



## Avian spatial segregation at edges and interiors of urban parks in Madrid, Spain

ESTEBAN FERNÁNDEZ-JURICIC

*Depto de Biología Animal I, Facultad de Biología, Universidad Complutense de Madrid, Madrid E-28040, Spain; Present address: Department of Zoology, University of Oxford, South Parks Road, Oxford, OX1 3PS, UK (e-mail: estebanfj@yahoo.com)*

Received 15 February 2000; accepted in revised form 25 September 2000

**Abstract.** Few studies have investigated the effects of urban landscape composition on avian habitat selection at urban-park edges. I assessed how the number of species, density of guilds, and density of individual species varied between edge and interior habitats in six large wooded parks in Madrid (Spain), and analysed such patterns in relation to habitat structure, car traffic, and pedestrian traffic. Few differences in habitat structure were found; whereas car and pedestrian traffic were significantly higher at edges. Species foraging in trees and on the ground, and nesting in trees and in tree cavities had lower numbers and breeding densities at edges, probably as a result of the disturbance from traffic noise and pedestrians. Species highly habituated to human activities (House Sparrows *Passer domesticus* and Rock Doves *Columba livia*) displayed opposite patterns, with higher breeding densities at urban-park edges, probably due to their higher foraging opportunities (refuse, people leftovers, deliberate feeding) and nest site availability in adjacent buildings. Urbanisation sprawl may increase the prevalence of edge specialists and diminish the representation of species with specific habitat requirements.

**Key words:** birds, edge effects, landscape composition, urban landscape

### Introduction

Fragmentation increases the proportion of edge-influenced area in remnant forest patches (Saunders et al. 1991; Faaborg et al. 1995). Landscape composition can greatly affect the occurrence and interaction of species at forest edges (Andrén 1995; Murcia 1995; McCollin 1998; Fagan et al. 1999). For instance, the strength of edge effects on the occurrence and nesting success of forest species is higher at agricultural edges than at edges of regenerating forest patches (Hawrot and Niemi 1996; Darveau et al. 1997; Hartley and Hunter 1998). Therefore, the composition of the landscape matrix can modify the degree of fragmentation effects, probably by increasing or limiting the availability of foraging and/or nesting resources (Andrén 1995). Most of the observational and experimental studies on edge effects have been conducted in fragments surrounded by agricultural or suburban matrices (McCollin 1998; Debinski and Hold 2000). However, comparatively little is known about the effects of the urban matrix on the pattern of avian habitat selection in forest fragments. This is particularly relevant due to the increasing urbanisation sprawl of the last decades (World

Resources Institute 1996) that increased fragments of native vegetation surrounded by a build environment.

This study evaluated the effects of urban landscape composition on avian spatial segregation at urban-park edges. I determined how the number of species, the density of guilds (species with similar nesting and feeding requirements), and the density of individual species varied between edge and interior areas of large wooded parks in Madrid (Spain), and analysed such patterns in relation to habitat structure, car traffic, and pedestrian traffic. Habitat structure is expected to modify habitat selection patterns at edges due to the different availability of nesting and foraging substrates (Fuller and Whittington 1987). Car traffic would negatively affect breeding bird species at edges of urban parks due to high noise levels (Reijnen et al. 1997). Pedestrians would affect species distributions differently according to the degree of species tolerance. Low-tolerant species would restrict their foraging opportunities because of the presence of people (Fernández-Juricic and Tellería 2000; Fernández-Juricic 2000a); whereas those species highly habituated to human activities (House Sparrows *Passer domesticus*, and Rock Doves *Columba livia*) would be highly associated with pedestrians because people can become a source of food (e.g., human leftovers, deliberate feeding) (Erz 1966).

## Methods

### *Study area*

The study was carried out in Madrid, Spain, from May to July 1998 and 1999. Madrid has an extensive network of urban parks, from which I sampled six: Retiro (118 ha), Oeste (98 ha), Austria (29 ha), Moro (19 ha), Ciudad Universitaria (16 ha), and Fuente del Berro (15 ha). All parks were representative of the urban parks of this city, with areas of watered grass, shrub cover, and a mix of deciduous and coniferous trees. Shrubs included both introduced and native plants, such as: *Ligustrum* sp., *Buxus* sp., *Viburnum* sp., *Rubus* sp., etc. The most common deciduous trees were *Populus* sp., *Platanus hybrida*, *Ulmus campestris*, and *Acer negundo*; whereas coniferous trees consisted mainly of *Cedrus* sp., *Pinus* sp., and *Abies alba*. An schematic representation of the vegetation structure in the sampled parks is presented in Figure 1. Urban parks in Madrid can be considered forest fragments imbedded in an urban matrix, connected by wooded streets or corridors (Fernández-Juricic 2000b). Bird species in urban parks are affected by similar factors (area, isolation, habitat structure, etc.) to other fragmented landscapes (Fernández-Juricic 2000a, c).

### *Bird surveys*

I conducted a preliminary study in 1997 to establish the minimum number of visits required to sample most bird species at edges and interiors of urban parks. I carried



*Figure 1.* Schematic representation of the habitat structure in the six parks studied in the city of Madrid, Spain. Drawn by Gabriela Sincich.

out eight weekly surveys in five parks (Retiro, Oeste, Austria, Moro, Fuente del Berro) to record species richness. With cumulative curves, I concluded that 3–4 visits would be enough to detect bird diversity with 95 and 97% confidence, respectively. Each park was then sampled four times per year from 07:00 to 11:00 in order to determine species richness and the density of individual species. The number of individuals seen and vocalising within 100-m long and 50-m wide fixed transects were recorded while moving at a steady speed (Järvinen and Väisänen 1975; Seber 1982). All surveys were conducted during sunny or partly cloudy conditions, but never when raining. Transects were separated by 50 m so that each was an independent sample unit, as demonstrated by spatial autocorrelation analyses (Hanowski et al. 1993). Each transect (0.5 ha) was located on a map, and the number of individuals of each species within 0.5 ha was later used to calculate breeding densities after averaging the number of birds in each transect across the

four visits. To reduce the confounding effects of fragment size (Brawn and Robinson 1996) and distance to edge (Paton 1994), I considered the edge to be the 50-m-wide belt that constituted the wooded border of an urban park (Kroodsma 1982). Interior areas were considered those sectors within a park located at least 70 m from the border. An equal number of transects were conducted at edge and interior areas in each park, totalling 28 transects in the Retiro park, 26 in the Oeste park, 22 in the Austria park, 16 in the Moro park, 12 in the Ciudad Universitaria park, and 10 in the Fuente del Berro park. Four transects in the Retiro park were visited only three times in both years due to restricted public access. The number of transects varied among parks because of differences in park size, and because sampling efforts were focussed only on those edges surrounded by sidewalks and streets in order to evaluate in all fragments the effects of pedestrians and car traffic. Final parameters for each park and edge/interior areas included the mean number of species per transect, and the mean density of species (individuals/0.5 ha) per transect. Species were classified in guilds (see below), and guild density was the sum of the mean densities of individual species. Data for the 1999 breeding season is presented as a replicate to corroborate the results obtained in 1998.

Species were assigned to different categories based upon their food and nesting requirements (Table 1, Fernández-Juricic 2000a, b), as described by Cramp (1992) and Tellería et al. (1999). This classification was used successfully to assess habitat selection in parks and wooded streets in Madrid (Fernández-Juricic 2000b), and was preferred over others that take into account edge and interior forest requirements (McCollin 1998) because many urban species have conflicting classification criteria. Food substrates were classified in two categories: ground and tree. Nest substrates included those constructed in tree cavities and open nests in trees. By combining these categories, I created 4 groups (the first word indicating food and the second, nesting substrates) that can be regarded as guilds because they share similar habitat requirements during the breeding season: ground/tree, ground/cavity, tree/tree, and tree/cavity (Table 1). I considered House Sparrows and Rock Doves in a separate guild (HS-RD), due to their ability to exploit different sources of food in urban settings, and to nest in trees as well as in buildings (Rolando et al. 1997). Another six species were recorded in urban parks belonging to four different groups (ground/rock, *Motacilla alba*; tree/ground, *Phylloscopus bonelli*; ground/ground, *Galerida cristata* and *Erithacus rubecula*; bush/bush, *Troglodytes troglodytes* and *Sylvia melanocephala*). These species were found at interiors, but were not analysed because of low sample size for comparisons between edges and interiors.

At the individual species level, I included only those species that were recorded in all parks, to find out whether their mean densities varied between edge and interiors within each park. The species studied were: House Sparrow, Rock Dove, Blackbird, Magpie, Serin, Woodpigeon, Green Woodpecker, Starling, Stock Dove, and Coal Tit.

Table 1. Classification of species into four guilds. Shown are the common and scientific names of the species, and their habitat requirements as a combination of two letters, the first indicating the feeding and the second, the nesting substrates. Feeding substrates: ground (G), tree (T); nesting substrates: tree cavity (C), open tree (T). (Urban) indicates species highly habituated to human activities in cities.

Common name	Genus and species	Habitat requirements
House Sparrow	<i>Passer domesticus</i>	Urban
Rock Dove	<i>Columba livia</i>	Urban
Blackbird	<i>Turdus merula</i>	GT
Goldfinch	<i>Carduelis carduelis</i>	GT
Greenfinch	<i>Carduelis chloris</i>	GT
Hawfinch	<i>Coccothraustes coccothraustes</i>	GT
Magpie	<i>Pica pica</i>	GT
Serín	<i>Serinus serinus</i>	GT
Song Thrush	<i>Turdus philomelos</i>	GT
Woodpigeon	<i>Columba palumbus</i>	GT
Ring-necked Parakeet	<i>Psittacula krameri</i>	GT
Green Woodpecker	<i>Picus viridis</i>	GC
Hoopoe	<i>Upupa epops</i>	GC
Starling	<i>Sturnus vulgaris</i>	GC
Stock Dove	<i>Columba oenas</i>	GC
Tree Sparrow	<i>Passer montanus</i>	GC
Crossbill	<i>Loxia curvirostra</i>	TT
Blackcap	<i>Sylvia atricapilla</i>	TT
Long-tailed Tit	<i>Aegithalos caudatus</i>	TT
Monk Parakeet	<i>Myopsitta monachus</i>	TT
Blue Tit	<i>Parus caeruleus</i>	TC
Coal Tit	<i>Parus ater</i>	TC
Great Spotted Woodpecker	<i>Dendrocopus major</i>	TC
Great Tit	<i>Parus major</i>	TC
Treecreeper	<i>Certhia brachydactyla</i>	TC

### Habitat structure

Vegetation structure included several measures of vegetation cover (grass, shrub, and forest), number of shrub and tree species, and number of stems <10, 10–50, and >50 cm diameter at breast height (D.B.H.). Cover and height variables were visually estimated following Prodon and Lebreton (1981). Measures were taken in 25-m circular plots uniformly located at 50-m intervals in edge and interior areas to include most of the areas in which bird surveys were conducted (see also Tellería and Santos 1995). I took the same number of samples in edge and interior areas for comparison, totalling 20 samples for the Retiro park, 26 for the Oeste park, 14 for the Austria park, and 16 for each in Moro, Ciudad Universitaria, and Fuente del Berro.

### Car and pedestrian traffic

I measured car traffic and pedestrian traffic in edge and interior areas in 1998, following Fernández-Juricic (2000a). Within each bird survey transect (0.5 ha), the

number of pedestrians observed walking and sitting in 3-min periods were recorded at 08:00–09:00 and 13:00–14:00. In regard to car traffic, I sampled the number of cars in motion in 3-min periods in 1.5 ha, which encompassed the bird survey transect (0.5 ha) as well as the 0.5 ha sectors immediately adjacent to it (in the case of edge transects, one of this adjacent sectors corresponded to a street or avenue). Sampling of car and people traffic was repeated three times at each park, separated by 20-day intervals, with final values converted into rates of pedestrians and cars/min 0.5 ha. The number of cars/min can be considered a good estimator of traffic load and noise levels (Reijnen et al. 1997).

#### *Statistical analysis*

The sampling design was aimed at testing whether car traffic, pedestrian traffic, species richness, guild density, and individual species density varied between edge and interior areas within each of the six parks. To analyse such design, I used a nested ANOVA with two factors (edge/interior and parks), in which edge/interior was nested within parks. McKone and Lively (1993) suggest that nested designs are more suitable to analyse the effects of fixed factors (e.g., edge/interior) within different sites, especially when the number of sites is limited, as in this case. To allow generalisation to other urban parks with similar habitat structure and community composition, park was considered a random factor (Underwood 1997). I only reported the results pertaining location effects (edge/interior) in relation to individual species density. When significant differences in car or pedestrian traffic were found, I conducted a Tukey's *post-hoc* test for unequal sample size to determine which parks had higher disturbance. I performed *t*-tests for independent samples to analyse vegetation variations between edge and interior areas in each park. Each vegetation trait was compared separately to determine subtle differences in habitat structure that may have been hidden with procedures that resumed the information of several variables (e.g., principal component analysis).

I checked for normality and homogeneity of variances in the data by means of a Shapiro-Wilk test and a Cochran *C*-test, respectively. To circumvent the effect of increasing the probability of Type I error due to the high number of probability estimations, a Bonferroni sequential correction was performed (Rice 1989). However, applying the same correction to a high number of tests (in this case, 127) will lose power in the individual tests. To overcome this problem, I conducted Bonferroni corrections for group of tests according to the five dependent factors being tested (Chandler 1995). The number of *P* estimates, which included effects of different years, and the corrected *P*-levels are as follows: habitat structure (66 estimates,  $P = 0.0008$ ), car traffic and pedestrian loads (19 estimates,  $P = 0.007$ ), species richness (4 estimates,  $P = 0.035$ ), guild density (20 estimates,  $P = 0.014$ ), and species density (18 estimates,  $P = 0.0096$ ).

## Results

### *Habitat structure*

Few differences in habitat structure were found between edge and interior areas in the six parks studied. Of 66 vegetation structure comparisons (11 per park), 64 were non-significant (Retiro,  $t$  ranged from  $-1.76$  to  $2.41$ ,  $df = 18$ ; Oeste,  $t$  ranged from  $-2.44$  to  $2.89$ ,  $df = 24$ ; Austria,  $t$  ranged from  $-2.29$  to  $2.99$ ,  $df = 12$ ; Moro,  $t$  ranged from  $-0.89$  to  $1.14$ ,  $df = 14$ ; Berro,  $t$  ranged from  $-2.31$  to  $4.3$ ,  $df = 14$ ; Ciudad Universitaria,  $t$  ranged from  $-2.28$  to  $2.3$ ,  $df = 14$ ), and only two yielded significant results. Bare ground cover was significantly higher in edge than in interior areas in both the Oeste (mean % cover, edge =  $43.7 \pm 20.7$ , interior =  $7.8 \pm 5.4$ ,  $t = -6.44$ ,  $df = 24$ ,  $P < 0.0008$ ) and Fuente del Berro parks (mean % cover, edge =  $66.3 \pm 15.1$ , interior =  $24.7 \pm 9.5$ ,  $t = -6.27$ ,  $df = 14$ ,  $P < 0.0008$ ).

### *Car and pedestrian traffic*

Car traffic was significantly higher in edge than in interior areas within each of the six parks ( $F_{6,102} = 36.62$ ,  $P < 0.007$ , Table 2). Moreover, car traffic differed significantly among parks ( $F_{5,102} = 6.24$ ,  $P < 0.007$ , Table 2). The only significant differences were between Austria ( $71.6-18.9$ ) and Ciudad Universitaria ( $30.4-10.3$ ) parks (Tukey's test,  $P < 0.007$ ), and between Austria ( $71.6-18.9$ ) and Oeste ( $25.1-9.5$ ) parks (Tukey's test,  $P < 0.007$ ); in both cases Austria park had higher traffic loads. Pedestrian traffic was also significantly higher at edges within each park ( $F_{6,105} = 5.69$ ,  $P < 0.007$ , Table 2); whereas no differences were found among parks ( $F_{5,102} = 1.69$ ,  $P = 0.14$ , Table 2).

### *Species composition*

In 1998, 4 species were found at edges in all parks: House Sparrows, Rock Doves, Starlings, and Blackbirds; whereas in 1999, 6 species were found: House Sparrows,

Table 2. Mean ( $\pm$ SE) car (cars/min) and pedestrian traffic (people/min) in edge and interior areas in six urban parks of Madrid during 1998.

Park	Edge		Interior	
	Car traffic	Pedestrian traffic	Car traffic	Pedestrian traffic
Retiro	97.50 $\pm$ 9.65	2.54 $\pm$ 0.63	0.08 $\pm$ 0.06	0.70 $\pm$ 0.12
Oeste	52.32 $\pm$ 16.81	3.04 $\pm$ 1.21	0.003 $\pm$ 0.002	0.41 $\pm$ 0.12
Austria	143.18 $\pm$ 21.41	1.34 $\pm$ 0.3	0.05 $\pm$ 0.03	0.66 $\pm$ 0.12
Moro	80.83 $\pm$ 8.05	1.18 $\pm$ 0.2	0.03 $\pm$ 0.03	0.16 $\pm$ 0.8
Fberro	154 $\pm$ 26.6	1.47 $\pm$ 0.21	0.009 $\pm$ 0.008	0.37 $\pm$ 0.06
C. Univ.	54.42 $\pm$ 15.84	1.50 $\pm$ 0.34	0.005 $\pm$ 0.004	0.58 $\pm$ 0.15

Rock Doves, Starlings, Blackbirds, Woodpigeons, and Magpies. However, 13 and 14 species in 1998 and 1999, respectively, were occasionally recorded at edges in different parks. All these species were not just at edges as they were also recorded in interior areas. In 1998, 7 species were found in interior areas in all parks (House Sparrow, Blackbird, Magpie, Serin, Woodpigeon, Green Woodpecker, and Treecreeper); whereas in 1999, 8 species were recorded (House Sparrow, Blackbird, Magpie, Woodpigeon, Starling, Long-tailed Tit, Blue Tit, Coal Tit).

### *Species richness*

In 1998 and 1999, mean species richness was lower in edge than in interior areas within each park (1998,  $F_{6,102} = 24.43$ ,  $P < 0.035$ ; 1999,  $F_{6,102} = 12.45$ ,  $P < 0.035$ , Table 3). I also encountered a park effect, probably associated with the high number of

Table 3. Mean avian species richness ( $\pm$ SE) and guild densities ( $\pm$ SE) in edge (E) and interior (I) areas in six urban parks of Madrid during 1998 and 1999 breeding seasons. Guilds: HS–RD, House Sparrows and Rock Doves; GT, species forage on the ground and nest in trees; GC, species forage on the ground and nest in tree cavities; TT, species forage and nest in trees; TC, species forage in trees and nest in tree cavities.

Park	E/I	Species	HS–RD	GT	GC	TT	TC
		richness					
1998							
Retiro	E	3.64 $\pm$ 0.19	27.55 $\pm$ 5.11	2.64 $\pm$ 0.57	0.43 $\pm$ 0.29	0.00	0.07 $\pm$ 0.07
Retiro	I	6.07 $\pm$ 0.37	5.93 $\pm$ 0.95	9.36 $\pm$ 0.89	3.00 $\pm$ 0.77	0.14 $\pm$ 0.14	0.64 $\pm$ 0.25
Oeste	E	4.08 $\pm$ 0.43	10.58 $\pm$ 2.03	3.42 $\pm$ 0.54	0.75 $\pm$ 0.28	0.00	0.25 $\pm$ 0.17
Oeste	I	8.63 $\pm$ 0.46	2.23 $\pm$ 0.45	10.15 $\pm$ 0.99	5.00 $\pm$ 1.09	0.62 $\pm$ 0.24	1.38 $\pm$ 0.38
Fuente B.	E	4.00 $\pm$ 0.38	9.43 $\pm$ 2.51	3.29 $\pm$ 0.78	0.14 $\pm$ 0.14	0.14 $\pm$ 0.14	0.14 $\pm$ 0.14
Fuente B.	I	8.00 $\pm$ 0.87	4.86 $\pm$ 1.06	7.86 $\pm$ 1.78	2.71 $\pm$ 1.06	0.71 $\pm$ 0.28	0.86 $\pm$ 0.45
Austria	E	2.91 $\pm$ 0.31	7.00 $\pm$ 1.83	3.55 $\pm$ 0.47	0.09 $\pm$ 0.09	0.00	0.00
Austria	I	6.27 $\pm$ 0.47	2.27 $\pm$ 0.64	8.27 $\pm$ 0.54	1.09 $\pm$ 0.39	0.18 $\pm$ 0.18	0.91 $\pm$ 0.43
Moro	E	4.00 $\pm$ 1.05	9.20 $\pm$ 3.72	4.00 $\pm$ 2.02	1.40 $\pm$ 0.6	0.00	1.20 $\pm$ 0.37
Moro	I	7.82 $\pm$ 0.58	1.45 $\pm$ 0.36	8.27 $\pm$ 0.86	2.00 $\pm$ 0.52	1.36 $\pm$ 0.67	1.36 $\pm$ 0.36
C. Univ.	E	4.00 $\pm$ 0.5	15.88 $\pm$ 3.86	3.75 $\pm$ 1.01	1.50 $\pm$ 0.8	0.00	0.25 $\pm$ 0.16
C. Univ.	I	6.20 $\pm$ 0.58	3.00 $\pm$ 2.00	11.00 $\pm$ 1.22	1.00 $\pm$ 0.45	0.00	1.00 $\pm$ 0.63
1999							
Retiro	E	3.92 $\pm$ 0.19	25.93 $\pm$ 7.83	2.86 $\pm$ 0.71	1.07 $\pm$ 0.34	0.00	0.00
Retiro	I	6.67 $\pm$ 0.25	6.13 $\pm$ 0.84	7.88 $\pm$ 0.68	4.25 $\pm$ 0.72	0.13 $\pm$ 0.09	1.21 $\pm$ 0.37
Oeste	E	4.56 $\pm$ 0.24	10.33 $\pm$ 2.5	2.78 $\pm$ 0.46	0.78 $\pm$ 0.22	0.00	0.33 $\pm$ 0.17
Oeste	I	7.69 $\pm$ 0.75	1.38 $\pm$ 0.59	7.62 $\pm$ 0.77	4.15 $\pm$ 1.31	0.76 $\pm$ 0.36	1.15 $\pm$ 0.15
Fuente B.	E	4.86 $\pm$ 0.34	14.86 $\pm$ 2.6	5.00 $\pm$ 1.38	1.57 $\pm$ 0.52	0.00	0.00
Fuente B.	I	6.71 $\pm$ 0.36	3.86 $\pm$ 1.16	6.71 $\pm$ 0.74	2.43 $\pm$ 1.52	0.71 $\pm$ 0.35	0.86 $\pm$ 0.40
Austria	E	3.80 $\pm$ 0.51	8.50 $\pm$ 3.41	4.10 $\pm$ 0.73	1.00 $\pm$ 0.47	0.00	0.00
Austria	I	6.67 $\pm$ 0.47	1.89 $\pm$ 0.73	9.00 $\pm$ 0.92	3.22 $\pm$ 1.32	0.11 $\pm$ 0.11	0.67 $\pm$ 0.29
Moro	E	3.80 $\pm$ 0.37	6.20 $\pm$ 2.15	4.20 $\pm$ 0.58	1.40 $\pm$ 0.67	0.00	0.00
Moro	I	5.15 $\pm$ 0.43	0.54 $\pm$ 0.26	5.38 $\pm$ 0.59	4.92 $\pm$ 1.46	0.77 $\pm$ 0.26	1.15 $\pm$ 0.36
C. Univ.	E	5.75 $\pm$ 0.52	11.38 $\pm$ 5.71	5.00 $\pm$ 0.93	1.50 $\pm$ 0.5	0.00	0.13 $\pm$ 0.13
C. Univ.	I	6.00 $\pm$ 0.67	3.67 $\pm$ 1.55	6.11 $\pm$ 1.24	2.11 $\pm$ 0.61	0.89 $\pm$ 0.35	1.00 $\pm$ 0.33



species in parks with more vegetation complexity and larger size (1998,  $F_{5,102} = 4.80$ ,  $P < 0.035$ ; 1999,  $F_{5,102} = 2.60$ ,  $P < 0.035$ , Table 3, Fernández-Juricic 2000c).

#### *Guild density*

In 1998, the densities of ground/tree, ground/cavity and tree/cavity species were significantly higher in interior areas of each park (ground/tree,  $F_{6,102} = 20.37$ ,  $P < 0.014$ ; ground/cavity,  $F_{6,102} = 7.03$ ,  $P < 0.014$ ; tree/cavity,  $F_{6,102} = 3.18$ ,  $P < 0.014$ , Table 3). Although a similar trend was found for tree/tree species, the pattern was not significant (tree/tree,  $F_{6,102} = 2.26$ ,  $P = 0.043$ , Table 3). The guild formed by House Sparrows and Rock Doves showed a reversed pattern; both species being significantly more abundant in edge than in interior areas within each park ( $F_{6,102} = 10.76$ ,  $P < 0.014$ , Table 3). A park effect was only found for House Sparrows and Rock Doves, by which their combined densities were higher in the Retiro and Ciudad Universitaria parks ( $F_{5,102} = 6.83$ ,  $P < 0.014$ ). No park effect was detected in the other guilds considered (ground/tree,  $F_{5,102} = 0.68$ ,  $P = 0.63$ ; ground/cavity,  $F_{5,102} = 2.97$ ,  $P = 0.015$ ; tree/tree,  $F_{5,102} = 1.41$ ,  $P = 0.22$ ; tree/cavity,  $F_{5,102} = 2.23$ ,  $P = 0.06$ ), which means that the overall densities of these species did not vary among parks.

Similar results were obtained in 1999. Ground/tree, ground/cavity, tree/tree, and tree/cavity species were all more abundant in interior areas within each park (ground/tree,  $F_{6,102} = 10.62$ ,  $P < 0.014$ ; ground/cavity,  $F_{6,102} = 3.74$ ,  $P < 0.014$ ; tree/tree,  $F_{6,102} = 3.97$ ,  $P < 0.014$ ; tree/cavity,  $F_{6,102} = 5.97$ ,  $P < 0.014$ , Table 3). House Sparrows and Rock Doves, on the contrary, were more abundant at edges ( $F_{6,102} = 5.27$ ,  $P < 0.014$ , Table 3). Similarly, a park effect was only detected for House Sparrows and Rock Doves, with higher densities in the Retiro and Fuente del Berro Parks (HSRD,  $F_{5,102} = 4.07$ ,  $P < 0.014$ ), but not for the other species (ground/tree,  $F_{5,102} = 0.94$ ,  $P = 0.45$ ; ground/cavity,  $F_{5,102} = 0.45$ ,  $P = 0.81$ ; tree/tree,  $F_{5,102} = 1.56$ ,  $P = 0.18$ ; tree/cavity,  $F_{5,102} = 0.55$ ,  $P = 0.73$ ).

#### *Individual species*

When considering individual species, their distribution patterns were similar to those found at the guild level. House Sparrows and Rock Doves were more abundant in edges within each park in both years (Table 4). In 1998, the densities of Blackbirds, Magpies, Serins, Starlings, and Coal Tits were significantly higher in interiors (Table 4), as were those of Woodpigeons and Green Woodpeckers despite their lack of significance (Table 4). In 1999, Blackbirds, Magpies, Serins, Woodpigeons, and Stock Doves were significantly more abundant in interiors (Table 4). Starlings and Coal Tits showed similar, but non-significant, patterns of higher abundance in interior areas (Table 4).

Table 4. Mean ( $\pm$ SE) densities of species in edges and interiors of six urban parks in Madrid, Spain. Shown are the results of a nested ANOVA indicating whether the density of species differed between edges and interiors within each park. All tests had the same degrees of freedom (6, 106).

Species	Edge density	Interior density	<i>F</i>	<i>P</i>
1998				
House Sparrow	8.92 $\pm$ 0.87	2.13 $\pm$ 0.28	11.98	<0.0096
Rock Dove	5.61 $\pm$ 1.38	1.18 $\pm$ 0.24	5.23	<0.0096
Blackbird	1.19 $\pm$ 0.18	3.52 $\pm$ 0.35	9.87	<0.0096
Magpie	0.32 $\pm$ 0.09	1.14 $\pm$ 0.16	6.94	<0.0096
Serin	0.67 $\pm$ 0.12	1.36 $\pm$ 0.19	6.87	<0.0096
Woodpigeon	0.81 $\pm$ 0.17	1.93 $\pm$ 0.23	2.23	0.013
Green Woodpecker	0.02 $\pm$ 0.01	0.23 $\pm$ 0.05	2.41	0.032
Starling	0.51 $\pm$ 0.15	1.28 $\pm$ 0.25	3.91	<0.0096
Coal Tit	0.12 $\pm$ 0.05	0.49 $\pm$ 0.02	3.05	<0.0096
1999				
House Sparrow	6.83 $\pm$ 0.77	1.67 $\pm$ 0.26	9.11	<0.0096
Rock Dove	7.64 $\pm$ 2.22	0.91 $\pm$ 0.23	4.32	<0.0096
Blackbird	1.51 $\pm$ 0.24	2.82 $\pm$ 0.25	2.99	<0.0096
Magpie	0.49 $\pm$ 0.11	1.18 $\pm$ 0.23	3.33	<0.0096
Serin	0.79 $\pm$ 0.16	1.24 $\pm$ 0.19	4.58	<0.0096
Woodpigeon	0.74 $\pm$ 0.19	1.54 $\pm$ 0.17	4.64	<0.0096
Stock Dove	0.17 $\pm$ 0.06	1.32 $\pm$ 0.27	3.28	<0.0096
Starling	0.79 $\pm$ 0.16	1.60 $\pm$ 0.36	0.56	0.76
Coal Tit	0.05 $\pm$ 0.03	0.44 $\pm$ 0.09	2.87	0.012

## Discussion

The results of this study underscore that at urban-park edges there is a spatial segregation of bird species, which is supposed to be affected by pedestrian and car traffic rates. Two general groups of species can be distinguished in urban landscapes based on their representation in edge and interior areas: those with specific habitat requirements and those highly habituated to human activities (House Sparrows and Rock Doves).

All species foraging in trees and on the ground, and nesting in trees and in tree cavities, except House Sparrows and Rock Doves, had lower numbers and breeding densities at edges relative to interior areas. The lack of significant effects for Woodpigeons and Green Woodpeckers in 1998, and Starlings and Coal Tits in 1999 (Table 4) may be related to the low power of the tests due to a rather reduced sample size (six parks). Nevertheless, trends were similar, with higher densities at interiors. Unlike other landscapes (Helle and Helle 1982; Fuller and Whittington 1987; Lopez de Casenave et al. 1998), habitat structure appears not to play a significant role in the spatial segregation between edge and interior areas of urban woodlots. The overall variation in vegetation structure may be lessened by the continuous action of gardeners who maintain similar structural conditions within urban parks. Other

factors may also modify patterns of fragment use. For instance, many ground/tree, ground/cavity, tree/tree, and tree/cavity species feed on insects, which can become progressively less available towards edges due to microclimatic modifications, such as increased net radiation, wind speed, and temperature, and lower humidity (Báldi 1999; reviewed in McCollin 1998). All such conditions may prevent some birds from occupying edges due to the dearth of food resources (Burke and Nol 1998; Zarette et al. 2000). Moreover, the effects of air-pollution from traffic load may intensify the decrease in insect availability at edges (Andre and Lebrun 1982; Bolsinger and Flückinger 1989).

Higher car and pedestrian traffic at edges can affect the occurrence and abundance of bird species. Above certain threshold levels, car traffic noise appears to diminish habitat quality for breeding birds (Reijnen et al. 1995), because it increases stress, and cause a distortion in vocal communication (Reijen and Foppen 1994; Reijnen et al. 1997). Pedestrians can limit the availability of resource patches for birds both spatially and temporarily, thereby reducing their foraging and breeding opportunities (Fernández-Juricic and Tellería 2000; Fernández-Juricic 2000a). The combination of noise and pedestrians can reduce the overall suitability of urban-park edges for many species, causing declines in abundance and recruitment as the proportion of edge areas increases with smaller fragments (Robinson et al. 1995; Fernández-Juricic and Tellería 1999).

House Sparrows and Rock Doves increased their breeding densities at urban-park edges. These species are urban specialists due to their habituation to people (Blair 1996; Rolando et al. 1997). Their prevalence appears to increase with the proportion of forest edges. For instance, in Madrid, the density of House Sparrows and Rock Doves is negatively affected by fragment size, an indicator of the proportion of edges, and positively affected by the rate of visitors to urban parks (Fernández-Juricic, unpublished data). Hence, it is not surprising that these species abound at edges, where they can find food from people (refuse, people leftovers, deliberate feeding), and at the same time nest in buildings or tree cavities. Similar patterns have been found for other species that make use of resources in both fragments and the surrounding matrix, and that are considered edge specialists (Lynch and Whigham 1984; Reese and Ratti 1988; McCollin 1998).

The type and amount of edge in a landscape may affect the number and density of species in adjacent patches (Hansson 1983; Hawrot and Niemi 1996). The characteristics of the edges surrounding urban parks modify avian microhabitat selection within urban parks, which hold a relevant conservation value in cities because they are reservoirs of wildlife. The influence of the urban matrix is more pronounced in small parks (Fernández-Juricic 2000a), because they are edge habitats (Levenson 1981). Urbanisation sprawl is expected to increase the prevalence of edge specialists and diminish the representation of species with specific habitat requirements, which are more bound to undergo local extinction (Blair 1996; Fernández-Juricic 2000c). Therefore, for native avifauna to be conserved in increasingly urbanised landscapes,

it is recommended that urban parks reach a minimum area (between 15 and 20 ha, Fernández-Juricic 2000c) to provide interior habitats for many bird species, and that the effects of car and pedestrian traffic be reduced by means of buffer zones. Such measures are expected to enhance the abundance and persistence of interior species in highly urbanised landscapes.

### Acknowledgements

I thank Duncan McCollin and Tomás Santos for critically reviewing earlier versions of the manuscript, and three anonymous referees for their constructive comments. I was funded by the Agencia Española de Cooperación Internacional (MUTIS Fellowship).

### References

- Andre HM and Lebrun PH (1982) Effects of air pollution on coricolous microarthropods in the urban district of Charleroi (Belgium). In: Bornkamm R, Lee JA and Seaward MRD (eds) *Urban Ecology*, pp 191–200. Blackwell Scientific Publications, Oxford
- Andrén H (1995) Effects of landscape composition on predation rates at habitat edges. In: Hansson L, Fahrig L and Merriam G (eds) *Mosaic Landscapes and Ecological Processes*, pp 225–255. Chapman & Hall, London
- Báldi A (1999) Microclimate and vegetation edge effects in a reedbed in Hungary. *Biodiversity and Conservation* 8: 1697–1706
- Blair RB (1996) Land use and avian species diversity along an urban gradient. *Ecological Applications* 6: 506–519
- Bolsinger M and Flückinger W (1989) Ambient air pollution induced changes in amino acid pattern of phloem sap in hostplants: relevance to aphid infestation. *Environmental Pollution* 56: 209–216
- Brawn JD and Robinson SK (1996) Source-sink population dynamics may complicate interpretation of long-term census data. *Ecology* 77: 3–12
- Burke DM and Nol E (1998) Influence of food abundance, nest-site habitat, and forest fragmentation on breeding ovenbirds. *Auk* 115: 96–104
- Cramp S (ed) (1992) *The Birds of the Western Palearctic*, Vol 5. Oxford University Press, Oxford
- Chandler R (1995) Practical considerations in the use of simultaneous inference for multiple tests. *Animal Behaviour* 49: 524–527
- Darveau LD, Huot J, Mélançon E and DeBeilefueille S (1997) Forestry practices and the risk of bird nest predation in a boreal coniferous forest. *Ecological Applications* 7: 572–580
- Debinski DM and Holt RD (2000) A survey and overview of habitat fragmentation experiments. *Conservation Biology* 14: 342–355
- Erz W (1966) Ecological principles in the urbanization of birds. *Ostrich Supplement* 6: 357–363
- Faaborg J, Brittingham MC, Donovan TM and Blake J (1995) Habitat fragmentation in the temperate zone. In: Martin TE and Finch DM (eds) *Ecology and Management of Neotropical Migratory Birds*, pp 357–380. Oxford University Press, Oxford
- Fagan WF, Cantrell RS and Cosner C (1999) How habitat edges change species interactions. *American Naturalist* 153: 165–182
- Fernández-Juricic E (2000a) Local and regional effects of pedestrians on forest birds in a fragmented landscape. *Condor* 102: 247–255
- Fernández-Juricic E (2000b) Avifaunal use of linear strips in an urban landscape. *Conservation Biology* 14: 513–521
- Fernández-Juricic E (2000c) Bird community composition patterns in urban parks of Madrid: the role of age, size, and isolation. *Ecological Research* 15: 373–383

- Fernández-Juricic E and Tellería JL (1999) Recruitment patterns of blackbirds (*Turdus merula*) in urban fragmented populations. *Ardeola* 46: 61–70
- Fernández-Juricic E and Tellería JL (2000) Effects of human disturbance on Blackbirds *Turdus merula* spatial and temporal feeding patterns in urban parks of Madrid, Spain. *Bird Study* 47: 13–21
- Fuller RJ and Whittington PA (1987) Breeding bird distribution within Lincolnshire ash-lime woodlands: the influence of rides and the woodland edge. *Acta Oecologica* 8: 259–268
- Hanowski JM, Blake JG, Niemi GJ and Collins PT (1993) Effects of extremely low frequency electromagnetic fields on breeding and migrating birds. *American Midland Naturalist* 129: 96–115
- Hansson L (1983) Bird numbers across edges between mature coniferous forest and clearcuts in central Sweden. *Ornis Scandinavica* 14: 675–676
- Hartley MJ and Hunter Jr. ML (1998) Meta-analysis of forest cover, edge effects, and artificial nest predation rates. *Conservation Biology* 9: 1316–1318
- Hawrot RY and Niemi GJ (1996) Effects of edge type and patch shape on avian communities in a mixed conifer-hardwood forest. *Auk* 113: 586–598
- Helle E and Helle P (1982) Edge effect on forest bird densities on offshore islands in the northern Gulf of Bothnia. *Annales Zoologici Fennici* 19: 165–169
- Järvinen O and Väisänen RA (1975) Estimating relative densities of breeding birds by the line transect method. *Oikos* 26: 316–322
- Kroodsma RL (1982) Edge effect on breeding forest birds along a power-line corridor. *Journal of Applied Ecology* 19: 361–370
- Levenson JB (1981) Woodlots as biogeographic islands in Southeastern Wisconsin. In: Burgess RL and Sharpe DM (eds) *Forest Island Dynamics in Man-dominated Landscapes*, pp 13–39. Springer-Verlag, Berlin
- Lopez de Casenave J, Pelotto JP, Caziani SM, Mermoz M and Protomastro J (1998) Responses of avian assemblages to a natural edge in a Chaco semiarid forest in Argentina. *Auk* 115: 425–435
- Lynch JF and Whigham DF (1984) Effects of forest fragmentation on breeding bird communities in Maryland, USA. *Biological Conservation* 28: 287–324
- McCollin D (1998) Forest edges and habitat selection in birds: a functional approach. *Ecography* 21: 247–260
- McKonne MJ and Lively CM (1993) Statistical analysis of experiments conducted at multiple sites. *Oikos* 67: 184–186
- Murcia C (1995) Edge effects in fragmented forests: implications for conservation. *TREE* 10: 58–62
- Paton PWC (1994) The effect of edge on avian nesting success: how strong is the evidence? *Conservation Biology* 8: 17–26
- Prodon R and Lebreton JD (1981) Breeding avifauna of a Mediterranean succession: the holm oak and cork oak series in the eastern Pyrenees, 1. Analysis and modelling of the structure gradient. *Oikos* 37: 21–38
- Reese KP and Ratti JT (1988) Edge effects: a concept under scrutiny. *Transactions of the North American Wildlife and Natural Resource Conference* 53: 127–136
- Reijnen R and Foppen R (1994) The effects of car traffic on breeding bird populations in woodland. I. Evidence of reduced habitat quality for willow warblers (*Phylloscopus trochilus*) breeding close to a highway. *Journal of Applied Ecology* 31: 85–94
- Reijnen R, Foppen R and Veenbaas G (1997) Disturbance by traffic of breeding birds: evaluation of the effect and considerations in planning and managing road corridors. *Biodiversity and Conservation* 6: 567–581
- Reijnen R, Foppen R, ter Braak C and Thissen J (1995) The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology* 32: 187–202
- Rice WR (1989) Analysing tables of statistical tests. *Evolution* 43: 223–225
- Robinson SK, Thompson III FR, Donovan TM, Whitehead DR and Faaborg J (1995) Regional forest fragmentation and the nesting success of migratory birds. *Science* 267: 1987–1990
- Rolando A, Maffei G, Pulcher C and Giuso A (1997) Avian community structure along an urbanization gradient. *Italian Journal of Zoology* 64: 341–349
- Saunders DA, Hobbs RJ and Margules CR (1991) Biological consequences of ecosystem fragmentation: a review. *Conservation Biology* 5: 18–32

- Seber GAF (1982) *The Estimation of Animal Abundance and Related Parameters*. Griffin, London
- Tellería JL and Santos T (1995) Effects of forest fragmentation on a guild of wintering passerines: the role of habitat selection. *Biological Conservation* 71: 61–67
- Tellería JL, Asensio B and Díaz M (1999) *Aves Ibéricas. II. Paseriformes*. JM Reyero, Madrid
- Underwood AJ (1997) *Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance*. Cambridge University Press, Cambridge
- World Resources Institute (1996) *World Resources 1996–1997: A Guide to the Global Environment. The Urban Environment*. Oxford University Press, New York
- Zanette L, Doyle P and Trémont S (2000) Food shortage in small fragments: evidence from an area-sensitive passerine. *Ecology* 81: 1654–1666