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Characteristics of Urban Natural Areas Influencing Winter Bird Use in Southern Ontario, Canada

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Abstract Characteristics of urban natural areas and surrounding landscapes were identified that best explain winter bird use for 28 urban natural areas in southern Ontario, Canada. The research confirms for winter birds the importance of area (size) and natural vegetation, rather than managed, horticultural parkland, within urban natural areas as well as percent urban land use and natural habitat in surrounding landscapes. Alien bird density and percent ground feeding species increased with percent surrounding urban land use. Higher percent forest cover was associated with higher percentages of forest, bark feeding, small (<20 g) and insectivorous species. Natural area size (ha) was related to higher species richness, lower evenness and higher percentages of insectivorous, forest interior, area-sensitive, upper canopy, bark feeding, and non-resident species. Higher number of habitat types within natural areas and percent natural habitat in surrounding landscapes were also associated with higher species richness. Common, resident bird species dominated small areas (<6.5 ha), while less common non-residents increased with area, indicative of a nested distribution. Areas at least 6.5 ha and more generally >20 ha start to support some area-sensitive species. Areas similar to rural forests had >25% insectivores, >25% forest interior species, >25% small species, and <5% alien species. Indicator species separated urban natural areas from rural habitats and ordination placed urban natural areas along a gradient between urban development and undisturbed, rural forests. More attention is needed on issues of winter bird conservation in urban landscapes.

Keywords Winter birds · Urban ecology · Natural area · Urbanization

Introduction

Great interest in conservation ecology research has focused on the effect of fragmentation on breeding birds of natural areas in human-dominated landscapes (Whitcomb and others 1981, Fernández-Juricic and Jokimäki 2001, Fahrig 2003). In parallel, research has documented the effects of urbanization on breeding birds in urban habitats (Friesen and others 1995, Jokimäki and Suhonen 1998, Jokimäki 1999, Marzluff 2001b, Chace and Walsh 2006). But the influence of both fragmentation and urbanization on winter bird use of urban natural areas is not as well understood (Tilghman 1987, Telleria and Santos 1995, 1997, Ichinose and Katoh 1998, Marzluff and others 1998, Nour and others 1999, Jokimäki and others 2002, Smith 2003). Conservation practitioners have also focused on assessing breeding bird use of urban natural areas (Adams 1994, Thompson and others 2001). The enormous continuing growth of urbanization around the world and its impacts on nature makes it crucial to understand urbanization's effects on all aspects of avian ecology, including winter habitat (Marzluff 2001a, Thompson and others 2001).

The nested distributions and area sensitivity of forest and grassland bird species in fragmented natural areas

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in human-dominated landscapes have particularly preoccupied conservation biologists (Whitcomb and others 1981, Robbins and others 1989, Bellamy and others 1996a,b, Jokimäki 1999, Fernández-Juricic and Jokimäki 2001). But relatively fewer studies have examined nestedness and area sensitivity of wintering bird species or the minimum size of habitat where wintering species occur (Blake 1987, Tilghman 1987, Telleria and Santos 1995, 1997, Nour and others 1999, Fernández-Juricic and Jokimäki 2001).

Protecting networks of urban natural areas is widely regarded as key to conserving biological diversity in cities and on the urban fringe and now is routinely proposed through regional and urban planning in many jurisdictions (Adams and Dove 1989, Margules and Pressey 2000, Fairbanks and others 2001), including within Canada (Smith and others 1991, Pim and Ornoy 2002, Ontario Ministry of Municipal Affairs and Housing 2005, Ontario Ministry of Public Infrastructure Renewal 2006). The effectiveness of natural area networks in conserving breeding bird species is often considered, but rarely are winter birds considered, perhaps leading to less informed decisions (Thompson and others 2001). Because many bird species in urban habitats are year-round residents (Jokimäki and Suhonen 1998), knowledge of their habitat needs during winter is especially important for urban planning.

Conservation evaluation assesses the value of natural areas and helps design natural area networks for land use decision-making (Margules and Pressey 2000, Cabeza and Moilanen 2001, Ontario Nature 2004, Williams and others 2005, Platt and Lill 2006). The diversity, representativeness, naturalness, integrity, irreplacability, and rarity of breeding bird life are frequently used to assess natural areas (Smith and Theberge 1986, 1987, Williams and others 1996, Possingham and others 2000, Bryce and others 2002) but seldom winter birds. Multivariate analysis is sometimes used to assess criteria, particularly representativeness and naturalness, also examined in this paper (e.g., Saetersdal and Birks 1993, Taggart 1994, Fairbanks and others 2001).

This paper examines the influence of the characteristics of urban natural areas on their use by birds in winter in terms of the following questions:

- Do winter birds of urban natural areas exhibit trends similar to breeding birds in terms of the relation of density, diversity and species, and guild composition to the size and habitat features of urban natural areas and surrounding landscapes? If so, what are the similarities and differences in these trends?
- Do winter birds of urban natural areas exhibit a nested distribution, and do winter bird species exhibit area sensitivity? If so, are there minimum sizes of urban natural areas in winter for particular species?
- Can data on winter birds be used for conservation evaluation of urban natural areas and the design of natural area networks?

Methods

Study Plots

The Winter Bird Population Study (WBPS) is a method for sampling the winter birds of census plots used to sample hundreds of plots across North America. The method involves a complete count of all birds occurring on defined plot areas on at least eight days, mid-December to mid-February using standardized methods (Kolb 1965, Robbins 1972, 1981, Smith 1984a, Roberts and Schnell 2006). All sites used in this paper were surveyed either by professional biologists or highly skilled amateur field ornithologists. Smith (1984a) found that the variance in surveys by three observers with a range of experience (drawn from the observers in the 28 studies reported on here) was low compared with the among-site variance, thus validating use of surveys by different observers. This is also an example of use of the extensive data bases of "citizen science" initiatives like the Christmas Bird Count, Breeding Bird Census, and Breeding Bird Survey.

Urban natural areas are defined for the purposes of this study as areas that include significant portions of remnant natural vegetation and do not contain areas covered by residential or commercial buildings and associated roads. Twenty-eight urban natural areas were analyzed in cities within the Greater Golden Horseshoe urban area (population 7.5 million) in south-central Ontario, Canada, including 11 sites in Toronto (population ~2,480,000), one site in York Region (population ~810,000), one site in Hamilton (population ~490,000), and 15 sites in Waterloo Region (population ~440,000) (Campbell and Dagg 1976, Smith and others 1981, 1982, Smith 1984a, b, 2003). The range of winter weather conditions in the region includes average January temperatures of –7.0 to –4.2°C, average snowfall of 38.2 to 43.5 cm, and average snow depth of 7 to 12 cm.

The sites represent all the urban natural areas sampled in Ontario using the Winter Bird Population Study methods and published in the journals *Audubon*

Field Notes, *American Birds*, and *Ontario Field Biologist* (Smith 2003). The plots were sampled from one to seven years and, where several years' data were available, mean values for each plot were used in analyses. Table 1 summarizes the characteristics of the areas.

The urban natural areas were also compared with urban commercial and residential areas and with rural mixed habitats and rural forests to examine their position on the urban-rural gradient. The winter bird data on the 28 urban natural areas were compared with 21 other plots in cities, rural forests, and rural mixed habitats across southern Ontario, Canada, reflecting the urban-rural gradient including urban core residential and commercial, suburban, mixed rural habitats, and forests protected in national and provincial parks (Smith 2003). These are all the plots sampled in southern Ontario using the Winter Bird Population Study methods and published in *Audubon Field Notes*, *American Birds*, and *Ontario Field Biologist* (Smith 2003). Specific comparisons are also made between the 28 urban natural areas and 10 plots in relatively undisturbed rural forests and mixed rural habitats.

Characteristics of Urban Natural Areas

The characteristics of each urban natural area and their surrounding landscapes were determined through field reconnaissance and interpretation of aerial photographs and topographic maps. Table 1 defines and describes the characteristics and gives the range of values for each characteristic for the 28 urban natural areas.

The sizes of the 28 urban natural areas varied from 0.7 to 81 hectares (ha) (Table 1; also see Smith 2003). Habitats within each natural area were classified as forest, successional field, managed horticultural parkland, riparian habitat, or open water. The percentage of each natural area covered by forest, field, and managed parkland was estimated from maps and aerial photographs from the period of each survey. The presence or absence of riparian habitat and open water (>50 m^2) was identified. The number of habitat types was assessed as the number of the following present in each urban natural area: forest, successional field, horticultural parkland, riparian habitat, and open water. These variables summarize the patch or site-level characteristics of each urban natural area. The variables are also inherently and statistically correlated.

The percentage of surrounding lands in urban land use within 1 km of the edge of each natural area was estimated from aerial photographs and land use maps, as was the percentage of land covered by natural area within 1 km (Table 1). Distances were measured from the natural area to the edge of the city (boundary between suburban development and the rural landscape) and the closest other natural area >5 ha. These measurements characterize the urbanization, habitat availability, and connectivity within surrounding landscapes and location within the city for each urban natural area. These ''buffers'' and distances are among the common spatial measures of landscape habitat availability and connectivity (Moilanen and Nieminen 2002, Fahrig 2003).

Bird Metrics

A variety of measures of community structure were used to examine variation in diversity, density, bird size, and species composition. Several measures of

Table 1 Characteristics of urban natural areas and surrounding landscapes[a]

Characteristic	Description of characteristic
Area	Total area in hectares of the urban natural area 7 sites <2.5 ha; 4 sites 2.5–9.9 ha; 7 sites 10–19.9 ha; 8 sites ≥20 ha
Percent forest	Percent cover of forest within urban natural area (range 0–100%)
Percent field	Percent cover of successional field habitat within urban natural area (range 0–85%)
Percent managed parkland	Percent cover of managed, horticultural parkland (turfgrass and ornamental trees and shrubs) within urban natural area (range 0–100%)
Open water	Presence or absence of open water (> 50 m^2) during year(s) of study
Riparian habitat	Presence or absence of riparian habitat within urban natural area
Number of habitats	The number of habitats or biotopes within the urban natural areas (i.e., forest, field, managed parkland, open water, riparian; range from 1–5)
Percent surrounding urban land use	Percent cover of urban land uses (e.g., commercial, residential, industrial) within 1 km of the edge of the urban natural area (range 10–100%)
Distance to city edge	Distance (km) to rural land use (range 0–18.0 km)
Percent surrounding natural area	Percent cover of natural areas within 1 km of the urban natural area (range 0–90%)
Distance to nearest natural area	Distance (km) from urban natural area to nearest other natural area greater than 5 ha (range 0–4.0 km)

[a] The first seven characteristics listed are area-level characteristics and the last four are landscape-level characteristics

diversity were used including species richness and evenness ($E_{2,1}$), which are reported on here (Hill 1973, Magurran 2004).

Alien bird density, water bird density, native land bird density, and the density of each species were assessed as the number of birds per hectare or bird density (Kolb 1965, Robbins 1972, 1981). The percentages of birds in four size classes were calculated for each plot, < 20 g; 20–40 g; 41–100 g; and > 100 g, using the average mass for each species (from Dunning 1993). The four size classes were devised based on a frequency analysis of size distribution.

The percentage of birds in different feeding and substrate guilds was estimated using the guild classifications of DeGraaf and others (1985). The percentages of field, field edge, forest edge, forest interior, permanent resident, non-resident, and area-sensitive species were calculated using information in Cadman and others (1987), Whitcomb and others (1981), Root (1988), McLaren (1998), Holloway and others (2004) and Ontario Partners in Flight (2005). Urban species are European Starling, *Sturnus vulgaris*, Rock Pigeon, *Columba livia*, and House Sparrow, *Passer domesticus*.

Statistical Methods

Regression analysis was used to analyze relationships between the bird assemblage variables described above and the characteristics of urban natural areas (Table 1). α was set at 0.05 for all statistical tests (sample size, n = 28), keeping in mind the limitations of statistical tests in multi-model comparisons. All possible subset regression analysis (Miller 2002, Johnson and Omland 2004) was used to compare among likely models using the Akaike Information Criterion (AIC) for optimal model selection and comparison (Burnham and Anderson 2002, Kadane and Lazar 2004). In the model selection process, all potential explanatory variables (Table 1) were considered individually and in combination for each dependent variable. Competing models were compared using AIC, and the ‘‘best’’ model, minimizing AIC, for each dependent variable is presented in the Results section. The only models selected were those that minimized AIC and where all variables achieved statistical significance at the 0.05 level. Again, the statistical tests should not be viewed as definitive, as multiple models are possible. Where competing models are within ΔAIC<2 of the ‘‘best’’ model, which indicates substantial evidence for the competing model (Burnham and Anderson 2002), some discussion is provided of potential competing models.

In general, bird metrics were expected to respond to either patch-level habitat characteristics (first seven variables in Table 1) or landscape-level characteristics (last four variables in Table 1), or a combination of both. Correlations among the variables influenced the model selection process. Variables were transformed using the $\log_{10}$ and arcsine functions for density and percentage variables, respectively. Categorical variables, presence of open water and riparian habitat, were entered into regression analyses as ‘‘dummy’’ variables (i.e., 1 or 0).

For density variables, sampling efforts influence or bias the precision of density estimates (Bock and Root 1981, Smith 2003). As a result, for alien bird density, water bird density, native land bird density, and the density of each species, the average number of survey hours per hectare was entered into the regression equations to remove any spurious influence sampling effort might have on analysis.

Nestedness was assessed using the nestedness calculator software and correlation methods recommended by Patterson and Atamar (2000). Detrended correspondence analysis (Hill and Gauch 1980, Oksanen and Minchin 1997) was used to compare the 28 urban natural areas with 24 plots in other rural and urban habitat types in a larger study across southern Ontario (Smith 2003). Two-way indicator species analysis was used to classify the plots and identify indicator species (Hill and others 1975, Gauch and Whittaker 1981).

Non-parametric, Epanechnikov kernel discriminant analysis (McLachlan 2004) was also used to examine bird assemblage characteristics that would differentiate urban natural areas from undisturbed rural forested and mixed habitats.

Results

Density, Size, and Diversity

Alien land bird density increased with percent surrounding urban land use (Table 2). Waterbird density, primarily Mallard (*Anas platyrhynchos)*, increased with the presence of open water and percent surrounding urban land use and decreased with percent field (Table 2). Similarly, the percentage of large birds (>100 g), primarily Mallard and raptors, increased with open water and with size of natural area. The percentage of small birds (<20 g) decreased with percent managed parkland (Table 2), with an alternate model increasing with percent forest (ΔAIC = 1.76). Percent managed parkland and percent forest are inversely correlated (Pearson's r = –0.789).

Table 2 Regression of density, biomass, bird size, and diversity with characteristics of urban natural areas[a]

Bird assemblage variable	Characteristic of urban natural areas and direction of effect	Parameter estimate ± standard error[b]	Percent of variance explained (adjusted R^2)	Akaike Information Criterion
Density and Bird Size[c]				
Alien bird density	% Surrounding urban land use (+)	0.2622 ± 0.1178*	15.9%	–90.4
Water bird density	Open water (+)	0.4996 ± 0.0893***	58.2%	–96.9
	% Surrounding urban land use (+)	–0.4517 ± 0.1421**		
	%Field (–)	–0.2587 ± 0.1133**		
% Small birds (<20g)	% Managed parkland (–)	–0.3763 ± 0.1221**	23.9%	–70.6
% Large birds (>100g)	Open water (+)	0.3796 ± 0.1069****	55.2%	–84.3
	Area (+)	0.2160 ± 0.0757**		
Diversity				
Species richness	Area (+)	7.019 ± 1.432****	73.2%	69.6
	Number of habitats (+)	1.812 ± 0.6694**		
	% Surrounding natural area (+)	12.612 ± 4.378**		
Evenness index $E_{2,1}$	Area (–)	–0.1303 ± 0.0275****	48.0%	–135.5
	Distance to city edge (+)	0.0860 ± 0.0401*		

[a] Models selected based on minimization of the Akaike Information Criterion.

[b] Statistical significance of F-test is indicated by * $P \leq 0.05$; ** $P \leq 0.01$; **** $P \leq 0.001$; *** $P \leq 0.0001$ (see Methods for caveats regarding statistical tests).

[c] Regression analysis corrects for effects of sampling effort (hours/ha) on bird density.

Species richness increased with area, number of habitats, and percent surrounding natural area (Table 2). Evenness ($E_{2,1}$ is illustrated) declined with area, as additional less common species are found, and increased with distance from city edge. While area was included in all the best models, number of habitats, percent surrounding natural area, and percent surrounding urban land use performed almost as well as explanatory variables in place of distance from city edge (similar but slightly higher AIC values, $\Delta AIC < 2$).

Guilds and Species

The percentages of insectivorous, frugivorous, carnivorous, and herbivorous birds all responded to variables related to the amount of natural habitat cover in and around urban natural areas (Table 3). Percent insectivorous species showed a strong relationship with area and percent forest. Frugivorous species increased with the percent of surrounding natural area. Percent carnivorous bird species (14 species) decreased with percent surrounding urban land use (Table 3). Percent herbivorous species correlated with the presence of open water (Table 3). Granivores and omnivores showed no statistical relationships with the characteristics of urban natural areas and were dominant on most sites (combined average percentage of omnivorous and granivorous species was 66.4%).

Percentages of upper canopy, lower canopy, and bark-feeding birds increased with different measures of natural habitat availability in and around the urban natural areas (Table 3). Percent upper canopy species increased with size of natural area and decreased with the presence of open water. Percent lower canopy species decreased with percent managed parkland, although percent surrounding urban land use performed reasonably as well ($\Delta AIC = 1.47$). Bark-feeding species increased with percent forest and area. In contrast, percent ground-feeding species responded positively to urbanization, increasing with percent surrounding urban land use.

The percentage of alien urban species increased with percent managed parkland and percent surrounding urban land use (Table 3), although percent forest performed almost as well in place of percent managed parkland ($\Delta AIC = 0.28$). Density of Starling (*Sturnus vulgaris*) showed increases with percent surrounding urban land use (Table 4), although distance to city edge performed nearly as well ($\Delta AIC = 1.2$). Percent permanent resident birds decreased with area, while percent non-resident species increased with area (Table 3).

The percent of forest edge and forest interior species increased with percent forest cover, and forest interior species also increased with area (Table 3). The area-sensitive forest species, Brown Creeper (*Certhia familiaris*) and Golden-crowned Kinglet (*Regulus satrapa*), responded to the availability of habitat in and around the urban natural areas. No clear ''best'' model was identified for either species. Brown Creeper increased with forest cover and decreased with distance

Table 3 Regression of bird guilds and species groups with characteristics of urban natural areas[a]

Bird assemblage variable	Characteristics of urban natural areas and direction of effect	Parameter estimate ± standard error[b]	Percent of variance explained (adjusted R^2)	Akaike Information Criterion
Feeding Guilds				
% Insectivorous species	% Forest (+)	0.2085 ± 0.0503***	26.2%	–100.2
	Area (+)	0.1678 ± 0.0499**		
% Carnivorous species	% Surrounding urban land use (–)	–0.1937 ± 0.0651**	22.5%	–121.9
% Frugivorous species	% Surrounding natural area (+)	0.2013 ± 0.0920**	12.3%	–119.1
% Herbivorous species	Open water (+)	0.1208 ± 0.0290****	37.7%	–153.0
% Upper canopy feeding species	Area (+)	0.1878 ± 0.0409**	42.0%	–118.8
	Open water (–)	–0.1454 ± 0.05775**		
% Lower canopy feeding species	% Managed parkland (–)	–0.3242 ± 0.1322*	15.7%	–66.2
% Bark feeding species	%Forest (+)	0.1782 ± 0.0533**	26.1%	–117.2
	Area (+)	0.1120 ± 0.0466*		
% Ground feeding species	% Surrounding urban land use (+)	0.3373 ± 0.1351*	16.2%	–81.1
Species Groups				
% Alien urban species	% Managed parkland (+)	0.3362 ± 0.1145**	45.0%	–79.2
	% Surrounding urban land use (+)	0.3451 ± 0.1526*		
% Resident species	Area (–)	0.2105 ± 0.0498***	38.4%	–103.3
% Non-resident species	Area (+)	–0.2105 ± 0.0498***	38.4%	–103.3
% Forest interior species	Area (+)	0.1114 ± 0.0385**	18.4%	–100.3
	% Forest (+)	0.1244 ± 0.0388**		
% Forest edge species	% Forest (+)	0.3454 ± 0.0710****	45.6%	–90.6
% Area-sensitive species	Area (+)	0.2051 ±0.0484***	38.0%	–111.5
	% Field (–)	–0.1916 ± 0.0808**		

[a] Models selected based on minimization of the Akaike Information Criterion.

[b] Statistical significance: *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$; ****$P \leq 0.0001$ (see Methods for caveats regarding statistical tests).

Table 4 Regression of bird species densities with characteristics of urban natural areas[a,b]

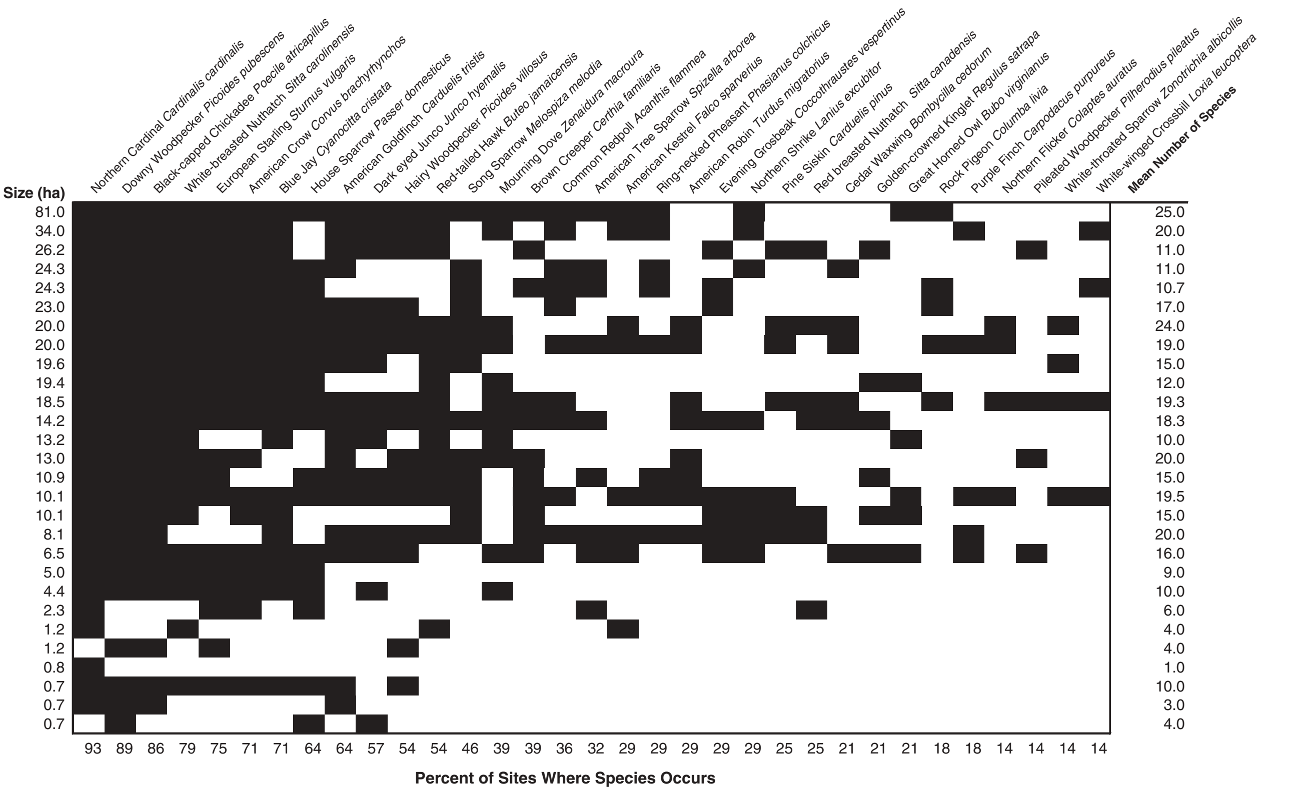
Species	Characteristics of uban natural areas and direction of effect	Parameter estimate ± standard error[c]	Percent of variance explained (adjusted R^2)	Akaike Information Criterion
European Starling *Sturnus vulgaris*	% Surrounding urban land use (+)	0.1676 ± 0.0743*	11.2%	–104.6
Blue Jay *Cyanocitta cristata*	Distance to city edge (+)	0.0730 ± 0.0206**	27.2%	–175.8
Mourning Dove *Zenaidura macroura*	Number of habitats (+)	0.0330 ± 0.0104**	27.8%	–156.9
	Open water (–)	0.0780 ± 0.0311*		
Ring-necked Pheasant *Phasianus colchicus*	%Field (+)	0.2696 ± 0.0862**	35.2%	–117.4
	Open water (+)	0.1382 ± 0.0551*		
American Tree Sparrow *Spizella arborea*	% Forest (%)	–0.0695 ± 0.0252*	22.7%	–160.1
	Riparian (–)	–0.0513 ± 0.0221*		
Rock Pigeon *Columba livia*	Open water (+)	0.01487 ± 0.0044**	31.7%	–262.7
Mallard *Anas platyrhynchos*	Open water (+)	0.4339 ± 0.0972***	50.1%	–94.8
	% Surrounding natural area (–)	–0.4552 ± 0.1830*		

[a] Models selected based on minimization of the Akaike Information Criterion.

[b] Regression corrects for effect on species densities of sampling effort (hours/ha).

[c] Statistical significance is indicated by *$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$ (see Methods for caveats regarding statistical tests).

Table 5 Occurrence of species by size of urban natural area illustrating nested distribution of species[a, b]



[a] Black area = species present; white area = species absent.

[b] The table is sorted by size of urban natural area, not maximally packed by species richness.

to city edge (adjusted R^2 = 53.8%, AIC = –260.2), but models including percent surrounding natural habitat (positive effect), surrounding urban land use (negative effect), and number of habitats (negative effect) all performed reasonably well (ΔAIC < 2). Golden-crowned Kinglet decreased with both surrounding urban land use and number of habitats (adjusted R^2 = 32.2%, AIC = –274.9), but models including percent surrounding natural area and presence of open water also performed reasonably well (ΔAIC < 2).

Density of some individual field and field edge species showed relationships with percent field habitat or number of habitats, including Mourning Dove (*Zenaidura macroura*) and Ring-necked Pheasant (*Phasianus colchicus*) or, in the case of American Tree Sparrow (*Spizella arborea*), with riparian habitat and a negative relationship with forest cover (Table 4).

Mallard Duck density increased with the presence of open water, as expected, and declined with percent surrounding natural area, although percent managed parkland (positive effect) also performed well (ΔAIC = 0.3). Rock Pigeon (*Columba livia*), Mourning Dove, and Ring-necked Pheasant also increased with open water.

Nestedness and Area-Sensitive Bird Species

The occurrence of bird species within urban natural areas displays a nested pattern (Table 5) with a temperature T = 11.45 (probability of a lower T = 8.12×10^{-36}). Area is the variable with highest correlation with the nestedness rank for each site (Spearman rho = 0.6607, $P \leq 0.001$ with Bonferroni correction). Table 5 shows a large gap in species occurrences in the lower right for small natural areas and less common species, typical of nested distributions.

Only the most ubiquitous bird species occurred consistently in urban natural areas less than 6.5 ha in size (Table 5) and most are year-round resident species. These included the native species Northern Cardinal (*Cardinalis cardinalis*), Black-capped Chickadee (*Poecile atricapillus*), Blue Jay, American Crow (*Corvus brachyrhynchos*), and Downy Woodpecker (*Picoides pubescens*). Resident species dominated smaller urban natural areas (Table 3). On the other hand, percentage of area-sensitive species (Table 3) increased with area and decreased with percent field, although number of habitats (negative effect) and

Table 6 Sizes of urban natural areas supporting selected forest interior, forest edge, and field bird species[a]

Species	Smallest urban natural areas (ha) with species present	Mean size (ha) of urban natural area with species present[a]	Mean size (ha) of urban natural area with species absent	F-test and significance[b]
White-breasted Nuthatch *Sitta carolinensis*	0.7	18.4	2.3	19.00***
Hairy Woodpecker *Picoides villosus*	0.7	19.0	9.7	3.37
Red-tailed Hawk *Buteo jamaicensis*	1.2	21.2	8.0	10.23*
Red-breasted Nuthatch *Sitta canadensis*	2.3	14.9	14.8	0.75
Golden-crowned Kinglet *Regulus satrapa*	6.5	14.5	14.9	1.23
Pileated Woodpecker *Pilherodius pileatus*	6.5	17.1	14.5	0.76
Brown Creeper *Certhia familiaris*	6.5	21.0	11.2	4.84*
Northern Shrike *Lanius excubitor*	6.5	22.1	11.2	4.12*
Common Redpoll *Acanthis flammea*	10.1	24.4	8.3	12.88**
White-winged Crossbill *Loxia leucoptera*	10 1	19 0	13.9	2.03
Song Sparrow *Melospiza melodia*	10.1	23.2	9.1	11.24**

[a] Only species recorded at four or more sites are included.

[b] Significant differences between the sizes of natural areas where species is present and absent are indicated by $*P \le 0.05$; $**P \le 0.01$; $***P \le 0.001$ (General Linear Model, log-transformed area)

percent forest cover (positive effect) also performed well (ΔAIC ≤ 0.8) compared to percent field.

The sizes of urban natural areas where some area-sensitive forest interior, forest edge, and field-edge species were observed is shown in Table 6. Both Tables 5 and 6 suggest that there may be minimum winter habitat sizes required to support some of these bird species. A couple of these species occur occasionally in urban natural areas less than 1 ha in size, while more occur in areas larger than 6.5 ha. Average size of areas where these species were recorded ranged from 18 to 25 ha (Table 6).

In this study, urban natural areas at least 6.5 ha in size, and more generally >20 ha, start to support a larger variety of species and a small number of forest interior or area-sensitive species (Tables 5 and 6). Characteristics other than size are also important in attracting additional species as shown earlier. Optimal natural area size is obviously a great deal larger than 20 ha.

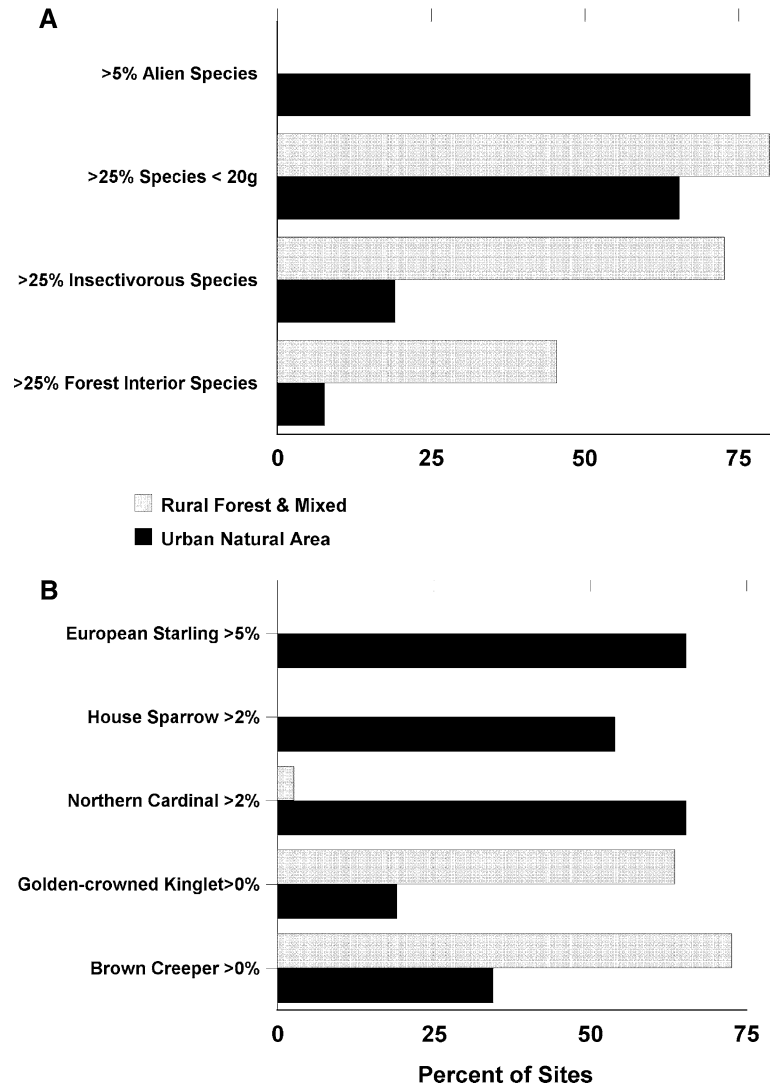
Using Winter Bird Studies in Conservation Evaluation

Three techniques are illustrated here that are useful for comparing urban natural areas for conservation evaluation. First, the differences in guild structure, bird size, and habitat affinities of species at different sites are compared using discriminant analysis. Second, indicator species are identified that separate urban natural areas from rural natural areas using two-way indicator species analysis. Finally, ordination is used to place urban natural areas along a rural-urban or disturbance gradient based on the bird species composition.

A nonparametric discriminant analysis successfully distinguished 100% of urban natural areas from rural forests and mixed habitats based on presence of insectivorous birds, forest interior species, small birds (<20 g), and alien urban species (F-test = 7.49, $P \le 0.0002$). Based on the discriminant analysis, the data allow a simpler formula or rule-of-thumb. Urban natural areas with >25% forest interior species, >25% insectivores, >25% small birds (<20 g), and <5% alien urban birds can be considered similar to undisturbed natural forest conditions in southern Ontario (Figure 1).

Two-way indicator species analysis successfully separated urban natural areas from undisturbed rural forests and mixed habitat. Separation is made using the occurrence of European Starling, House Sparrow

Fig. 1 Percentages of urban and rural natural areas that (**A**) have certain percentages of forest interior, insectivorous, small (<20 g) and alien species and (**B**) have certain percentages of urban and forest indicator species. Percentages derived from discriminant analysis (A) and two-way indicator species analysis (B) to separate urban and rural natural areas



(*Passer domesticus*), and Northern Cardinal as urban indicator species, and Golden-crowned Kinglet and Brown Creeper as forest indicator species (Figure 1). Sites lacking European Starling (at less than 5% relative density), House Sparrow, and Northern Cardinal (both at less than 2% relative density) and including Brown Creeper and/or Golden-crowned Kinglet can be considered in relatively natural forest conditions (Figure 1).

The first axis of a detrended correspondence analysis (eigenvalue = 0.702) of rural and urban plots across southern Ontario provides an index of urbanization, disturbance, naturalness, or ecological integrity. Plots in residential and commercial urban development occupy the high end of the axis and rural forests have the lowest scores on the axis. Urban natural areas fall between residential and commercial urban areas and rural mixed habitats and forests.

Figure 2 plots the urban natural areas along the urbanization-disturbance gradient and shows the increase of forest interior, insectivorous, and smaller species (<20 g) along the gradient and the decrease of alien species. The first axis separates less disturbed urban natural areas from more disturbed sites, providing an index of disturbance, naturalness, or integrity.

Discussion

Cities affect breeding bird assemblages, including those in urban natural areas, causing increased density and biomass, decreased diversity, and favoring granivorous, omnivorous, alien, and generalist species (Adams and Dove 1989, Gilbert 1989, Adams 1994, Marzluff 2001b, Chace and Walsh 2006). These same general patterns are found in this study and others on winter birds

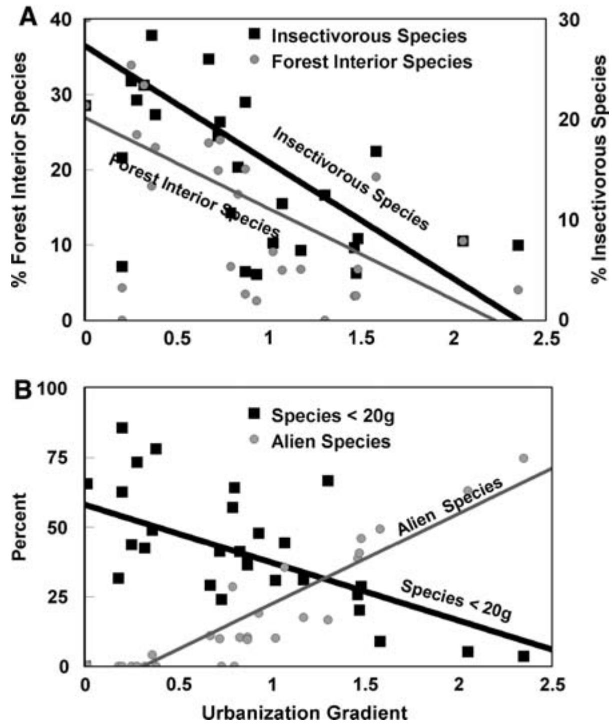


Fig. 2 Trends in percent forest interior species, insectivorous species, small birds (<20 g), and alien bird species along an urbanization-disturbance gradient defined by the first axis of a detrended correspondence analysis. Forest interior species and insectivorous species are shown in **A** and small birds (<20 g) and alien species in **B**

(Lancaster and Rees 1979, Tilghman 1987, Jokimäki and others 2002, Smith 2003) despite the remarkably different feeding strategies and behavioural mechanisms in winter (Telleria and Santos 1995, 1997, Boonstra 2004). However, in boreal and sub-arctic landscapes, species richness can be similar or higher in cities compared with the surrounding landscapes (Jokimäki and others 1996, Clergeau and others 2006).

In this study, the density of alien birds increased with percent surrounding urban land use. Tilghman (1987) found total winter bird density in urban natural areas increased with greater density of surrounding buildings and presence of water but decreased with greater vegetation density. Waterbird density, especially Mallard, increased with the presence of open water in this study. Concentration of wintering Mallards and other waterfowl in artificially warmed, open water in city parks is a common phenomenon in northern climates (Figley and VanDruff 1982, Heusmann and Burrell 1984).

Urban bird assemblages generally have higher biomass due to high density (Marzluff 2001a, Chace and Walsh 2006) and more large species and fewer small species than undisturbed rural forests (Smith 2003). Within urban natural areas, small birds (<20 g) avoided managed parkland and favored forest habitat, consistent with their prevalence in undisturbed rural forests (Smith 2003). Polo and Carrascal (1999) point out that forest habitat generally contains smaller bird species adapted to foraging in small branches in the canopy. It is the underlying differing sizes of different guilds (Polo and Carrascal 1999) that appears to explain the variation in bird size, as insectivores tend to be the smallest winter bird species.

In this study, winter bird species richness increased with area, number of habitat types, and amount of natural area in the surrounding landscape in that order of importance, paralleling similar findings in many breeding season studies (Jokimäki 1999, Marzluff 2001a, Fernández-Juricic and Jokimäki 2001, Chace and Walsh 2006) and other studies during winter season (Tilghman 1987, Telleria and Santos 1995, 1997, Doherty and Grubb 2000). Evenness is generally thought to decline with urbanization (Marzluff 2001a). However, evenness was greater for smaller urban natural areas both in this study and in Donnelly and Marzluff (2004). Abundant resident species dominated smaller areas, while less common, non-resident species were more prevalent on larger urban natural areas (also see Blake 1987, McIntyre 1995) leading to higher evenness in smaller areas.

The percentage of insectivorous, frugivorous, carnivorous, upper canopy, lower canopy, and bark-feeding birds responded to variables measuring the availability of natural habitat within and surrounding urban natural areas. On the other hand, ground feeders and urban alien species increased with surrounding urban land use. Cities are known to favor granivorous, omnivorous, and ground-feeding species (Adams 1994, Jokimäki 1999, Marzluff 2001b, Chace and Walsh 2006). More generally, open, unforested habitats are known to favor larger, ground-feeding species (Polo and Carrascal 1999). Raptors respond to urbanization in differing ways: some exploit the abundant urban prey, while others avoid cities (Bird and others 1996, Chace and Walsh 2006).

Percent insectivorous birds increased with percent forest in this study and forests provide both a larger source of insects in winter and more variety in feeding substrates for small, insectivorous species (Gilbert 1989, Telleria and Santos 1995, 1997). The prevalence of insectivorous species is a key feature differentiating winter bird assemblages of undisturbed rural natural areas from those of urban areas (Smith 2003). Insectivores were also more prevalent in larger urban natural areas in this study. Flock formation in wintering insectivorous species can be disrupted in small urban natural areas, decreasing their occurrence in small fragments and increasing the level of nestedness (Fernández-Juricic 2002).

The findings above indicate the importance of the size and habitat within urban natural areas, landscape-level habitat availability, and connectivity of urban natural areas for conservation of wintering native bird species and a wide range of guilds, common recommendations for breeding birds (Jokimäki 1999, Marzluff 2001b, Chace and Walsh 2006, Zajc 2005). Reconfirmed here is the fact that a prevalence of managed horticultural parkland in urban natural areas reduces the habitat value for native species during winter (Chace and Walsh 2006).

Small, isolated natural areas are known to be less favored than larger, more-connected natural areas by forest interior and ''area-sensitive'' bird species during the breeding season (Robbins and others 1989, Hinsley and others 1996, Bellamy and others 1996a,b, Jokimäki 1999, Burke and Nol 2000, Austen and others 2001). Some research suggests similar patterns exist for winter bird species (Blake 1987, Tilghman 1987, Telleria and Santos 1995, 1997, Doherty and Grubb 2000, Smith 2003). Three studies show that many bird species considered forest interior and area-sensitive species in summer also appear to prefer larger areas with forest interior in winter, in southern Ontario (Smith 2003) and in the nearby northern U.S. (Illinois: Blake 1987, Massachusetts: Tilghman 1987). These studies report similar minimum areas for a number of species.

The smallest urban natural areas (0.7–5.0 ha) support only the most common and primarily resident native winter species, species also common in surrounding urban residential and commercial areas, although at lower densities (Smith 2003). A number of researchers (Tilghman 1987, Telleria and Santos 1995, 1997, Ichinose and Katoh 1998) reported similar findings for winter, Telleria and Santos (1997) noting that bird species with the highest densities occurred in isolated forests of all sizes. This common ecological phenomenon is nestedness, and analysis of patterns of nestedness is often used to assess minimum areas for species (Patterson and Atmar 2000, Fernández-Juricic and Jokimäki 2001, Donnelly and Marzluff 2004, Fischer and Lindenmayer 2005).

Different research has suggested different minimum areas for differing species and ecosystems using varying criteria (Environmental Law Institute 2003). Some suggest at least 4 ha are needed to provide any forest interior habitat (Ranney and others 1981, Ontario Nature 2004). Others suggest 20–30 ha represents a minimum area in temperate zones (Mörtberg 2001, Environment Canada 2004). Donnelly and Marzluff (2004) suggest most forest birds would occur in natural areas 42 ha in size in the northwest U.S. In contrast, Burke and Nol (2000) suggest that areas as large as 500 ha are needed before forest species achieve enough reproductive success to maintain existing populations, due to high nest predation in small woodlots.

In the three studies, Blake (1987), Tilghman (1987), and the current study, a few forest interior and area-sensitive bird species occur occasionally in fragmented natural areas of less than 6 ha in size while most occur only on larger sites. The average size of areas occupied in this study by a number of species is 18–25 ha, consistent with some breeding season studies (Mörtberg 2001, Environment Canada 2004). Many of these species were also classified as ''urban avoiding'' species in winter in Ohio by Crosby and Blair (2001). One interesting finding is that for some northern species, not typically covered by temperate region, breeding season assessments may be area-sensitive in winter, such as Northern Shrike, *Lanius excubitor*, and Common Redpoll, *Acanthis flammea* (this study) and White-winged Crossbill, *Loxia leucoptera*, and Pine Siskin, *Carduelis pinus* (Tilghman 1987).

Small natural areas also can have lower winter survivorship of resident species (Doherty and Grubb 2002, Fernández-Juricic 2002). Thus, estimation of minimum areas should take into account the lower survivorship in small fragments, much as breeding season studies assess the potential for fragments to be population sources or sinks for species (e.g., Burke and Nol 2000). Simple occurrence of a species in a small fragment does not ensure that the fragment is a suitable habitat in terms of survivorship and not an ''ecological trap'' (Schlaepfer and others 2002).

Without analysis of survivorship, estimation of the optimal size of natural areas during winter falls beyond the scope of this study. Estimates in this region for optimal size during breeding season are in the hundreds of hectares (Burke and Nol 2000, Austen and others 2001, Environment Canada 2004). Further research into optimal natural area size during winter incorporating survivorship seems warranted.

Southern Canada's winter climate offers significant constraints for urban birds not present in many studies of winter birds in temperate or warm climates (e.g., Telleria and Santos 1995, 1997, Fernández-Juricic 2002). The prolonged snow cover of considerable depth and frozen watercourses in more northern climates such as Canada and northern Europe make conditions difficult for many species found in temperate regions, particularly insectivores (Erskine 1980, Jokimäki and others 2002, Boonstra 2004). Temperature or energy levels are correlated with both winter densities and species richness of native birds, both at a biogeographic scale (Hawkins and others 2003, Meehan and others 2004) and local scale (Huertas and Diaz 2001, Herbers and others 2004). Winter may be more critical for birds in urban natural areas in higher latitudes due to the thermal stress, flock formation disruption, and predominance of resident species that are subject to lower winter survivorship (Erskine 1980, Doherty and Grubb 2002, Fernández-Juricic 2002). It is conceivable that larger minimum size natural areas may even be needed to support some species at higher latitudes.

Many studies examine the relative contribution of plot- or patch-level factors and landscape or regional level factors in influencing bird assemblages in natural areas, in both summer (Trzcinski and others 1999, Burke and Nol 2000, Austen and others 2001, Mörtberg 2001, Clergeau and others 2001) and winter (Jokimäki and Suhonen 1998, Fernández-Juricic 2002). Low regional percent cover of natural vegetation, high percent surrounding urban land use, and high density of housing and roads reduce the breeding of some species (Friesen and others 1995, Jokimäki 1999, Hennings and Edge 2003, Donnelly and Marzluff 2004, Zajc 2005). Some argue that surrounding urban land use makes urban natural areas particularly inhospitable to many bird species, compared with rural, agricultural landscapes (Mancke and Gavin 2000, Environment Canada 2006).

Zajc (2005) found urban land use more important than size of natural area in influencing bird species, and that a 10% increase in habitat area would increase species richness by ~10%, but a 10% increase in urban land use would decrease species richness by ~20%. Surrounding urban land use has also been shown to reduce winter bird species richness in urban natural areas in this study and others (Tilghman 1987). Other findings based on analysis of reproduction emphasize the paramount importance of size of natural area (e.g., Burke and Nol 2000). This study confirms the importance of patch characteristics, surrounding habitat availability and urbanization for many wintering species, guilds, and assemblage variables.

Evaluation of natural areas for importance to birds usually involves criteria such as great abundance, high species richness, rare species, or species that are indicators of a particular condition (Smith and Theberge 1986, Williams and others 1996, Thompson and others 2001). As forests were prevalent in pre-settlement eastern North America, the woodland condition is also construed as most natural and having high ecological integrity (Bryce and others 2002).

Ordination of sites in this study placed each urban natural area along an urbanization-disturbance gradient and different ecological distances from undisturbed rural forests, providing a way to use winter bird data to assess ecological conditions much as breeding bird data are often used (e.g., Bryce and others 2002). Ecologists often model gradients with the aim of predicting species occurrence from environmental data (e.g., Jokimäki and Suhonen 1998, Fairbanks and others 2001). Such methods have been adapted to assess environmental health and biological integrity (Karr 1993, Woodley and others 1993, Bryce and others 2002). Modelling of gradients using multivariate analysis has been used in conservation evaluation (e.g., Saetersdal and Birks 1993, Taggart 1994, Belbin 1995).

High-quality urban natural areas can also be identified using winter data as those areas with high percentages of forest interior birds, insectivorous birds, and small birds (<20 g) and a low percentage of alien bird species. Indicator species can also be used effectively to separate disturbed and less disturbed urban natural areas using undisturbed rural forests as the reference point. In southern Ontario, European Starling, House Sparrow, and Northern Cardinal can be used as winter, urban indicator species and Golden-crowned Kinglet and Brown Creeper as winter, forest indicator species. European Starling and House Sparrow are widespread urban species. The Northern Cardinal is near its northern range edge in Ontario and reaches its highest abundance in residential areas in Ontario (Cadman and others 1987, Smith 2003). Both Golden-crowned Kinglet and Brown Creeper are associated with mature forest conditions in Ontario (Cadman and others 1987; McLaren 1998, Holloway and others 2004). Golden-crowned Kinglet was also recorded as an ‘‘urban avoiding’’ species in Ohio during winter by Crosby and Blair (2001). Tilghman (1987) found that Brown Creeper avoided smaller urban woodlands and was most abundant in the largest woodlands.

Regional nature conservation strategies focus on protecting systems of the most significant natural areas, connecting these core areas together with corridors and restoring selected natural areas (Margules and Pressey 2000, Pim and Ornoy 2002, Environment Canada 2004, 2006, Platt and Lill 2006). Size, disturbance, vegetation, and surrounding habitat and urban land use influence the ecological value of urban natural areas. The importance of the size and vegetation of natural areas and surrounding habitat availability and land use is confirmed for winter birds in this study. Also confirmed is the need to conserve and restore natural habitats within urban natural areas, and to avoid conversion to horticultural parkland. A variety of techniques illustrated here can be used to assess the relative conservation value of different urban natural areas using data on wintering birds. Yet conservation issues regarding wintering birds are seldom considered. In one of the few applications of non-breeding bird data to conservation evaluation, Thompson and others (2001) concluded "that only assessing breeding distribution does not reliably predict relative importance of areas used by birds... and should not be used exclusively to identify potential gaps in conservation for land-use evaluation and planning."

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