the eight landscape variables to determine which variables to use or drop as predictors in multiple regression analyses. Road density was highly correlated with building density (r = 0.85); we chose to remove road density and keep building density because landscape plantings associated with buildings can escape to adjacent areas (Dirr, 1998). Percent tree cover was highly correlated with percent impervious surface (r = -0.87); consequently, we removed percent trees and included percent impervious surface in the model as a measure of urbanization because impervious surface represents human-mediated disturbances including altered hydrology and forest fragmentation. The remaining variables were not highly correlated (Table 2), so were used as explanatory variables in our analyses.

2.5.1. Multiple regression model selection

To determine the effect of landscape variables on woody vegetation community measures we used a model-ranking approach that does not rely on conventional hypothesis testing and significance to reject variables or models (Cunningham and Johnson, 2006; Diniz-Filho et al., 2008). We ranked models using a multiple-model inference approach rather than attempting to determine only a single "best" model that described the data (Burnham and Anderson, 2002). By using this approach we could rank possible explanatory models and retain all models that fit our data well based on the assumption that several models (and variables) could be similarly important in explaining woody vegetation measures.

To identify competitive landscape feature models, we took an exploratory 'all possible models' approach to model selection, including all six explanatory variables characterizing the surrounding landscape, which is in contrast to developing a suite of candidate models based on *a priori* hypotheses. Given that our goal was to gain insight into the relative importance of landscape variables and to assess unanticipated relationships, not prediction, we felt obliged to take an exploratory approach (Diniz-Filho et al., 2008).

Specifically, we used an information theoretic method to evaluate a set of models based on their explanatory value determined by corrected Akaike's information criterion (AIC_c; adjusted for small sample-size in relation to number of parameters), and identified the best-fitting models (or strongest) based on Δ AIC_c values (Burnham and Anderson, 2002); Δ AIC_c = 0 represented the "best" model and we considered all models with Δ AIC_c < 3 to be competitive candidate models (Cunningham and Johnson, 2006). We computed Akaike weights for models in order to assess the evidence of a particular model based on the observed data. We also computed Akaike weights for each explanatory variable so that we could compare the relative importance of each variable, which prevented us from discarding variables that might be important for explaining vegetation measures yet do not appear in the "best" selected model (Burnham and Anderson, 2002). For each analysis, we ranked models by running a model selection routine in SAS (PROC MIXED SAS version 9.2, SAS Institute, Cary, NC, USA) that calculated AIC_c, Δ AIC_c, model weights, and variable weights; each model included one or more explanatory variables. We report adjusted R^2 values for the "best" model based on linear regression as a way to evaluate goodness of fit.

2.5.2. Canonical correspondence analysis

To further investigate how urbanization influences riparian community composition, ordination methods were used to describe dominant patterns and complex relationships in species composition (McCune and Grace, 2002). We chose to use canonical correspondence analysis (CCA) in order to determine how community composition was related to the selected environmental variables. CCA is a direct gradient analysis ordination technique, and represents a special case of multivariate regression, and differs from indirect gradient analysis in that species composition is directly and immediately related to measured environmental variables (Ter Braak, 1986). Ordination of plot scores is based on CCA operations that perform a least-squares regression of sampling plot scores as dependent variables and environmental variables as independent variables (Jongman et al., 1995). PC-ORD (McCune and Mefford, 1999) was used to perform CCA of riparian woody plant species composition (importance values at plot-level) and landscape variables (Table 1). A Monte Carlo simulation with 1000 permutations was used to determine if a linear relationship existed between the landscape (environmental) variables and woody plant species. Results from the CCA produce eigenvalues that are used to describe how much variance is explained by each ordination axis, thus measuring the importance of each axis (Jongman et al., 1995; McCune and Grace, 2002). Separate CCA analyses were evaluated for canopy plants (stems >10 cm dbh) and understory plants (stems <10 cm dbh).

3. Results

A total of 6482 canopy and 39,182 understory stems were identified, comprising 51 canopy and 52 understory species encountered in the 71 study plots (Appendix A). Of all canopy species recorded, 12 were exotic and 39 were native. Three of the exotic species, tree of heaven (*Ailanthus altissima*), Osage-orange (*Maclura pomifera*) and white mulberry (*Morus alba*) were each encountered in >75% of the plots. Native canopy plants were more evenly distributed with 16 species found in >75% of plots. Among understory stems, 13 exotic and 39 native species were identified. Three understory species, Amur honeysuckle (*Lonicera maackii*), white mulberry (*M. alba*) and multiflora rose (*Rosa multiflora*) were found in 75% of plots and accounted for most of the exotic stems. Amur

Table 2

Table 3
Woody vegetation community measures, best landscape model, and variable weights (for variable codes refer to Table 1)

Community measure	Best model	Variable Akaike weights						
		Imp_250	G_250	BDEN_250	B_250	RD_D	RR_D	Adj. R ²
Canopy structure								
Total canopy_BA	-IMP_250 + BDEN_250	-0.93	-0.26	+0.78	-0.29	+0.29	-0.27	0.15
Native canopy_BA	-IMP_250 + BDEN_250	-0.93	-0.27	+0.77	-0.30	+0.31	-0.27	0.19
Exotic canopy_BA	+G_250 + IMP_250-RR_D	+0.59	+1.00	+0.39	+0.58	-0.60	-0.60	0.28
Total canopy_DEN	-IMP_250 + BDEN_250	-0.99	+0.30	+0.99	+0.25	+0.40	+0.27	0.35
Native canopy_DEN	-IMP_250 + BDEN_250	-0.99	-0.37	+0.98	-0.25	+0.45	+0.29	0.36
Exotic canopy_DEN	+G_250 + B_250-RR_D	+0.41	+0.98	+0.45	+0.71	-0.41	-0.53	0.21
Canopy diversity								
H_canopy	-IMP_250	-0.43	-0.27	+0.42	+0.31	-0.33	+0.36	0.00
D'_canopy	-IMP_250	-0.39	-0.28	+0.36	+0.31	-0.32	+0.33	0.00
E_canopy	-RR_D	+0.31	-0.32	+0.30	+0.29	-0.29	+0.32	0.00
S_native_canopy	-IMP_250 + RR_D-G_250	-0.73	-0.48	+0.39	+0.32	-0.25	+0.65	0.19
S_exotic_canopy	+G_250 + B_250-RD_D-RR_D	+0.35	+0.90	+0.31	+0.82	-0.54	-0.50	0.19
Understory structure								
Total understory_DEN	+RD_D	+0.25	+0.25	+0.26	-0.25	+0.94	+0.26	0.08
Native understory_DEN	-G_250-IMP_250	-0.76	-0.95	+0.26	-0.50	+0.44	+0.32	0.16
Exotic understory_DEN	+RD_D	+0.40	+0.60	+0.27	+0.29	+0.70	+0.33	0.04
Understory diversity								
H_understory	-IMP_250-G_250 + RD_D	-0.98	-0.99	+0.26	-0.25	+0.53	+0.24	0.27
D'_understory	-IMP_250-G_250	-0.98	-0.94	+0.32	-0.25	+0.39	+0.30	0.21
E_understory	-IMP_250-G_250	+0.90	-0.56	+0.44	-0.31	+0.31	+0.37	0.11
S_native_understory	-G_250-IMP_250 + RD_D	-0.82	-1.00	+0.33	-0.35	+0.66	+0.57	0.34
S_exotic_understory	-BDEN_250	-0.33	-0.49	-0.48	+0.29	+0.40	+0.52	0.02

Note: For best local landscape models, variables and signs of coefficients (positive or negative effects) are shown. For example, the best landscape model for total canopy basal area (Total canopy_BA) included a negative response to impervious surface and a positive response to building density. Strengths of effects are indicated by cumulative weights. Variable weights are the cumulative Akaike weights of models in which a variable occurred. In general, the best proximate models include the most important variables. Where secondary variables have comparable weights, omitted variables may contribute to alternative competitive models.

honeysuckle was the only woody plant species found at all 71 plots. Each of five native understory species (*Acer negundo, Celtis occidentalis, Fraxinus spp. (F. americana and pennsylvania), Ulmus spp. (Ulmus amer and Ulmus red), and Plantanus occidentalis)* were found at >75% of the plots. Ten species were classified as having high moisture requirements, nine as having low moisture requirements, and 41 as having moderate moisture needs (Appendix A).

3.1. Multiple regression results

Among the "best" landscape models for woody vegetation measures, percent impervious cover within 250 m was the most common variable and frequently the heaviest weighted or most important variable followed by grass cover within 250 m (Table 3). The best models for a given vegetation measure reflected the landscape variables with the highest cumulative Akaike weights across all models. Of the 19 best models, six yielded relatively weak models with adjusted R^2 values <0.10 (Table 3).

3.1.1. Canopy trees

Percent impervious cover within 250 m was the most important variable for four of the six best models describing canopy structure followed by building density within 250 m (Table 3). Total canopy basal area, total canopy stem density, native canopy basal area and native canopy density, were all positively correlated with the amount of impervious surface and negatively correlated with increasing building density in the landscape (Table 3). Interestingly, percent grass cover was the most important and heavily weighted variable for exotic canopy measures. Exotic canopy basal area and exotic stem density were positively correlated with the amount of grass; exotic basal area was positively associated with impervious cover within 250 m and exotic stem density was positively associated with building area (Table 3). Exotic canopy basal area and density decreased with increasing distance to railroads (Table 3).

For canopy diversity measures, only the best models for native and exotic species richness displayed relatively good fits (adjusted $R^2 > 0.10$; Table 3). Native canopy species richness was negatively associated with percent impervious surface and grass cover and positively associated with distance to railroad (Table 3). Exotic canopy richness was positively associated with percent grass cover and building area and negatively associated with distance to nearest road (Table 3).

When the canopy data were re-analyzed separately for species with high, medium, and low species' moisture requirements, stem density of high moisture species displayed the best fit across canopy models, and was negatively associated with percent impervious surface and positively associated with distance to nearest railroad (adj. $R^2 = 0.24$; Table 4). Canopy stem density of species with medium moisture requirements was negatively associated with percent grass cover and percent impervious surface and positively with distance to nearest railroad (Table 4). The best model for canopy density of low-moisture-requiring species was relatively weak (adj. $R^2 < 0.10$). Canopy species richness for medium-moisture-requiring species decreased with percentage of impervious surface and increased with distance from nearest railroad track; models for canopy richness for low and high moisture-requiring species were relatively weak (adj. $R^2 < 0.10$).

3.1.2. Understory woody plants

Best models for understory structure were relatively weak when compared to canopy structure models with native understory density reflecting the best fit (Table 3). Total understory density was positively associated with distance to nearest road and railroad (Table 3). Native understory density was negatively associated with increases in impervious surface and grass cover (Table 3). Exotic understory density was positively associated with distance to nearest road (Table 3).

In contrast, understory diversity models reflected stronger relationships to landscape variables (Table 3). Percent impervious surface was the most important landscape measure for three of the

Table 4

Woody vegetation community measures based on moisture dependence, best landscape model, and variable weights (for variable codes refer to Table 1; moisture dependence based on Burns and Honkala (1990) and USDA-NRCS (2006; see Appendix A).

Community measure based on	Best model	Variable Akaike weights						
moisture requirement		Imp_250	G_250	BDEN_250	B_250	RD_D	RR_D	Adj. R ²
Low								
Canopy density	+BDEN_250	-0.30	+0.36	+0.73	+0.35	+0.27	-0.42	0.06
Understory density	-G_250 + RR_D	-0.44	-0.92	+0.27	+0.27	-0.25	+0.66	0.12
Canopy S	-RD_D	-0.47	+0.30	+0.44	+0.44	-0.67	-0.45	0.06
Understory S	-G_250-IMP_250	-0.45	-0.72	-0.29	-0.32	+0.27	+0.29	0.05
Medium								
Canopy density	-G_250-IMP_250 + RR_D	-0.82	-0.89	+0.45	+0.32	+0.25	+0.46	0.18
Understory density	+RD_D	-0.26	+0.30	-0.26	-0.26	+0.89	-0.29	0.08
Canopy S	+RR_D-IMP_250	-0.45	-0.36	+0.35	+0.29	-0.42	+0.84	0.17
Understory S	-G-250-IMP_250 + RD_D	-0.84	-1.00	+0.24	-0.36	+0.56	+0.34	0.33
High								
Canopy density	-IMP 250 + RR D	-0.69	+0.38	+0.37	-0.34	+0.34	+0.69	0.24
Understory density	$-G_{250} + RD_D + RR_D$	-0.53	-0.99	-0.27	-0.40	+0.92	+0.56	0.23
Canopy S	+G_250	-0.28	+0.82	+0.31	+0.27	+0.25	-0.33	0.05
Understory S	+RD_D	-0.41	-0.52	+0.37	+0.32	+0.57	+0.43	0.01

five best models for understory diversity (Table 3). Shannon–Weiner index was negatively associated with impervious surface and grass cover within 250 m and positively associated with distance to nearest road. Simpson index of diversity and evenness were negatively associated with percent impervious surface and grass cover (Table 3). Understory native species richness was negatively associated with grass cover and impervious surface and positively associated with distance to road (Table 3).

Analyzing understory community measures separately for sets of species with different moisture requirements revealed trends similar to those found for canopy measures. Understory density for high moisture-requiring species was negatively associated with percent grass cover and positively associated with distances to nearest road and railroad (Table 4). Low moisture understory density was negatively associated with percent grass cover and positively associated with distance to nearest railroad, but the relationship was weak (adj. $R^2 = 0.12$; Table 4). Understory richness of medium moisture-requiring species displayed the best fit (adj. $R^2 = 0.33$; Table 4), and was negatively associated with percent grass cover and percent impervious surface and positively associated with distance to nearest road. Richness of species with high and low moisture requirements was not well explained by our models.

3.2. Ordination

3.2.1. Canopy trees

Patterns in species composition of canopy trees, based on plot-level importance values entered in the CCA, were related to measures of urbanization and the resulting biplots illustrate the fine-scale heterogeneity present in a highly urbanized area (Fig. 3). Results of the CCA ordination of the canopy community are summarized in the correlations between CCA species ordination scores and environmental variables (Table 5) and biplots of species scores along the first two axes of the ordination (Fig. 3). The eigenvalues for both axes were significant based on Monte Carlo simulations (axis 1 = 0.26, P = 0.001; axis 2 = 0.06, P = 0.001), and the species-environment correlations, indicating the ability of landscape variables to explain canopy composition, were 0.89 and 0.69, for axis 1 and axis 2, respectively. Axis 1 was positively influenced by distance to nearest railroad and negatively by percent impervious surface, building area and building density (Table 5; Fig. 3). Because impervious surface cover was highly negatively correlated with tree cover, axis 1 can be interpreted as the urbanization gradient represented by heavily urbanized areas with relatively low tree cover at the negative end to less urbanized areas with greater tree cover at the positive end (Table 5; Fig. 3). Axis 2 was negatively influenced by percent grass cover and distance to nearest road and railroad (Fig. 3), and separates plots along a gradient consisting of open grassy riparian areas further away from roads and railroads at the negative end of axis 1 to areas containing little or no grass cover, closer to roads at the positive end (Fig. 3). Several unique patterns emerged along these land use gradients. Canopy composition of more urban plots was characterized by several exotic species (e.g., *A. altissima, Alnus glutinosa, Ulmus pumila, M. alba, Acer platanoides*), as well as native pioneer species (e.g., *Robinia pseudoacacia, Acer negundo, Populus deltoides*); however, the least urbanized plots were characterized almost exclusively by native canopy species, many of which characterize late-successional forests in the area (e.g., *Aesculus glabra, Acer saccharum, T. americana, Quercus muehlenbergii*) (Fig. 3B).

3.2.2. Understory woody plants

Patterns in species composition for the riparian understory were directly related to landscape measures and again illustrated the fine-scale heterogeneity within an urban area. Results of the CCA for the understory community are summarized by correlations between CCA species ordination scores and environmental variables (Table 5) and in the biplot of species scores along the first two axes of the ordination (Fig. 4). Both eigenvalues were significant based on Monte Carlo simulations (axis 1 = 0.19, P = 0.002; axis 2 = 0.07, P = 0.01), and the species-environment correlations were 0.84 and 0.72 for axis 1 and axis 2, respectively. Axis 1 was positively influenced by distance to nearest railroad and negatively influenced by percentage of impervious surface, building area and building density, and represents a gradient of more to less urban development (Table 5; Fig. 4). Axis 2 was negatively influenced by percent grass cover and distance to nearest road and railroad (Table 5; Fig. 4). A pattern in species composition was apparent with most exotic species (e.g., A. altissima, Catalpa speciosa, U. pumila, M. alba) being associated at the negative, 'urbanized' end of axis 1 and native species characteristic of late-successional forests (e.g., A. saccharum, F. grandifolia, Carya cordiformis, Carya ovata, Cercis canadenis, Cornus florida) located at the positive end (Fig. 4B). Several native early-successional species (e.g., R. pseudoacacia, P. deltoides, A. negundo, Celtis occidentalis) were plotted toward the urbanized end of the axis 1 gradient. In contrast to the canopy CCA, A. altissima saplings were most common in more urbanized areas. The exotic shrub species, L. maackii, was found throughout the study area (Fig. 4B). Several of the native shrubs were only found at the least urbanized sites (e.g., Hydrangea arborescens, Rhus aromatica). Species scores on axis 2 were difficult to interpret, with exotic and native species distributed at both ends.



Fig. 3. Canonical correspondence analysis (CCA) ordination of canopy (>10 cm dbh) species composition of 71 plots in the Mill Creek watershed, southwestern Ohio. For biplot A, codes correspond to individual study plots; "A" represents plots along Sharon Creek and Mill Creek and "B" represents plots located along West Fork Mill Creek. For biplot B, codes of individual species (Appendix A) show their scores as a function of the first two axes. Arrow length indicates the importance of each landscape variable and its influence on each species.

Table 5

Correlations between the environmental matrix and the first two axes of the CCA canopy and understory species ordination scores (based on intraset scores, Ter Braak, 1986).

Variable	Canopy		Understory	
	Axis 1	Axis 2	Axis 1	Axis 2
IMP_250	-0.866	0.436	-0.779	0.256
G_250	-0.159	-0.943	-0.323	-0.415
BDEN_250	-0.299	0.141	-0.279	-0.076
B_250	-0.559	0.397	-0.444	-0.211
RD_D	0.077	-0.446	0.082	-0.794
RR_D	0.712	-0.424	0.622	-0.381

4. Discussion

Our results indicate that urban riparian areas can harbor a high diversity of native canopy and shrub species and also relatively high exotic species diversity as well; however, native and exotic woody plant species responded differently to urbanization in the Cincinnati area. Riparian forests of highly urbanized areas (i.e., more impervious surface, higher building density, and closer proximity to buildings and roads) were more likely to have a canopy characterized by native early-successional species and exotic species with an understory dominated by exotic shrubs. In contrast, riparian forests of less urbanized areas were likely to have a more diverse composition of understory and subcanopy species with few exotic species. In general, riparian forest understory diversity displayed a greater response to measures of urbanization than canopy diversity measures. Native canopy and native understory structure measures both had a negative association with percentage of impervious surface within a 250 m buffer (Table 3), similar to responses seen for riparian forests in Manitoba, Canada, and Maryland and Georgia, USA. (Groffman et al., 2003; Moffatt et al., 2004; Burton and Samuelson, 2008). Interestingly, native canopy density also had a positive relationship with the number of buildings in the 250 m buffer, which for this study area likely represents residential developments within and around the riparian forest. It is tenable these native species were either planted for landscape purposes or represent early-successional species that are able to thrive as development increases and consequently fragments riparian forests in urban environments (Reichard and White, 2001; McKinney, 2006).

Exotic canopy and understory vegetation structure measures were positively associated with the landscape variables of percent impervious cover and percent grass cover (Table 3). Interestingly, exotic canopy species measures were the only variables to have a positive association with percent grass cover. It is possible that percentage grass cover reflects transition areas between grass and forest edge. It is likely that the exotic species encountered in this study are plants that have escaped adjacent developed landscapes over time and have become an established part of the riparian plant community, since we sampled few obviously planted stems. For example, U. pumila, A. altissima and L. maackii were introduced to North America as ornamental plants during the 1800s (Dirr, 1998), and all were commonly found throughout the study area. For L. maackii, fragmentation has been shown to mediate its invasion into southwestern Ohio forests (Hutchinson and Vankat, 1998). Other studies report correlations between exotic plant invasion and urbanization (Barton et al., 2004; Duguay et al., 2007).

We also found that exotic woody measures increased while native woody measures decreased with proximity to railroads and roads. Railway routes and roads represent another possible mechanism of exotic species invasion (Watkins et al., 2003). Railways and roads have historically been situated along waterways because floodplains and valleys often provided a relatively level landscape for infrastructure construction. These factors may adversely affect native species diversity by mediating exotic invasion by directly



Fig. 4. Canonical correspondence analysis (CCA) ordination of understory (<10 cm dbh) species composition of 71 plots in the Mill Creek watershed. For biplot A, codes correspond to individual plots: "A" represents plots along Sharon Creek and Mill Creek and "B" represents plots located along West Fork Mill Creek. For biplot B, codes of individual species (Appendix A) show their scores as a function of the first two axes. Arrow length indicates the importance of each landscape variable and its influence on each species.

aiding seed dispersal (Tikka et al., 2001) or indirectly by increasing light availability via fragmentation (Medley, 1997; Tilman and Lehman, 2001).

Canopy diversity was also negatively affected by urbanization, but to a lesser degree (Table 3). This finding appears due to complementary responses of native vs. exotic canopy species, similar to that reported by Burton and Samuelson (2008). In our study, exotic canopy richness increased with measures of urbanization, whereas native canopy richness decreased (Table 3). These findings suggest that many native canopy species are sensitive to impacts associated with urbanization (i.e. fragmentation, competition with invasive plants, hydrological changes; Didham et al., 2007). This interpretation is supported by our ordination, which shows many native tree species to be associated with the least urbanized sites, as we discuss below (Fig. 3B). Species richness of native understory woody plants, over 65% of which were tree saplings, was even more negatively affected by urbanization (Table 3). We strongly suspect that the impacts of the landscape in the present and recent decades are manifest in the understory, but of course this understory composition shapes the composition of the future canopy. Research on the composition of riparian seed banks has documented a shift from native to exotic species with increasing levels of urbanization (Moffatt and McLachlan, 2003). Canopy trees are several decades old and likely reflect the landscape conditions that existed at the time they were established, when human impact was less apparent than indicated by current measures.

Our results are consistent with the hypothesis that altered site hydrology influences riparian woody plant composition and structure within urban areas. In general, medium- and high-moisturerequiring species, canopy stem density was lower in plots within landscapes having a higher proportion of impervious surface, and understory stem density was lower where there was more grass cover; both were lower in plots closer to railroad tracks (Table 4). Low-moisture-requiring species were widely distributed across the study area. Changes in hydrology associated with urbanization, such as the replacement of pervious natural vegetation with impervious surfaces and an increase in stormwater discharge via sewers, can lead to lower water tables. This "urban drought" phenomenon in turn influences associated soil, vegetation, and microbial processes (Groffman et al., 2003). Our results provide further support for this hypothesis, and are similar to findings from Baltimore and the Georgia Piedmont (Groffman et al., 2003; Burton and Samuelson 2008). In addition, our results on species' moisture requirements suggest that railroad and road construction near the stream might also affect streambank hydrology. The construction of these structures parallel to stream channels can result in lateral hydrological disconnections leading to drier soil conditions (Blanton and Marcus, 2009). Such floodplain disconnections can have a significant impact on the ecological function of riparian landscapes by negatively affecting floodplain evolution, riparian ecosystem processes, side-channel habitats, and associated biodiversity (Snyder et al., 2002; Forman, 2003).

For the Cincinnati metropolitan area, the CCA for both canopy and understory species composition revealed a diffuse pattern rather than a distinct ordering of sites on a single gradient of urbanization (Figs. 3A and 4A). The presence of a diffuse rather than a distinct gradient differs from what has been documented for other large-scale urban-to-rural gradient vegetation studies (e.g., McDonnell et al., 1997; Burton et al., 2005); and illustrates the complex heterogeneity comprised of both built and vegetative elements found within an urban area (Cadenasso et al., 2007). This is important since urban areas are often incorrectly assumed to represent a homogenous landscape or land-use type. Indeed, our findings reveal a complex patterning of species composition on the landscape that is directly influenced by landscape changes within and surrounding urban riparian forests.

The CCA also demonstrated that riparian canopy and understory species composition responded to landscape metrics (Fig. 2). From these analyses, we can identify indicator species of the riparian plant community associated with urbanization (Kremen, 1992). For example, it is clear from species biplot scores that certain species are identified with more or less urbanized areas. Exotic canopy species M. alba, A. platanoides, U. pumila and Pyrus ornamentalana were found at the most urbanized sites. These species are highly tolerant of urban growing conditions and appear capable of exploiting the environmental conditions associated with urbanization, and could be described as urban exploiters (Mckinney, 2002). Little research has investigated the invasiveness of *M. alba*, but the species' high phenotypic plasticity has been suggested as a reason for its success in highly disturbed environments (Gray, 1990). A. platanoides has been documented as being highly invasive of disturbed Midwestern forests (Webster et al., 2005) and to negatively impact native understory regeneration (Galbraith-Kent and Handel, 2008), but in our study area it is currently limited to only the very most urbanized sites. The shade-intolerant exotic species, A. altissima, is a known invader of open areas (Kowarik and Säumel, 2007), but more rarely an invader of forests; however, this species was found at nearly all sites (Fig. 3B, center), and appears to be the most invasive exotic tree species in the study area.

Early-successional native species, such as A. negundo, P. deltoides and Salix nigra, were among the most common canopy species at urbanized sites and possibly represent urban adapters capable of tolerating disturbances associated with urbanization. Conversely, native canopy species characteristic of late-successional forests such as, A. saccharum, Fagus grandifolia, Diospyros virginiana, Carya spp., T. americana and Quercus spp., were found at only the least urbanized sites (Fig. 2), often large urban parks - indeed, the only sites having all three species present were located in a state nature preserve. Consequently, these species represent possible urban avoiders that are highly intolerant to the novel interactions and a process associated with urbanization, and highlights the importance of urban remnant woodland areas and parks as havens for these species. These results are consistent with the large-scale studies of Moffatt et al. (2004) and Burton and Samuelson (2008), who reported a dominance of exotic and pioneer species in more developed riparian areas compared to rural areas.

As stated above, understory diversity and structure were greatly influenced by urbanization. The CCA of the composition of understory species revealed similar results to that of canopy species. These results provide a glimpse of what the riparian forest composition could be in the future. For example, the native species that are characteristic of late-successional forests, such as Carpinus caroliniana, Carya ovata, Fagus grandifolia, Hydrangea arborescens, Ostrya virginiana, and Quercus alba, are likely to be replaced by a combination of early-successional native species, such as C. occidentalis, P. deltoides, P. occidentalis, and R. pseudoacacia, and exotic species including A. altissima, U. pumila, P. ornamentalana, and M. alba. It is not clear if shifts in species composition along the urban gradient suggest a permanent shift in forest successional trajectory. Our findings indicate that many native shrubs and saplings of subcanopy and upper canopy species regenerate poorly in the moderately to highly urbanized sites. The most abundant understory shrub, L. maackii, dominated the understory of all but the least urbanized sites, and we observed few herbaceous or other woody species growing under this species. As discussed below, this particular species could significantly impact future forest structure and function.

The exotic understory species, *L. maackii*, is of particular interest because of its ubiquitous presence throughout the study area. Hutchinson and Vankat (1997) showed that cover of the invasive shrub *L. maackii* is correlated to canopy openness and inferred that canopy disturbance promotes invasion by this shrub in Southwest Ohio. However, Bartuszevige et al. (2006) found that landscape parameters, such as the amount of edge habitat in a 1500 m buffer, predicted L. maackii density better than any other woodlot parameters. In upland forests this exotic shrub reduces native tree seedling survival (Gorchov and Trisel, 2003), survival and reproduction of native annual herbs (Gould and Gorchov, 2000), growth and reproduction of perennial herbs (Miller and Gorchov, 2004), and canopy tree growth increments (Hartman and McCarthy, 2007). Furthermore, chronosequences indicate that L. maackii invasion reduces density and diversity of herbs and tree seedlings and saplings (Hartman and McCarthy, 2008). Similar effects are likely for riparian forests. The invasive tree A. altissima is also likely to negatively impact riparian plant communities, as it suppresses seedling growth of native trees through allelopathy (Gómez-Aparicio and Canham, 2008). In addition, another contributing factor that could influence woody species composition is excessive browsing from the overabundance of whitetail deer (Odocoileus virginianus) in our study area, which can negatively affect the growth and survival of many shrub and trees species (Cute et al., 2004). Further research is needed to fully understand the potential importance of species invasion on the functioning of riparian systems.

Our findings are important because compositional and structural changes in riparian plant communities by exotic species invasions could diminish the ecological functioning of these systems (Hooper et al., 2005; Richardson et al., 2007). For example, exotic species have been shown to influence biogeochemical cycles in deciduous forests (Ashton et al., 2005). Chen et al. (2007) documented that invasion of exotic plants can alter ecosystem functions indirectly by influencing soil decomposers such as nematodes. In addition, it has been documented that the diversity of riparian leaf litter can influence decomposition rates by stream invertebrates (Lecerf et al., 2005), and the presence of exotic species leaf litter can cause cascading ecological effects that alter the composition of benthic invertebrate communities (Lecerf et al., 2007). A recent study of the invasive A. altissima showed its litter decomposes more rapidly in streams than litter of native trees, and is preferred by aquatic detritivores (Swan et al., 2008).

This research also illustrates the complex heterogeneity that exists within cities, and underscores the importance of urban greenspaces, such as riparian areas, in harboring native biodiversity. Even though our study focused on a highly urbanized area, we still identified relatively large fragments of diverse riparian forest. Efforts by land-use planners and managers should focus on limiting building, railroad and road development within and surrounding these remaining and unique riparian forests. Such efforts may help reduce the spread of exotic species whose invasions pose unknown changes to future successional trajectories. Finally, additional research is needed to determine the relative influence that can be attributed to hydrologic disturbances, past land-use legacies, and habitat fragmentation and loss on the structure and function of urban riparian systems.

Cities represent what Hobbs et al. (2006) describe as "novel ecosystems" that are comprised of new combinations of species that result from the direct interaction with people (Hobbs et al., 2006). These new biotic assemblages comprised of native and introduced species can significantly alter important interactions and processes of ecosystem functioning (Richardson et al., 2007), and will become more important with increasing urbanization. Further research is needed to examine the provisioning of various ecosystem services by urban riparian areas. For example, several of the riparian forests we sampled represented mixtures of native and exotic species, and although altered, these forests have been shown to provide important migratory habitat for avian species (Pennington et al., 2008) and mitigate local flooding (Thurston et al., 2003).

This study poses an important management and restoration question for future research: how can we manage these urban riparian ecosystems for maximizing their beneficial aspects, while reducing their more deleterious ones?

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Appendix A

Canopy and understory woody plant species found tributaries of the Mill Creek watershed in Cincinnati, Ohio. Native status is native (N) or exotic (E) in North America (Braun, 1989); Strata refers to whether species was found in canopy (C) or understory (U) in this study. Moisture requirement is high (H), medium (M), low (L), or no information (NI), and were classified based on Burns and Honkala (1990) and USDA-NRCS (2006).

Code	Latin name	Common name	Native status	Strata	Moisture requirement		
Woody plant species							
ACNE	Acer negundo L.	Boxelder	Ν	C, U	М		
ACNI	Acer nigrum Michx. f.	Black Maple	Ν	C, U	М		
ACPL	Acer platanoides L.	Norway Maple	Е	C, U	М		
ACRU	Acer rubrum L.	Red Maple	Ν	C, U	Н		
ACSAN	Acer saccharinum L.	Silver Maple	Ν	C, U	М		
ACSA	Acer saccharum Marshall	Sugar Maple	Ν	C, U	М		
AEGL	Aesculus glabra Willd.	Ohio Buckeye	Ν	C, U	М		
AIAL	Ailanthus altissima (Mill.) Swingle	Tree of Heaven	Е	C, U	М		
ALGL	Alnus glutinosa (L.) Gaertn.	European Alder	Е	Ċ	М		
AMFR	Amorpha fruticosa L.	Indigobush Amorpha	Ν	U	Н		
ASTR	Asimina triloba (L.) Dunal	Common Pawpaw	Ν	C. U	М		
BENI	Betula nigra L.	River Birch	Ν	C	Н		
CACA	Carpinus caroliniana Walter	American Hornbeam	Ν	C. U	М		
CACO	Carva cordiformis (Wang.) K. Koch	Bitternut Hickory	Ν	C. U	М		
CAOV	Carva ovata (Mill.) K. Koch	Shagbark Hickory	Ν	C. U	М		
CASP	<i>Catalpa speciosa</i> (Warder ex Barney) Englem.	Northern Catalpa	Е	C. U	L		
CEOC	Celtis occidentalis L.	Common Hackberry	N	C. U			
CECA	Cercis canadensis L.	Eastern Redbud	N	C. U	L		
COFL	Cornus florida L	Flowering Dogwood	N	C. U	L.		
COSE	Cornus sericea L	Redosier Dogwood	N	U	_		
CRPH	Crataegus phaenopyrum (L. f.) Medik.	Washington Hawthorn	N	C.U	М		
DIVI	Diospyros virginiana L	Common Persimmon	N	C, C	M		
EUAL	Euonymus alatus (Thunb.) Sieb.	Winged Euonymus	E	Ū	M		
FAGR	Fagus grandifolia Ehrh.	American Beech	N	C. U	M		
FROU	Fraxinus auadrangulata Michx.	Blue Ash	N	C. U	NI		
FRSP	Fraxinus sp.	Ash	Ν	C. U	н		
GLTR	Gleditsia triacanthos L.	Common Honevlocust	N	C. U	M		
GYDI	<i>Gymnocladus dioicus</i> (L.) K. Koch	Kentucky Coffeetree	N	с, 2 С	M		
HISY	Hibiscus svriacus L	Shrub Althea	E	Ŭ	NI		
HYAR	Hydrangea arborescens L	Smooth Hydrangea	N	Ŭ	M		
IUNI	luglans nigra L	Black Walnut	N	СU	Н		
IUVI	Juniperus virginiana L.	Eastern Redcedar	N	C. U	L		
LIVU	Ligustrum vulgare L	European Privet	E	U	M		
LIST	Liquidambar styraciflua L.	American Sweetgum	N	C	M		
LOMA	Lonicera maackii (Rupr.) Maxim.	Amur Honeysuckle	E	Ū	M		
MAPO	Maclura nomifera (Raf.) Schneid.	Osage-orange	E	I	M		
MASP	Malus sp. Mill	Flowering Crabapple	N	Ī	M		
MOAL	Morus alba L	White Mulberry	E	Ī	L		
NYSY	Nyssa sylvatica Marsh.	Black Tupelo	N	C	M		
OSVI	Ostrva virginiana (Mill.) K. Koch	American Hophornbeam	N	I	L		
PIAB	Picea abies (L.) Karst.	Norway Spruce	E	C	M		
PIPU	Picea pungens Engelm.	Colorado Spruce	E	C	M		
PINI	Pinus nigra Arn.	Austrian Pine	E	C	M		
PLOC	Platanus occidentalis L.	Svcamore	N	I	Н		
PODE	Populus deltoides Bartr. ex Marshall	Eastern Cottonwood	Ν	Ι	Н		

Appendix A (continued)

Code	Latin name	Common name	Native status	Strata	Moisture requirement
				(contin	ued on next page)
PRSE	Prunus serotina Ehrh.	Black Cherry	Ν	Ι	Μ
PRVI	Prunus virginiana L.	Common Chokecherry	Ν	С	М
PYCA	Pyrus ornamentalana Decne.	Ornamental Pear	Ν	Ι	М
QUAL	Quercus alba L.	White Oak	Ν	Ι	М
QUMA	Quercus macrocarpa Michx.	Burr Oak	Ν	Ι	М
QUMU	Quercus muehlenbergii Engelm.	Chinkapin Oak	Ν	Ι	Μ
QURU	Quercus rubra L.	Red Oak	Ν	Ι	Μ
RHCA	Rhamnus cathartica L.	European Buckthorn	E	С	NI
RHAR	Rhus aromatica Ait.	Fragrant Sumac	Ν	U	L
RHTY	Rhus typhina L.	Staghorn Sumac	Ν	U	L
RISP	Ribes sp.	Currant	Ν	U	NI
ROPS	Robinia pseudoacacia L.	Black Locust	Ν	Ι	Μ
ROMU	Rosa multiflora Thunb. Ex Murray	Multiflora Rose	E	U	Μ
RUSP	Rubus L.	Blackberry	E	U	L
SABA	Salix babylonica L.	Weeping Willow	E	С	Н
SANI	Salix nigra Marsh.	Black Willow	Ν	Ι	Н
TIAM	Tilia americana L.	American Linden	Ν	Ι	М
ULPU	Ulmus pumila L.	Siberian Elm	E	Ι	М
ULSP	Ulmus sp.	Elm	Ν	Ι	Н
VITR	Viburnum opulus L.	European Cranberrybush	E	U	М
VIRH	Viburnum rhytidophyllum Hemsl.	Leatherleaf Viburnum	E	U	Μ

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