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RELATIONSHIP BETWEEN HABITAT TRAITS AND BIRD DIVERSITY AND COMPOSITION IN SELECTED URBAN GREEN AREAS OF MEXICO CITY

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Resumen. – Relación entre aspectos del hábitat y la composición y diversidad de aves en áreas verdes selectas de la Ciudad de México. – Los espacios verdes de las ciudades contrarrestan la pérdida de la diversidad de aves debida a la urbanización, ya que proporcionan alimento, sitios de anidación y protección contra depredadores. Sin embargo, la influencia de la vegetación, el área, y superficies impermeables sobre la distribución de las especies silvestres todavía no es bien conocida y puede variar entre estaciones e incluso de ciudad en ciudad en diferentes partes del mundo. En el presente estudio se estimó la abundancia de aves en 12 parques de la Ciudad de México durante dos temporadas del 2008. Encontramos 96 especies de aves canoras y las agrupamos según sus afinidades urbanas y estado migratorio. El número de especies aumentó con respecto al área en la temporada de reproducción, pero no durante la época migratoria. En contra de lo esperado, la riqueza de aves migratorias aumentó en parques lejanos a las áreas naturales. Además, siete especies de Parulinae invernales fueron comunes en todos los parques, por lo que podrían ser consideradas como suburbanas. Por otra parte, las especies que utilizan recursos urbanos y toleran las condiciones creadas por los seres humanos en las ciudades, fueron más abundantes en los parques con mayor superficie de áreas impermeables y/o situados lejos de las áreas naturales. En ambas estaciones, lo contrario fue cierto para las especies insectívoro-frugívoras, las cuales evitan las zonas urbanas por lo general. Este último grupo además fue más abundante en los parques más grandes. La mayoría de las especies ampliamente distribuidas fueron insectívoro-granívoras del suelo y varias fueron gregarias. Análisis de especies indicadoras seleccionaron 22 especies en invierno y 17 en la temporada de reproducción. La distribución de estas aves estuvo asociada con la distancia a las áreas naturales y superficies impermeables en ambas temporadas, y con la cobertura de árboles micrófilos en la temporada invernal y la de *Fraxinus uhdei* en la época de reproducción. Nuestros resultados pueden ser útiles para estrategias de manejo encaminadas a la conservación de aves canoras en parques urbanos.

Abstract. – Green spaces within cities counteract the loss of bird diversity due to urbanization because they provide food, nesting sites, and protection against predators. Nevertheless, the influence of vegetation, area, and impervious surfaces on the distribution of wild species is not well understood and can vary between seasons and even from city to city in different parts of the world. In this study we estimated bird abundances in 12 parks of Mexico City during two seasons in 2008. We found 96 songbirds and grouped them according to their urban affinities and migratory status. The number of species increased in relation to park area in the breeding season, but not during the migratory season. Unexpectedly, migratory bird richness increased in relation to distance from natural woodlands. Furthermore, seven winter transient parulines were common in all parks and could therefore be considered as suburban adaptable. On the other hand, species that use urban resources and tolerate the conditions created by human beings in towns and cities were more abundant in parks with a high impervious cover and/or located far from natural areas. In both seasons, the opposite was true for insectivore-frugivorous species, which generally avoid urban areas. The latter group was more abundant in larger parks as well. Widely distributed species tended to be ground insectivore-granivores and many were gregarious. Indicator value analyses selected 22 species in winter and 17 in the breeding season. The distribution of these birds was associated with distance to natural areas and impervious surfaces cover in both seasons, and with the cover of small-leaved trees in the wintering season and the cover of *Fraxinus uhdei* in the breeding season. These results may be useful for future management actions focused on the conservation of songbirds in urban parks. *Accepted 12 September 2013.*

Key words: Bird diversity, urban parks, urbanization, vegetation, Mexico.

INTRODUCTION

Green spaces within cities mitigate the loss of natural habitats and the potential disappearance of species caused by the growth of urban areas (Brawn *et al.* 2001, Fernández-Juricic 2003, Chace & Walsh 2004, Yeoman & MacNally 2005, Clergeau *et al.* 2006, McKinney 2006). Recreational parks and other forested areas within cities also help to counteract the biotic homogenization represented by cosmopolitan species, which thrive in many built-up environments (Fernández-Juricic & Jokimäki 2001, Renjifo 2001, MacGregor-Fors *et al.* 2010). This is partly explained by vegetation cover which provides nesting sites, increases food availability, and offers protection against predators (cats, dogs and rodents) for many bird species (Park & Lee 2000, Sandström *et al.* 2005). Large parks with high foliage height diversity (*sensu* MacArthur & MacArthur 1961) are particularly valuable to support a large number of species (Park & Lee 2000, Ortega-Álvarez & MacGregor-Fors 2010, Zuria 2010, Carbó-Ramírez & Zuria 2011, González-Oreja *et al.* 2012). Moreover, green areas close to natural vegetation can also encourage bird colonization of parks that are more isolated (Savard *et al.* 1999, Hess & Fischer 2001).

In general terms, the degree of urbanization within and around green areas can determine the type of birds found in cities (Blair 1996, Hostetler & Knowles-Yanes 2003). The so-called urban exploiters, capable of using man-made structures and urban resources (Blair 1996), are more abundant in highly urbanized parks. These birds are mainly non-territorial omnivores or insectivore-granivores (Crooks *et al.* 2004, González-Ortega *et al.* 2007, Shwartz *et al.* 2008). Inversely, woodland insectivorous species, which tend to avoid cities, are more common in suburban and better-preserved areas (Clergeau *et al.* 2001, McKinney 2006). Nevertheless, additional information concerning species diversity and distribution, as well as seasonal variations in green areas is necessary to understand urban bird communities and to recommend strategies for their conservation. With this in mind, we analyzed the possible influence of size, distance to the nearest natural location, and cover of impervious surfaces (proportion of paved roads and constructions within each park), as well as of vegetation structure on the diversity and distribution of the birds found in 12 parks in Mexico City during the breeding and non-breeding seasons. The cover of all trees and shrubs in each site was also estimated, and species were grouped according to foliage type. In addition to regression analyses between variables and community parameters, birds were grouped according to habitat specificity and fidelity in order to explore if foraging strategies, sociability (gregarious/solitary), and main food type differed between habitat specialists and generalists. Finally, indicator value analyses were used to determine which birds were associated with particular parks or groups of parks.

Our results were used to test the following hypotheses: 1. Species richness would be higher in large parks, particularly in those closer to natural habitats. 2. Dominance would be higher in parks with a high percentage of impervious surfaces and in those being most distant from natural areas due to the relatively high abundance of a few opportunistic species. 3. Non-territorial omnivores/granivores would be dominant in parks with a high cover of impervious surfaces farther from natural areas. 4. Woodland insectivores would be mainly present in large parks with a high vegetation cover and closer to natural areas.

METHODS

Study area. Mexico City is located between 19°03'–19°36'N and 98°57'–99°22'W at 2240 m a.s.l. Mean temperature fluctuates between 12.5°C (January) and 20°C (August) (Varona-Graniel 2001). Mean annual precipitations vary between 700 and 800 mm (Sanchez *et al.* 1979), and there are two well-defined periods: the rainy season from June to September, and the dry season from October to May.

The metropolitan area of Mexico City is approximately 7854 km^2, with a population of 20,137,152 inhabitants (INEGI 2010). It is one of the largest human concentrations in the world. The city includes 33.1 km^2 of green areas, including parks, gardens, arboreta, ecological reserves, and national parks (Benavides 1992). From these, we selected 12 sites (parks from here on) which included four reserves, one arboretum, one area dedicated to sports, and seven recreational parks: Aragón (Ara), Ciudad Deportiva (Cdd), Cerro de la Estrella (Cer), Primera Sección de Chapultepec (Ch1), Tercera Sección de Chapultepec (Ch3), Parque Hundido (Hun), Jardín Botánico UNAM (Jab), Parque Lira (Lir), Naucalli (Nau), Remedios (Rem), Tezozomoc (Tez), and Viveros de Coyoacán (Viv). The sites differed in area, proximity to natural areas, cover of impervious surfaces, and vegetation structure and composition.

Habitat characterization. We used 60 m in diameter circular plots in which we counted the number of tree species and estimated the following variables: 1) cover of all trees and shrubs, 2) total plant cover, 3) total vegetation density, 4) foliage height diversity, 5) cover of *Cupressus* spp., 6) cover of needle shaped-leaved trees, 7) cover of small-leaved trees, 8) cover of broad-leaved trees. In addition, we measured the distance to the nearest natural forested area, park area, and the proportion of the impervious surfaces cover.

Plant cover was estimated with an optical square or periscope marked with two perpendicular axes (Montaña & Ezcurra 1980). The apparatus has three mirrors arranged so that a person looking horizontally can see the objects found above. In each plot we counted the number of foliage contacts with the point of intersection of the perpendicular lines. This procedure was repeated every meter and a half in two 60 m perpendicular transects (N–S and E–W) within each circular plot. Cover was assessed by the frequency of contacts or presence of vegetation in each point. Foraging preferences of many insectivorous birds strongly depend on vegetation physiognomy (Holmes & Robinson 1981). Therefore, trees were grouped according to their foliage type (small-leaved, broad-leaved, needle-shaped, scale-shaped of cover of *Cupressus* spp.), and the sum of their cover was obtained for each type. The foliage height diversity (*sensu* MacArthur & MacArthur 1961) was estimated with the Shannon-Wiener index using the number of all contacts at 1 m intervals regardless of plant species (Corcuera & Zavala-Hurtado 2006).

The proportion of impervious areas, including roads, pathways, and buildings with respect to the vegetation cover (all permeable surfaces which included tree, shrub, and grass cover), was calculated using digital maps from Google Earth (http://www.google.es/intl/es_es/earth/download/ge/agree. html). We also measured the minimal distance of parks from the nearest natural forested area using the same maps.

Bird surveys. From January to August 2008, we determined the composition of all songbirds seen or heard in the 12 parks. The observations were conducted between sunrise (06:00 h in late spring–early summer, and 07:00 h in winter) and no later than 11:30 h. The length of the visits depended on the number of plots in each park.

We used 8x40 binoculars and the Peterson & Chalif (1998) and Kaufman (2005) guides to identify the bird species in the field. A circular point count protocol (Hutto 1985) with a fixed radius of 30 m was used for the bird counts. This radius has been used to reasonably detect birds in sites with varying vegetation densities (Hutto 1985, Corcuera & Zavala-Hurtado 2006). The number of point counts ranged from 5 to 20, and was based on the size and the accessibility of each park. We calculated the relative abundance by dividing the total number of individuals of each species by the number of plots in each location. All parks were visited four times before the final counts in order to gain familiarity with the bird songs and calls. Final relative abundances were obtained in February to early March 2008, which includes the dry season and migrants are still present (wintering season) and in June 2008, when the rains have already started and birds are breeding (breeding season). All individuals seen or heard within a 10 min period at each point count were recorded. This interval is long enough in order to count most birds present, including rare species, and short enough so that the probability of counting the same bird more than once is minimized (Hutto 1985).

The conservation status was defined according to the list of Mexican threatened species in the NOM-059-SEMARNAT-2010 (SEMARNAT 2010).

Finally, we searched for the main food type (insect/seed, insect/fruit, insects, nectar, broad), foraging strategy (hovering, gleaning, fly-catching), and main foraging substrate (foliage, bark, ground, flower, bark), grouping (solitary, flock) of each species included in the literature (Howell & Webb 1995, Del Olmo Linares & Roldán Velasco 2007, Grosselet & Ruiz 2008), the internet (http://neotropical.birds.cornell.edu/portal/home), and personal observations.

STATISTICAL ANALYSIS

Diversity. Since the sample size was different between parks, we used rarefaction analyses (James & Rathbun 1981, Colwell *et al.* 2004) to compare the number of bird species among sites. We used the first Jackknife and the second Chao order estimators with EstimateS (version 8, Colwell 2006) to assess the comprehensiveness of the bird species survey. These non-parametric species richness estimators have been found to give reasonable approximations at small grain size sample units (Hortal *et al.* 2006, González-Oreja *et al.* 2011). Empirical studies have also shown that they are relatively insensitive to sampling intensity (Colwell & Coddington 1994, Gotelli & Colwell 2001, Brose 2002, Witman *et al.* 2004, Hortal *et al.* 2006, González-Oreja *et al.* 2011). Species dominance was estimated with the Simpson index (Magurran 1988).

Simple linear regressions were used to analyze the relationship between rarefied species richness, relative abundance and dominance, and the independent variables. We previously confirmed that the data complied with the normality and homoscedasticity assumptions with the Number Cruncher Statistical System software (Hinze 2001).

Habitat specificity and fidelity. Bird species were classified according to their habitat breadth (percentage of sites where the species was present) and fidelity or incidence (percentage of plots in sites where the bird species was present) following González-Oreja *et al.* (2007). We selected an unweighted pair group average method (UPGMA) with the Bray-Curtis dissimilarity coefficient (Orlóci 1978) using MVSP (Kovach 1999), and compared the main food type, foraging strategy, substrate, and grouping between the resulting groups (e.g., low specificity vs high specificity and fidelity).

We used indicator value analyses (IndVal) to select species that were associated with one or a combination of two or more parks. A randomization procedure (Dûfrene & Legendre 1997) was used to obtain the value for each species. Specificity was estimated as: $A_{ij} = N\ individuals_{ij} / N\ individual_i$, where $N\ individuals_{ij}$ is the mean number of species *i* on site *j*, and $N\ individual_i$ the sum of the mean numbers of individuals of species *i* over all sites. Fidelity was estimated as follows: $B_{ij} = N\ sites_{ij} / N\ sites_j$, where $N\ sites_{ij}$ is the number of sites in habitat *j* where species *i* is present, and $N\ site_j$ the total number of sites in the habitat. The indicator value for species *i* in the habitat *j* is defined as: IndVal $ij = \text{v}\ (A_{ij} * B_{ij})$. The resulting values have an associated statistical significance and those species with an IndVal value > 70% were regarded as habitat indicators (Van Rensburg *et al.* 1999). The IndVal analyses were performed with the function "multipat" (with this code: func = "Indval.g", duleg = TRUE, nperm = 9999) with the package "indicspecies" (De Cáceres & Legendre 2009) in R 2.14.0 (http://cran.r-project.org/).

The relationship between the indicator species distribution and the independent variables was analyzed with a canonical correspondence analysis (CCA) with MVSP (Kovach 1999). This technique is used to obtain synthetic environmental gradients of groups of ecological data and to detect species distribution patterns that can be explained by a group of environmental variables (Ter Braak & Verdonshot 1995).

RESULTS

Independent variables. We registered 59 tree and shrub species. Non-native species, such as the gum tree or eucalypt (*Eucalyptus* spp.), sheoak (*Casuarina equisetifolia*), Australian silver-oak (*Grevillea robusta*), and Peruvian peppertree (*Schinus molle*) were dominant in most parks. The native vegetation was well represented by the Mexican white cedar (*Cupressus lusitanica*) and the tropical ash (*Fraxinus uhdei*). Park size varied from 11 to 1100 ha. Foliage cover ranged from 12.50 contacts per plot in Cer to 27.62 in Hun. Some parks consisted mainly of green areas (Cer, Ch3, and Rem with 12, 11.4, and 11.8% impermeable surfaces) while others, such as Cdd (52% impermeable surfaces) had a high percentage of paved roads and constructions (Table 1).

Bird species composition and diversity. During the study period, we registered a total of 1742 individuals, representing 96 species and 24 families (Appendix 1). According to the Mexican official standards for threatened species, NOM-059-SEMARNAT-2010 (SEMARNAT 2010), the Brown-backed Solitaire (*Myadestes occidentalis*, Turdidae) is under special protection.

In average, the estimated percentage of species for the wintering season ranged from 76%, according to Jackknife 1, to 81%, as indicated by Chao 2. The values were higher for the breeding season, and ranged from 84% as predicted by Jackknife 1, to 93%, according to Chao 2. Ciudad Deportiva, Viv, Ch1, and Ch3 had the highest rarefied richness in the migratory season (Table 2), and Cer and Rem in the breeding period (Table 3).

In the migratory season, the total bird abundance (R^2 = 0.4024, F_{10} = 8.57, P = 0.015), dominance (R^2 = 0.3441, F_{10} = 5.24, P = 0.045), and the number of migratory individuals (R^2 = 0.3504, F_{10} = 5.39, P = 0.045) showed a negative relationship with distance to natural areas. The same variable had a positive relationship with the abundance of resident species (R^2 = 0.3820, F_{10} = 6.18, P = 0.033) and the migratory rarefied richness (R^2 = 0.6581, F_{10} = 19.25, P = 0.001). The abundance of migratory species presented a positive relationship with total foliage cover (R^2 = 0.5562, F_{10} = 12.53, P = 0.005), and the dominance of the total bird community was positively related to foliage height diversity in the wintering season (R^2 = 0.5957, F_{10} = 14.84, P = 0.003).

During the breeding season, rarefied species richness was higher in larger parks (R^2 = 0.3587, F_{10} = 5.59, P = 0.039) and the proportion of impervious surfaces had a positive relationship with the number of birds (R^2 = 0.5163, F_{10} = 10.67, P = 0.008). We did not find any significant relationships between the bird community characteristics and the trees grouped according to their leaf types.

Indicator species. On first inspection, all species were classified according to their specificity and fidelity (or incidence) percentages. We obtained three clusters for each season. During the migratory season (Fig. 1a), the width of the distribution was 13.5 ± 4.0% for the first cluster and 21.3 ± 11.9% for the second one. Fidelity was higher in the first cluster (37.1 ± 16.2% v 10.9 ± 3.5%). Specificity and incidence in the third group were 73.7 ± 23.4% and 39 ± 15.1% respectively. In the breeding season (Fig. 1b), the first two groups included narrowly distributed species (10.7 ± 5.1% and 13.3 ± 7.5%), but incidence was low in the first group (12.7 ± 4.7%) in comparison with the second one (46.2% ± 15.8%). In the third group, birds were found in a wider range of parks (75.0 ± 23.4%) and had intermediate incidence values in comparison with the other clusters (19.2 ± 7.9).

During the migratory months, the first cluster (narrowly distributed birds) included 50% of foliage frugivores-insectivores (Fig. 1, species codes in Appendix 1). Most of them were gleaners (63%) but 38% used aerial foraging tactics. The second cluster included 86% gleaning species. Most were insectivorous (44%) and foraged in the foliage of trees and shrubs (41%). An additional 26% of the species were frugivore-insectivores. Most species from the third group (widely distributed birds) were ground gleaners (92%) that feed on seeds and insects, and 46% were gregarious.

The first cluster (narrow distribution, low incidence) for the reproductive season included 14 species (Fig. 2). Most of them were frugivore-insectivores (50%), solitary (86%), and foraged in the foliage of trees and shrubs (57%). The second group (narrow

TABLE 1. Number of count points, area size, distance to nearest natural area, percentage of impervious surfaces, number of tree species, total foliage cover, foliage height diversity, cover of *Cupressus* spp., needle shaped-leaved, broad-leaved, and small-leaved trees in twelve parks of Mexico City. Cover is expressed in number of contacts per plot (see text). Ara = Bosques de Aragón, Cdd = Ciudad Deportiva, Cer = Cerro de la Estrella, Ch1 = Primera Sección de Chapultepec, Ch3 = Tercera Sección de Chapultepec, Hun = Parque Hundido, Jab = Jardín Botánico de la UNAM, Lir = Parque Lira, Nau = Naucalli, Rem = Los Remedios, Tez = Tezozomoc, Viv = Viveros de Coyoacán.

Park	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Point count number	10	7	10	18	18	8	6	5	6	7	10	20
Area (ha)	114	150	1100	230	286	15	237	11	43	400	28	40
Distance to natural area (km)	24.0	17.5	10.9	12.3	12.3	11.3	4.6	9.5	3.5	2.6	5.6	10.5
Impervious surfaces (%)	30.0	52.0	12.0	24.7	11.4	30.0	18.5	36.4	29.9	11.8	32.1	40.7
Tree species number	11	20	10	18	15	22	20	15	11	15	27	12
Total foliage cover	13.1	15.1	12.5	18.2	17.7	27.6	19.1	24.0	19.5	24.5	12.7	19.1
Foliage height diversity (H´)	1.6	1.2	1.5	1.49	1.7	1.4	1.4	1.2	1.5	1.7	1.5	1.3
Cypress cover	0.4	0.1	0.5	1.6	0.4	4.7	0.6	3.0	1.5	2.5	0.9	3.2
Needle shaped-leaved cover	1.1	7.0	1.4	0.4	0.3	3.5	5.1	1.0	5.1	0.1	2.1	1.7
Broad-leaved cover	9.4	4.8	7.6	8.9	14.7	18.5	11.3	16.4	12.0	19.7	5.6	22.6
Small-leaved cover	2.0	2.2	3.0	0.7	0.3	0.8	2.0	0.2	0.6	2.1	2.3	1.2

distribution, high incidence) consisted of only five species (Fig. 2). Three were flycatchers: Cassin's Kingbird (*Tyrannus vociferans*), Northern Beardless Tyrannulet (*Camptostoma imberbe*), and Vermilion Flycatcher (*Pyrocephalus rubinus*), one was nectarivore (Cinnamon-bellied Flowerpiercer) and the other an understory insectivore (Carolina Wren, *Thryothorus ludovicianus*). The most-represented species corresponding to the third group (wide distribution) were granivore-insectivores (47%), and most foraged on the ground (65%). Many were gregarious (47%).

According to the indicator value analysis, 22 species in the migratory season and 17 in the breeding season were significantly associated to one park or to a combination of parks. The wintering season included seven species that were indicators of a single park, and six that were widely distributed and indicators of ≥ five parks (low habitat specificity but high fidelity). In the breeding season, there were 17 indicator species. Six species were associated to a single park, and another six had a wide distribution and were indicators of ≥ five parks.

During migration, the first axis of the CCA (Eigenvalue = 0.152) explained 17.36% of the variance and was significantly correlated with impervious surfaces (*Urb*, r = - 0.660, $P < 0.02$) and the cover of small-leaved trees (*Smal*, r = 0.731, $P < 0.01$) (Fig. 3). The second axis (Eigenvalue = 0.103) accounted for a further 11.71% of the variance and was correlated with the cover of small-leaved trees and distance to the nearest natural area (*Dist*) (r = 0.665, $P < 0.02$ and r = 0.775, $P < 0.005$ respectively). Besides the Great-tailed Grackle (qm), House Finch (cm), House Sparrow (pd), Rufous-backed Robin (tr), Bushtit (pmi), and Inca Dove (ci), which tend to be gregarious, solitary foliage insectivorous as Orange-crowned Warbler (*Oreothlypis celata*) (oc), Ruby-crowned Kinglet (rc), and Townsend's Warbler (*Setophaga townsendi*) (st), together with the Vermilion Flycatcher (pr) were associated to parks with high impervious surfaces (*Urb*) that were far from natural areas (*Dist*). Cassin's Kingbird (tv), Baltimore Oriole

TABLE 2. Observed specific richness, rarefied richness, mean abundance, abundance standard deviation (SD), and dominance (Simpson index) of birds found in 12 parks in Mexico City during the wintering season of 2008. The Jackknife1 and Chao2 estimators are also shown.

Parks	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Observed richness	18	15	16	20	18	18	17	14	13	12	9	23
Rarefied richness	8.5	13.1	9.6	11.7	11.0	9.8	10.5	14.0	7.8	7.7	7.6	12.9
Chao2	24.3	16.2	22.3	23.9	20.3	19.8	22.8	16.4	18.8	12.6	9.3	34.4
Chao2 (%)	74	92	71	83	88	90	74	85	69	94	96	66
Jackknife1	24.3	17.6	22.3	26.6	22.7	23.3	23.7	18.8	19.7	14.6	10.8	31.6
Jackknife1 (%)	74	85	71	75	79	77	74	74	66	82	83	72
Mean abundance	24.5	13.1	15.4	10.9	12.0	22.2	23.0	10.4	17.6	24.0	9.5	10.7
Abundance SD	15.2	3.9	10.0	11.0	16.8	10.4	11.7	2.3	9.6	16.5	7.2	10.9
Simpson index	0.20	0.09	0.21	0.15	0.30	0.17	0.33	0.10	0.39	0.46	0.27	0.03

TABLE 3. Observed specific richness, rarefied richness, mean abundance, abundance standard deviation (SD), and dominance (Simpson index) of birds found in 12 parks in Mexico City during the breeding season of 2008. The Jackknife1 and Chao2 estimators are also shown.

Parks	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Observed richness	14	13	23	16	19	13	13	14	11	17	13	16
Rarefied richness	10.9	10.1	16.7	10.1	13.8	10.6	12.4	14.0	9.9	15.5	10.8	11
Chao2	14.2	13.0	28.4	16.1	19.5	13.8	13.8	16.0	11.8	23.0	13.0	16.3
Chao2 (%)	98	100	81	99	97	94	94	88	93	74	100	98
Jackknife1	15.8	13.0	31.1	17.9	21.8	15.6	16.3	18.8	13.5	23.0	13.9	17.9
Jackknife1 (%)	88	100	74	89	87	83	79	74	81	73	93	89
Mean abundance	13.9	24.2	10.3	15.9	8.9	14.0	9.8	10.0	11.8	9.0	14.0	11.2
Abundance SD	7.5	10.6	5.8	19.1	8.2	7.1	3.4	2.6	4.1	2.5	7.7	12.4
Simpson index	0.13	0.16	0.13	0.07	0.18	0.17	0.14	0.11	0.14	0.07	0.13	0.12

(ig), Grey Silky-flycatcher (pc), and American Robin (tm) are solitary frugivore-insectivores and, together with House Wren (*Troglodytes aedon*) (ta) and Lesser Goldfinch (*Spinus psaltria*) (sps), were found in parks nearest to natural areas with a low cover of impervious surfaces and a high cover of small-leaved trees (*Smal*). The distribution of these species was narrow during this season. To a lesser extent, Yellow-rumped Warbler (sc), Bewick's Wren *Thryomanes bewickii* (tb), and Canyon Towhee (pf) were also more abundant in this type of parks.

During the breeding season (Fig. 4), the first axis (Eigenvalue = 0.094) explained 15.59% of the variation and was positively correlated with the cover of impervious surfaces (*Urb*, r = 0.691, $P < 0.02$). The second axis (Eigenvalue = 0.072) explained a further 12% of the variation) and was significantly correlated with the cover of Tropical Ash (*Fra*) (r = 0.898, $P < 0.001$). Great-tailed Grackle, Inca Dove, Vermilion Flycatcher, Rufous-backed Robin, and House Sparrow, together with Curve-billed Trasher (tc) and Northern Beardless Tyrannulet (cai), were again related with parks with a high cover of impervious surfaces. With the exception of the Vermilion Flycatcher all had wide distributions. Three frugivore-insectivores, Scott's

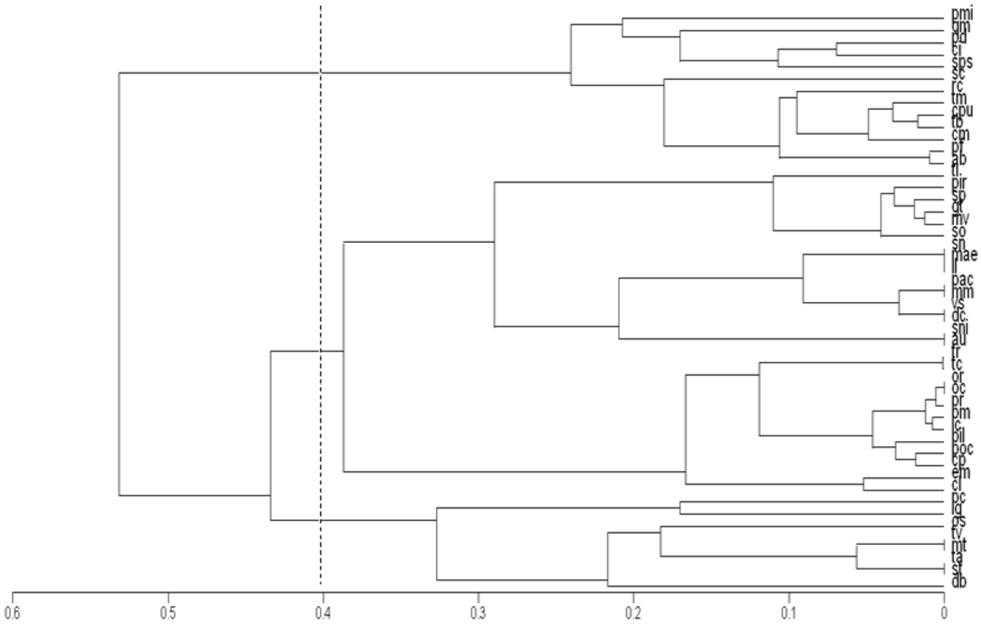

FIG. 1. Classification of the bird species found in 12 parks of Mexico City based on habitat specificity and incidence during the wintering season of 2008. The Bray Curtis distance with the UPGMA clustering method was used. Species codes are in Appendix 1.

Oriole (ip), Cassin's Kingbird, and Black-headed Grosbeak (pm), and two nectarivores, an unidentified species (hum) and Cinnamon-bellied Flowerpiercer (db), were negatively related with cover of impervious surfaces and positively with the cover of tropical ash.

DISCUSSION

The bird species distribution followed a non-random pattern. In general, birds that use man-made structures, also known as urban exploiters, were more common in parks with high cover of impervious surfaces. They were mainly omnivorous or insectivore-granivores, gregarious, and ground gleaners. Migratory foliage insectivores, which generally avoid urban areas, were more abundant in large parks close to natural areas. Nevertheless, some species of this guild were widespread throughout the study sites. Frugivore-insectivores that use an aerial strategy to catch prey were mainly found in the largest parks and/or in parks with low impervious surfaces that were relatively close to natural areas.

We found 96 species of resident and migratory songbirds. The species richness estimators showed that most of them were included in the counts. The number of species was similar to that reported by Varona-Graniel (2001) for seven parks in Mexico City. Species composition, on the other hand, varied considerably between the two studies. Fifty species were present in both reports, while 38 were observed only in the present study. Compositional changes of migratory species are common in urban areas (Husté & Boulinier 2007) and the difference between the species lists of both studies may be due to changes in the habitats used during stopover to the final destination (Griffis-Kyle & Beier 2005).

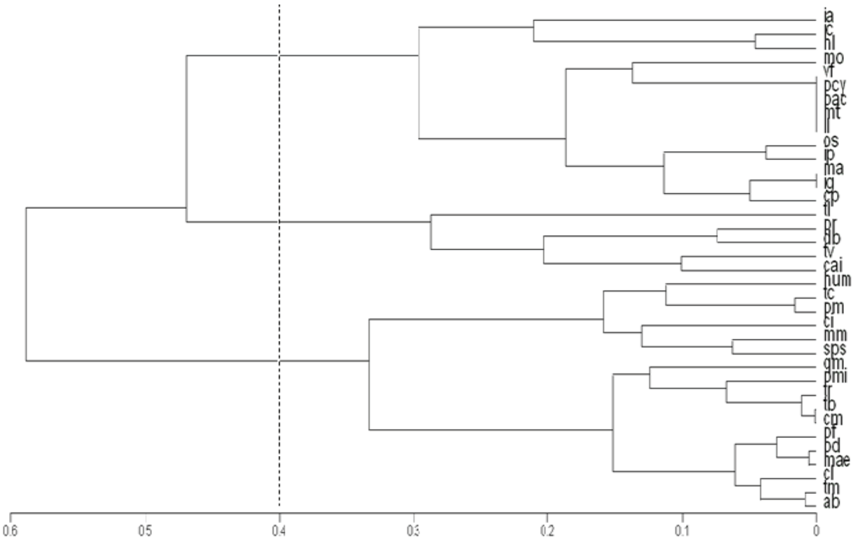

FIG. 2. Classification of the bird species found in 12 parks of Mexico City based on habitat specificity and incidence during the breeding season of 2008. The Bray Curtis distance with the UPGMA clustering method was used. Species codes are in Appendix 1.

As shown in other studies (Fernández-Juricic 2003, Crooks *et al.* 2004, Husté *et al.* 2006, MacGregor-Fors 2008), the regression between rarefied richness and park area was significant in the breeding season, as predicted by the island biogeography theory (MacArthur & Wilson 1967). This partially supports our first hypothesis because the same relationship did not hold for the wintering season. The lack of significance between area and number of migrant species is not unexpected. Askins *et al.* (1992), for example, found more species on the island of St. John than on St. Thomas, despite the former being smaller. This was because St. John had a much higher proportion of forest cover. Furthermore, the theory does not take into account factors, such as edge effect, surrounding matrix nature, and anthropogenic disturbance (Laurance 2008), and this could also explain the lack of a significant relationship between species richness and area for the birds that visit the parks during migration.

We expected to find high numbers of a few urban exploiter species in the parks with the highest cover of impervious surfaces, and furthest from the natural areas. This would be reflected in high dominance values, as predicted by our second hypothesis. During the migratory season we found that the opposite was true. Dominance was higher in parks near natural areas and with a low percentage of paved areas and constructions. This was due to large flocks of Yellow-rumped Warblers and it explains the negative correlation between the number of migratory individuals and distance and impervious surfaces. On the other hand, we observed high numbers of species typically found in urban areas (i.e., Rock Dove, Great-tailed Grackle) in neighborhood squares that were not included in our study. Furthermore, in the breeding season parks far from natural areas supported a higher number of birds. Abundance was also higher in those parks with a high cover of impervious surfaces. The positive relation

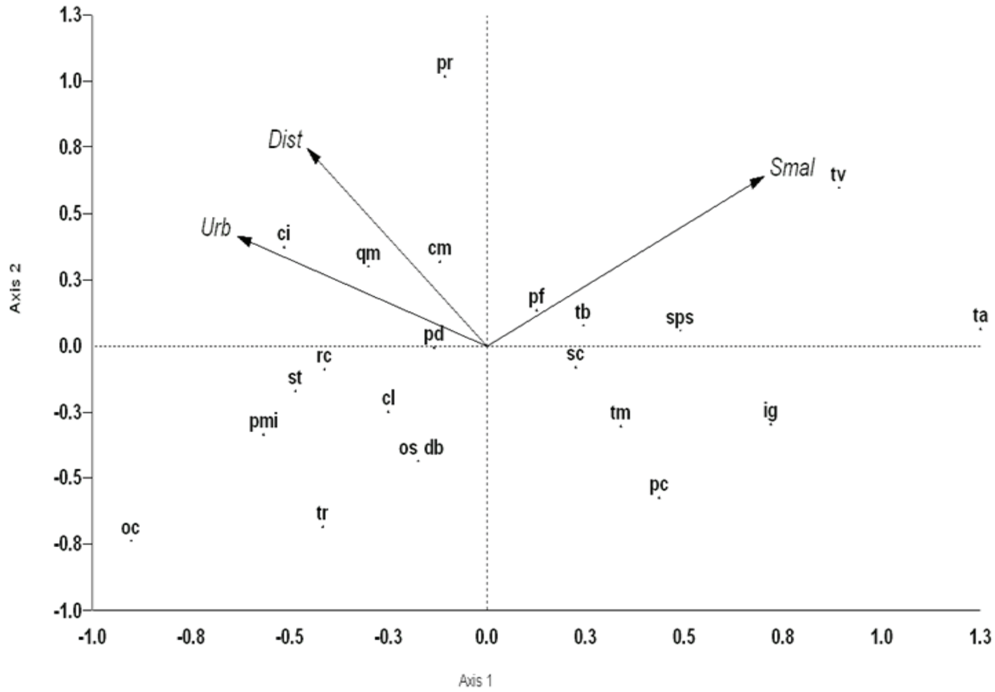

FIG. 3. Distribution of 22 indicator bird species in 12 parks of Mexico City according to a Canonical Correspondence Analysis (wintering season). Distance to the nearest natural area = *Dist*, small-leaved tree cover = *Smal*, impervious cover surfaces = *Urb*. Species codes are in Appendix 1.

between urban residents and urbanization has been reported elsewhere (Jokimäki *et al.* 1996, Ortega-Alvárez & MacGregor-Fors 2009) and it is the result of large populations of gregarious birds adapted to urban conditions. It has also been argued that during stopover, resident birds may be confined to central and highly urbanized areas to avoid competition with migrants which are more abundant in fragments close to woodlands (Rodewald & Brittingham 2002, Crooks *et al.* 2004, Piper & Catterral 2006).

The number of migrants was positively correlated with foliage height diverstiy and total plant cover. These results support additional studies showing that insectivorous migratory species are more abundant in areas with a high plant structural complexity (Holmes *et al.* 1979, Holmes & Robinson 1981, Strong 2000, Corcuera & Zavala-Hurtado 2006, Carbó-Ramírez & Zuria 2011). There is also evidence suggesting that proximate factors, such as branch arrangement and vertical foliage arquitecture, may have a direct influence on species richness, abundance, and dominance (Marzluff & Rodewald 2008, Müller *et al.* 2010).

The positive relationship between distance and migratory species richness was unexpected and could be explained by the presence of relatively large water bodies and/or well irrigated gardens with luxuriant vegetation that are closer to some of the parks located far from natural areas (Ara, Ch1, Lir).

In the incidence/habitat breadth classifications, most species with low habitat specificity were granivorous, ground gleaners, and gregarious in the two seasons, supporting our

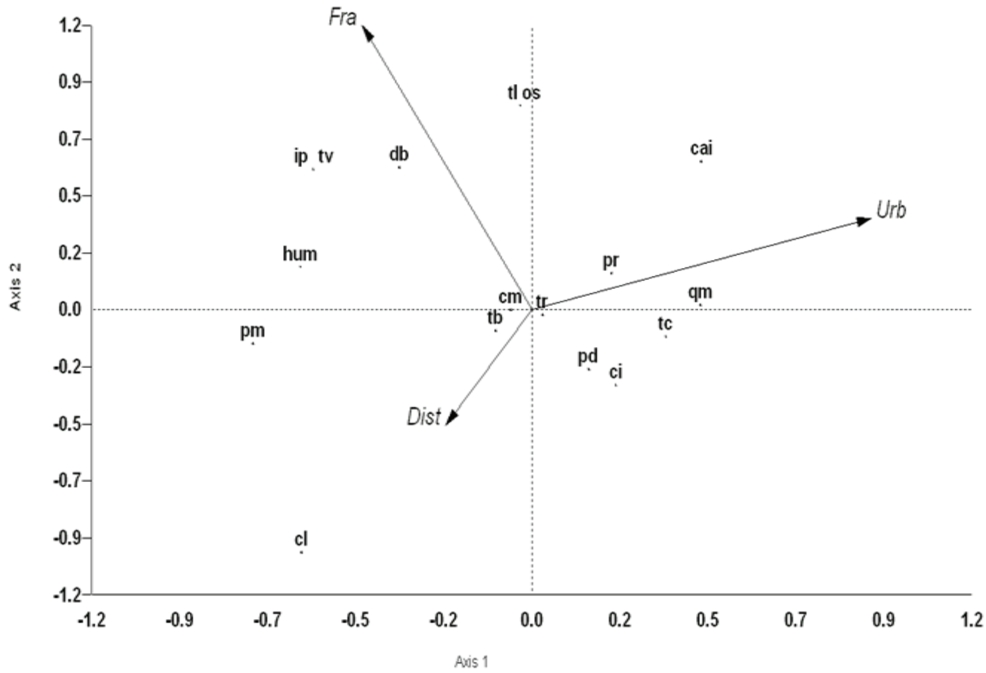

FIG. 4. Distribution of 17 indicator bird species in 12 parks of Mexico City according to a Canonical Correspondence Analysis (breeding season). Distance to the nearest natural area = *Dist*, Tropical Ash cover = *Fra*, impervious cover surfaces = *Urb*. Species codes are in Appendix 1.

third hypothesis. The indicator value analysis showed that generalist birds adapted to cities are typical of parks with the highest cover of impervious cities according with other studies (Mills *et al.* 1989, Blair 1996, González-Oreja *et al.* 2007, Carbó-Ramírez & Zuria 2011). These species include House Sparrow, Great-tailed Grackle, Inca Dove, and Rock Dove. They occur in all large cities in Mexico and illustrate the biotic homogenization tendency worldwide (Clergeau *et al.* 2006, McKinney 2006).

Even though migrant insectivores are usually rare in urban areas (McKinney 2006), the number of transient species responded positively to distance from natural areas in our study.

Moreover, three migrants (Ruby-crowned Kinglet, Townsend's Warbler, and Orange-crowned Warbler) were associated to parks with high impervious cover and far from natural areas, and five more: Yellow-rumped Warbler, Nashville Warbler (*Oreothlypis ruficapilla*), Wilson's Warbler, Blue-gray Gnatcatcher, and Least Flycatcher (*Empidonax minimus*) were abundant in all parks. González-Oreja (2011) also found an unexpected high number of Nearctic warbler species in urban sites throughout Mexico. This suggests that some of these birds may have the flexibility to exploit urban environments to a certain degree (González-Oreja 2011) and could be included in the suburban adapter category according to the classification used by Blair (1996). However, there is little information about habitat selection and foraging behavior of these parulines in urban areas, and further study is necessary to understand their habitat preferences in urban areas.

Specialist birds usually have higher abundances and richness in larger parks (Blair 1996, Rodewald & Brittingham 2002, Crooks *et al.* 2004, González-Oreja *et al.* 2007, MacGregor-Fors 2008), and our last hypothesis predicted that these species would be foliage-foraging solitary territorial birds. Even though species richness was correlated with area in the breeding season, park size was not significantly correlated with any of the main axes in the bird species ordination. On the other hand, we found that insectivores that include fruit as an important part of their diet during part of the year were negatively correlated with impervious surfaces. These included Western Kingbird in both seasons, Baltimore Oriole, Grey Silky-flycatcher, and American Robin in the wintering season, and Scott's Oriole and Black-Headed Grosbeak in the breeding season. The Cinnamon-bellied Flowerpiercer in the reproductive season and the House Wren during migration responded in the same way to this variable. It has been suggested that, for some species, shrub cover and vegetation physiognomy are more important than tree species composition (Park & Lee 2000, Carbó-Ramírez & Zuria 2011), and this may explain the presence in these parks of at least some of these birds (i.e., Carolina Wren, Northern Beardless Tyrannulet).

Our study confirmed what other studies have demonstrated regarding the ubiquitous presence of urban exploiters within city parks. On the other hand, some migrant foliage insectivores were present in all sites or were associated with urbanized parks, and this suggests that many species, at least during stopover, are more flexible in their habitat requirements than expected and/or that urban parks represent adequate habitats for a wide variety of birds. However, in both seasons a group of birds had a narrow distribution and were associated to the largest parks. These were mainly territorial fly-catching frugivore-insectivores, which may be more susceptible to the fragmentation of their habitats.

In addition to presenting recent information on the composition and diversity of birds in parks of Mexico City, our results could be incorporated into conservation and wildlife management plans in urban areas in other large cities elsewhere.

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APPENDIX 1. Bird species found in 12 parks within Mexico City, including the two seasons censes. The codes used in multivariate analyses are also shown.

Species	Code	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Aegithalidae													
Psaltriparus minimus	*pmi*	o	o	o	o	o	o	o	o	o	o	o	o
Bombycillidae													
Bombycilla cedrorum	*bc*	o				o		o	o			o	
Cardinalidae													
Cardinalis cardinalis	*cc*							o	o			o	
Passerina caerulea	*pcy*			o									
Passerina cyanaea	*pac*			o									
Pheucticus melanocephalus	*pm*			o	o	o	o	o			o	o	o
Corvidae													
Aphelocoma ultramarina	*au*							o					o
Cyanocorax yncas	*cy*				o			o					o
Columbidae													
Columbia livia	*cl*			o	o		o		o	o		o	o
Columbina inca	*ci*	o	o	o	o	o	o	o	o	o	o	o	o
Zenaida macroura	*zm*			o									
Emberizidae													
Aimophila ruficeps	*ar*					o							
Atlapetes pileatus	*ap*					o							
Diglossa baritula	*db*				o	o	o	o	o				o
Melospiza georgiana	*mg*												o
Melospiza lincolni	*ml*					o							
Melospiza melodia	*mm*				o	o	o	o			o		o
Oriturus superciliosus	*os*					o					o		
Pipilo fuscus	*pf*	o	o	o	o		o	o	o	o	o	o	o
Spizella passerina	*sp*		o	o		o		o					o
Spizella pusilla	*spu*							o					
Fringillidae													
Carpodacus mexicanus	*cm*	o	o	o	o	o	o	o		o	o	o	o
Spinus psaltria	*sps*	o	o	o	o	o	o	o		o	o	o	o

APPENDIX 1. Continuation.

Family/species	Code	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Icteridae													
Euphagus cyanocephalus	*ec*		o					o				o	
Icterus abeillei	*ia*							o			o		o
Icterus bullockii	*ib*						o	o					o
Icterus cucullatus	*ic*					o		o	o	o		o	o
Icterus galbula	*ig*					o		o			o		
Icterus parisorum	*ip*			o				o					
Molothrus aeneus	*mae*	o	o	o	o	o	o	o	o	o	o	o	o
Molothrus ater	*ma*	o	o		o						o		o
Quiscalus mexicanus	*qm*	o	o	o	o	o	o	o	o	o	o	o	o
Laniidae													
Lanius ludovicianus	*ll*	o	o	o							o		
Mimidae													
Dumetella carolinenis	*duc*					o							
Toxostoma curvirostre	*tc*	o	o	o	o		o	o	o	o	o	o	o
Toxostoma longirostre	*tol*												o
Melanotis caerulescens	*mc*					o							
Paridae													
Poecile sclateri	*pos*												o
Parulidae													
Basileuterus rufifrons	*br*					o							
Cardellina pusilla	*cpu*	o	o	o	o	o	o	o	o	o	o	o	o
Geothlypis nelsoni	*gn*				o			o					
Geothlypis tolmiei	*gt*				o	o	o	o	o				o
Icteria virens	*iv*		o										
Mniotilta varia	*mv*				o		o		o	o		o	o
Myioborus miniatus	*mym*			o	o	o	o	o			o		
Myioborus pictus	*myp*					o							
Oreothlypis celata	*oc*	o	o	o	o	o	o	o	o	o	o	o	o
Oreothlypis ruficapilla	*or*	o	o	o	o	o	o	o	o	o	o	o	o
Peucedramus taeniatus	*pt*										o		
Seiurus noveboracensis	*sn*										o		
Setophaga coronata	*sc*	o	o	o	o	o	o	o	o	o	o	o	o
Setophaga magnolia	*sm*						o						
Setophaga nigrescens	*sni*	o			o		o		o			o	o
Setophaga occidentalis	*so*				o	o	o	o	o				o
Setophaga petechia	*sep*				o	o	o					o	o
Setophaga townsendi	*st*				o	o	o	o	o			o	o
Setophaga virens	*svi*												o
Passeridae													
Passer domesticus	*pd*	o	o	o	o	o	o	o	o	o	o	o	o
Picidae													
Colaptes auratus	*ca*				o								
Picoides scalaris	*ps*		o		o	o		o		o	o	o	o
Sphyrapicus varius	*sv*		o	o	o			o			o	o	

APPENDIX 1. Continuation.

Family/species	Code	Ara	Cdd	Cer	Ch1	Ch3	Hun	Jab	Lir	Nau	Rem	Tez	Viv
Ptiligonatidae													
Ptilogonys cinereus	*pc*	o	o	o	o	o	o	o	o		o		o
Regulidae													
Regulus calendula	*rc*	o	o	o	o	o	o	o	o	o	o	o	o
Sturnidae													
Sturnus vulgaris	*svu*	o											
Sylviidae													
Polioptila caerulea	*poc*	o	o	o	o	o	o	o	o	o	o	o	o
Thraupidae													
Piranga ludoviciana	*pl*	o			o	o	o	o		o		o	o
Piranga olivacea	*po*				o	o		o			o		
Piranga rubra	*pir*		o	o	o	o	o	o	o		o	o	o
Trochilidae													
Amazilia beryllina	*ab*	o	o	o	o	o	o	o	o	o	o	o	o
Cynanthus latirostris	*cil*		o	o	o		o	o					o
Hylocharis leucotis	*hl*	o		o		o		o			o	o	o
Troglodytidae													
Catherpes mexicanus	*cam*					o							
Thryomanes bewickii	*tb*	o	o	o	o	o	o	o	o	o	o	o	o
Troglodytes aedon	*ta*			o	o	o		o	o		o		
Thryothorus ludovicianus	*tl*			o		o		o			o		
Turdidae													
Catharus guttatus	*cg*				o	o		o		o			
Myadestes occidentalis	*mo*			o	o	o			o				
Turdus migratorius	*tm*	o	o	o	o	o	o	o	o	o	o	o	
Turdus rufopalliatus	*tr*	o	o	o	o	o	o	o	o	o	o		o
Tyrannidae													
Camptostoma imberbe	*cai*					o							o
Contopus cooperi	*cc*	o											
Contopus pertinax	*cp*	o	o		o	o	o						o
Contopus sordidulus	*cs*						o					o	
Empidonax flaviventris	*ef*	o		o	o	o		o					o
Empidonax minimus	*em*	o	o	o	o	o	o	o	o	o	o	o	o
Mitrephanes phaeocercus	*mp*			o		o		o			o		
Myiarchus tuberculifer	*mt*			o					o				
Pyrocephalus rubinus	*pr*	o	o	o	o	o	o	o		o	o	o	o
Sayornis saya	*ss*		o					o					
Tyrannus vociferans	*tv*	o	o	o	o			o	o	o		o	o
Tyrannus tyrannus	*tt*					o							
Vireonidae													
Vireo cassini	*vic*				o								
Vireo flavifrons	*vf*							o					
Vireo gilvus	*vg*					o	o	o	o				o
Vireo huttoni	*vh*				o	o			o			o	o
Vireo solitarius	*vs*				o	o	o		o		o	o	o