Insectivorous and open-cup nester bird species suffer the most from urbanization

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Capsule Urbanization effects in an Eastern European city depend on feeding and breeding traits of bird communities with stronger negative effects on more specialized traits.

Aims To assess how urbanization affects feeding and breeding traits of bird communities in Cluj (Romania).

Methods Based on a stratified random sampling we selected 61 study squares of 200 × 200 m for bird surveys representing the following habitats: suburban, residential and apartment complex (representing an increasing urbanization gradient). We carried out bird censuses in both breeding and wintering seasons. The observed bird species were classified according to their feeding guilds and nesting sites.

Results Insectivorous and open-cup nesting species were most abundant in suburban areas. Omnivorous species richness was not related to urbanization gradient. Species showed similar patterns of distribution during breeding and winter with respect to feeding habits. However, in case of nesting preferences, species richness of cavity nesters increased with urbanization gradient in winter, but decreased in the breeding season.

Conclusions Food and nesting site availability are key drivers in limiting more specialist species in utilizing city centres. Future studies should assess the effect of how green areas can counteract such negative effects of increasing urbanization in the context of such specialist trait limitations.

Urbanization is the process in which an existing human settlement extends into previously unbuilt environments. It is triggered by the increase in the human population and/or its migration from a rural to an urban environment (Marzluff et al. 2001). In these conditions it is critical to understand how bird species and communities exist within the urban environment in order to lessen its negative effects (Chamberlain et al. 2009). Although there are several studies on the effects of urbanization on bird species diversity (Chace & Walsh 2006, Baker et al. 2010, Taylor et al. 2013), urban planning still largely ignores the ecological quality of the environment (Marzluff et al. 2001).

Several studies suggest that urbanization has a negative effect on birds (Palomino & Carrascal 2006, Husté & Boulmer 2007, Lepczyk et al. 2008). One of the most conspicuous effects of urbanization on bird communities is homogenization. The same species are present in most urban environments, with city centres and high-density residential areas being especially poor in diversity, although the few bird species present are usually represented in high numbers (Blair 2004). In general, less than half of the species that are present in natural habitats can be found in the city centres they replace (Clergeau et al. 2006). Despite these facts, species that are able to exploit urban environments can be successful (Kark et al. 2007).

The foraging and nesting behaviour of birds is important in success at utilization of urban environments (Evans et al. 2011). Rubbish dumps, feeding stations, irrigated lawns and man-made buildings that provide shelter are all human-related resources that are used successfully by many urban exploiter species (Chace & Walsh 2006, Palomino & Carrascal 2006). Omnivorous and seed eater species profit particularly in these habitats, and these species are the most common in cities. In contrast, birds that feed on insects are the most vulnerable to the negative effects of urbanization (Clergeau et al. 1998, Jokimäki et al. 2002). Nesting strategies also influence the occurrence of species and their distribution in urban environments. For example, studies have shown that birds that nest higher in trees have a better chance of survival, thus these species are more common in

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urban environments (Croci et al. 2008). Also, birds with more flexible nesting strategies are more likely to be more successful in urban environments in contrast to species with specialized nest sites (Reale & Blair 2005).

Several bird species appear to favour more urbanized areas of the city during winter in contrast with the breeding season. Jokimäki et al. (1996) and Caula et al. (2014) found that during spring more species were recorded in the most natural areas of the city, while during winter species richness was highest in the most urbanized parks, which were located in the city centre. In winter many species find better survival options within the cities, such as snow free places, a more favourable urban microclimate, unfrozen water or food resources like human food residues from garbage or even feeding stations (Jokimäki et al. 2002). This is supported by the fact that some species such as the Blackbird Turdus merula, the Mallard Anas platyrhynchos and the Coot Fulica atra spend the winter in the cities while non-urban population migrate (Jokimäki & Suonen 1998). Caula et al. (2014) also found that the composition of bird communities between consecutive breeding seasons is dynamic, and is driven by resource availability. Specialist species vary in their use of different urban areas between the seasons, while generalists tend to use the same areas throughout the year.

The urban environment is ecologically diverse, yet can change quickly due to industrial and urban development. In these conditions, there is an urgent need to understand how the bird communities are related to the urban environment. In particular, there is an overall lack of understanding about how bird communities arise in the major cities of Eastern Europe, where biodiversity is thought to be generally higher than in Western Europe (Tryjanowski et al. 2011). The main goal of the present research was to help fill this gap by examining the composition and seasonal change of the bird communities in an Eastern European city. Our study city, Cluj-Napoca (Romania) is known as being rich in bird species, including species with diverse nesting and foraging traits (Máthé & Szabo 2011). In this study we explored how the different levels of urbanization affect current bird distribution and diversity and the role that species traits play in their distribution. We posed the following hypotheses:

1. Species richness decreases with an increasing gradient of urbanization but this decrease will depend on the season (breeding vs. wintering) and the functional traits of the species (different feeding guilds or different breeding traits).

2. For feeding guilds we expect stronger effects of urbanization on specialized guilds (insectivores and granivores) than on omnivores.

3. For breeding traits we expect that urbanization negatively affects birds with open-cup nests and cavity nests, but a positive effect for bird species nesting in/on buildings.

4. Because we expect different sensitivity to urbanization for different feeding guilds and breeding traits, we also expect that the overall community composition of urban bird fauna will change as well with the urbanization gradient.

**METHODS**

**Study area and study design**

Cluj-Napoca is one of the major cities of Transylvania and the second largest city in Romania, with an area of 179.5 km² and a population of 410 000 residents. It is situated at 350 m a.s.l. The city is surrounded by hills, which peak at elevations between 500 and 825 m. The climate is continental with an average annual temperature of 10°C (average monthly min.–max. for summer: 12.1–23.8°C and for winter: −5.1–1.8) and 550 mm of rainfall (the number of rainy days per month ranges from 5 to 11).

First we overlaid the entire area of a satellite image of the city with 1399 squares of 200 × 200 m. Each of these squares were then categorized as wetlands (n = 27), parks (n = 13), suburban areas with family houses (n = 449), residential areas with family houses (n = 402) and apartment complexes with block houses (n = 508), representing a gradient of decreasing ‘naturalness’. The categorization was made by assessing the percentage of the land-use types using Google Earth (2009) adjusted with ground truthing. Parks were those squares, which had more than 70% of the surface covered by vegetation and at least two adjacent squares were the same. Wetlands were dominated by artificial ponds. Residential areas with single family houses had at least 30% vegetation cover in the square. Residential areas with family houses were typically found towards the city centre, whereas the suburban areas with family houses category was situated towards the periphery of the city, close to the semi-natural areas of the surroundings. These areas differed, however, mostly in the cover of family houses (more in residential areas)
and lawns (more in suburban areas) (Table 1). The apartment complex category had the highest percentage cover of built-up areas (more than 80%). Apartment complexes were mostly multi-storey buildings. From all squares, 61 were selected for the bird surveys using stratified random sampling: 22 in apartment complex areas, 20 in residential areas and 19 in suburban areas (for a map see Appendix S1 in Supplemental Online Material). Parks and wetlands were excluded because we focused on birds from built-up environments. The three study categories represent a gradient of built-up area cover with fewer buildings (and most vegetation cover) in the suburban area, an intermediate built-up area cover in the residential area squares and high built-up area cover in the apartment complex areas. We refer to this gradient as an ‘urbanization gradient’. The cover of land-use types of the study square (200 × 200 m) are presented in Table 1 for the urbanization gradient (these were measured in Google Earth with the use of polygons). Finally, we also estimated the level of disturbance based on the number of pedestrians, car traffic, which also increased with the urbanization gradient (Table 1). The estimation was based on the general use of the study squares (200 × 200 m) by counting the pedestrians and the cars for one minute: 1, less than 5 cars or less than 5 pedestrians; 2, 5–10 cars or 5–10 pedestrians; 3, 10–20 cars or 10–20 pedestrians; 4, 20–30 cars or 20–30 pedestrians and 5, more than 30 cars, more than 30 pedestrians. These values were collected once before each bird survey.

Table 1. The cover of land-use types in the three categories of urbanization gradient and percentage of disturbance (estimated based on pedestrian and car traffic at ordinal scale from 1 to 5) (mean ± se). Difference among urbanization categories was tested by one-way ANOVA (F-values are shown with level of significance as follows: *P < 0.05; **P < 0.01; ***P < 0.001). Letters next to the values indicate significant differences between urbanization categories based on Tukey honest significant difference post hoc test (P < 0.05) performed with the use of ‘multcomp’ package (Hothorn et al. 2008) of R (R Development Core Team 2013).

| Functional groups          |
|-----------------------------|
| Birds were surveyed with 5-minute point counts in the centre of a 200 m diameter circle. Bird counting points were designated as close to the centre of the squares as possible. The distance between the survey points was at least 500 m to reduce spatial autocorrelation. All species heard or seen were counted, apart from birds just flying over. Two surveys were made at each site during the winter (November 2010–February 2011) and two during the breeding season (April–June 2011). Sampling was carried out during the morning between 05:00 and 10:00 in good weather conditions (no precipitation and wind strength less than level 3 at Beaufort scale).

Statistical analysis
First, general linear mixed-effects models with restricted maximum likelihood method for nested sampling were used to analyse the effects of the three following explanatory variables for species richness in two full models: urbanization gradient (factor with three levels of increasing gradient: suburban area, residential area and apartment complex area), season (breeding vs. wintering) and the functional group or trait of interest (1st model: feeding guild with three-level factor: omnivorous, insectivorous and granivorous; 2nd model: breeding trait with three-level factor: building nesters, open-cup nesters and cavity nesters). Additionally, both models included all possible interactions among these three variables, and also their three-way interaction. Bird survey point ID was included as random factor to account for the fact that the number

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of species in each trait group was quantified at the same locations. Since both models resulted in significant three-way interactions (see Appendix S2 for model codes and results in Supplemental Online Material), we decided to analyse each trait level within seasons separately. Therefore, the effect of the urbanization gradient on bird species richness and species richness of each individual functional trait (omnivorous, insectivorous, granivorous, building nesters, open-cup nesters and cavity nesters) were analysed using separate linear models in the breeding and wintering seasons fitted by generalized least squares (gls) with a restricted maximum log-likelihood (Pinheiro & Bates 2000). To account for spatial autocorrelation, we fitted gls models with urbanization gradient as the sole response variable with Universal Transverse Mercator coordinates treated as spatial covariates assuming a spherical spatial correlation structure (Pinheiro & Bates 2000). All models were performed by using the ‘nlme’ package (Pinheiro et al. 2013) of R (R Development Core Team 2013).

In order to test the effect of urbanization gradient on the community composition of birds, we additionally performed redundancy analyses (RDA). For this we used the maximum abundance of each bird species per survey point from the replicate counts, because this represents the minimum number of birds present at the sampled location (Bibby et al. 2000). Prior to the analyses, the species matrix was transformed with the Hellinger-transformation (Legendre & Gallagher 2001). This transformation allows the use of Euclidean-based ordination methods with community composition data containing many zeros, i.e. characterized by long gradients. Pseudo-F values with the corresponding P values were calculated by permutation tests based on 999 permutations. Separate RDAs were performed for breeding and wintering seasons. Calculations were performed using the ‘vegan’ package for R (Oksanen et al. 2013).

RESULTS

Overall 68 species of birds (55 species in breeding season and 53 species in winter) were recorded (see Online Supplementary Material Appendix S3). The most commonly detected species in the breeding season was House Sparrow Passer domesticus (detected in 90% of the sites) followed by Rock Dove Columba livia (85%), Eurasian Collared Dove Streptopelia decaocto (78%), Great Tit Parus major (49%) and Rook Corvus frugilegus (30%). Species with the lowest percent of site occupancy in the breeding season surveys were Wryneck Jynx torquilla, Red-backed Shrike Lanius collurio, Great Grey Shrike Lanius excubitor, Pheasant Phasianus colchicus, Great Reed Warbler Acrocephalus arundinaceus, Reed Warbler Acrocephalus scirpaceus and Partridge Perdix perdix. These species were usually detected in suburban areas (detected in up to 3% of the sites). The most common species in winter were House Sparrow (89%) followed by Great Tit (58%). Some species were only present in winter, like Siskin Carduelis spinus, Bullfinch Pyrrhula pyrrhula, Brambling Fringilla montifringilla and Common Gull Larus canus. They were sighted in all three urbanization categories.

Species richness was highest in suburban areas, lowest in apartment complex areas and intermediate in residential areas in both seasons (Fig. 1). The difference was significant only between apartment complex areas and suburban areas in the breeding season (Table 2). The species richness of both insectivores and open-cup nesters in suburban areas was significantly higher than in the apartment complex areas or in the residential areas in both seasons, while the number of building-nesting species decreased in winter with the urbanization gradient (Figs 2 and 3). Omnivorous species richness was not related to the urbanization gradient either during the breeding or wintering season (Table 2). However, cavity nester species (of which species richness was higher in winter than in the breeding season, Online Supplementary Material Appendix S2) increased with the urbanization gradient in winter (Fig. 3).

In the ordination analysis, the urbanization gradient explained a significant part of the variation in the bird species community composition both in the breeding season and winter.
and wintering seasons (6.6%, pseudo-$F_{2,58} = 2.1$, $P < 0.001$; 8.0%, pseudo-$F_{2,58} = 2.5$, $P < 0.001$, respectively). Synanthropic species, such as the Rock Dove and corvids were mostly associated with apartment complex areas in both seasons (Fig. 4). The most representative species for the residential areas were Starling *Sturnus vulgaris* and Eurasian Collared Dove in the breeding season and Greenfinch *Carduelis chloris* in winter (Fig. 4). The suburban area bird communities were represented usually by woodland species such as the Lesser Whitethroat *Sylvia curruca* and the Chaffinch *Fringilla coelebs*, and mostly open-cup nesters and insectivorous species (Fig. 4).

Species with high conservation importance (e.g. listed in the EU’s Birds Directive) were observed only in the suburban area: Golden Oriole *Oriolus oriolus* (8% in breeding season), Red-backed Shrike *L. collario* (2% in breeding season), Great Reed Warbler *A. arundinaceus* (2% in breeding season) and Partridge *P. perdix* (2% in breeding season).

**DISCUSSION**

Our study suggests that cities can support a wide variety of species with diverse traits varying along an urbanization gradient. Our ordination analysis showed that while lower urbanization favours species with nesting and feeding specialism, birds that can exploit human-related resources for nesting and feeding typically have high abundance in the most urbanized areas (MacGregor-Fors et al. 2011). Although it should be noted that most urban building nesters, are species with a rather limited distribution in natural habitats due to their tight dependency on rock crevices, what qualifies them as specialist species with regard to the nesting location.

Species well adapted to urban environments, and thus occurring in high numbers in more than 80% of cities, such as the House Sparrow and the Rock Dove, have

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**Table 2.** Summary of the gls regression models for testing the effect of urbanization gradient (SA: suburban area; RA: residential area; AC: apartment complex) on total species richness and species richness of different traits of birds in breeding and wintering seasons. The table shows $t$-values from gls models fitted using treatment contrasts (i.e. the residential area was the reference level for all comparisons), where each row represents a separate model. The contrast between suburban area and apartment complex was derived by re-fitting the model using suburban area as the baseline level. Degree of freedom was 61 in total and 58 for residuals for each model. (*): $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

|                | RA–AC | RA–SA | SA–AC |
|----------------|-------|-------|-------|
| **Breeding season** |       |       |       |
| Total species richness   | −1.86(*) | 1.73(*) | 3.62*** |
| Omnivorous                | −0.23  | −1.25  | −1.06  |
| Insectivorous             | −1.15  | 2.77** | 3.97*** |
| Granivorous               | 0.24   | 2.02*  | 1.82(*) |
| Building nesters          | −0.73  | −1.41  | −0.73  |
| Open-cup nesters          | −0.66  | 2.66** | 3.37** |
| Cavity nesters            | −0.85  | 1.86(*) | 2.73** |
| **Winter**                |       |       |       |
| Total species richness    | −0.92  | 0.92   | 1.84(*) |
| Omnivorous                | 0.50   | −0.94  | −1.45  |
| Insectivorous             | −1.34  | 1.95*  | 3.31** |
| Granivorous               | −1.07  | 1.46   | 2.54*  |
| Building nesters          | 0.53   | −2.13* | −2.71** |
| Open-cup nesters          | −0.97  | 1.91(*) | 2.92*  |
| Cavity nesters            | −1.32  | 2.05*  | 3.39** |

**Figure 2.** Mean species richness (±se) of the foraging groups (omnivorous, insectivorous and granivorous) per survey point along an urbanization gradient in the breeding season and winter.
some typical traits (Jokimäki et al. 2002, Mason 2006, Palomino & Carrascal 2006, Kark et al. 2007, Aronson et al. 2014). They are not only omnivorous and sedentary, but they can use a high variety of artificial nesting sites (Kark et al. 2007, Möller 2009). Overall, their success in cities depends on their ability to exploit human-related resources like garbage, bird feeders, nesting boxes and buildings (Chace & Walsh 2006, Kark et al. 2007, MacGregor-Fors et al. 2011). Indeed, we also found that these two species were common in all three urbanization categories of our city with highest abundances among all species.

![Figure 3](image_url) Mean species richness (± se) of the nesting functional groups (cavity nester, open-cup nester and building nester) per survey point along an urbanization gradient in the breeding season and winter.

![Figure 4](image_url) RDA ordination diagrams with bird species (black points) and urbanization gradient (open circles; SA: suburban areas; RA: residential areas; AC: apartment complex areas) in the breeding season (a) and in the winter (b). For visibility, only bird species with the highest fraction of variance fitted by the two first factorial axes are indicated (Carcar: Carduelis carduelis, Carchl: C. chloris, Colliv: Columba livia, Corfru: Corvus frugilegus, Cormon: Corvus monedula, Cornix: Corvus corone cornix, Fricoe: Fringilla coelebs, Gargla: Garrulus glandarius, Parmaj: Parus major, Pasdom: Passer domesticus, Pasmon: Passer montanus, Phycol: Phylloscopus collybita, Picpic: Pica pica, Strdec: Streptopelia decaocto, Stuvul: Sturnus vulgaris, Sylat: Sylvia atricapilla, Sylcur: Sylvia curruca, Turner: Turdus merula, Turpil: Turdus pilaris).
Food is the most important factor determining reproductive success in birds (Møller 2009). The density and diversity of insects in heavily urbanized habitats is typically lower than in less urbanized or semi-natural habitats, for example, because of the lack of vegetation (DeGraaf & Wentworth 1986). This can explain the overall scarcity of insectivorous birds in the most urbanized areas (e.g. apartment complex areas) found in our study (see also Chamberlain et al. 2009, Sorace & Gustin 2010, Evans et al. 2011), whereas the richness of this group was highest in the least urbanized areas (suburban areas). The number of granivorous bird species was also low in highly urbanized areas (see also Chamberlain et al. 2009). Granivorous birds also significantly rely on insects in their breeding period (Snow & Perrins 1998) and this can explain their similarity with insectivorous birds in their sensitivity to very urbanized areas of the city. The suburban areas in our study had the highest green space, so probably supported a greater number of insectivorous and granivorous birds.

Open-cup nesters were negatively associated with the most urbanized areas (see also Chace & Walsh 2006, Kark et al. 2007). These birds need trees and shrubs to support their nests, both being poorly represented in the urbanized areas of cities (Botkin & Beveridge 1997, Chace & Walsh 2006). In addition, the very few trees that remain in urbanized areas are often isolated and managed (e.g. by pruning which reduces canopy and dead elements), and therefore have low quality as habitats for birds (Schlesinger et al. 2008). However, even these trees and wooded patches sustain some bird communities and provide foraging and nesting sites (Fernandez-Juricic 2000).

We found that the number of cavity nesting species was higher in winter than in the breeding season, and these species dominated in the most urbanized areas in winter. The increase in the abundance of Parus species was one of the most important determinants of this result. The use of bird feeders in the winter may be one explanation of this pattern (Jokimäki et al. 2002). Moreover, feeding preferences are less specialized in winter than in the breeding season for most species, and there is no need to defend breeding territories in winter. Overall, these conditions can make the towns attractive for some birds in winter (Caula et al. 2008). Despite all the detrimental effects of urban environments on wildlife, the city represents a refuge for many birds in winter, due to bird feeders, shelter and a more moderate microclimate (Clergeau et al. 1998, Jokimäki et al. 2002, Caula et al. 2014).

Clergeau et al. (1998) studying the avifauna of cities in two continents concluded that birds of urban environments can be classified in the following two groups: (1) omnivorous species adapted to urban environment and its food resources such as garbage and (2) species that exploit the same resources as in their original habitat. Our redundancy analyses seem to confirm this because the Rock Dove and corvids were mostly related to higher urbanization levels in both seasons, while granivorous and insectivorous species were more confined to suburban areas. As we show here, a study in Madrid found that representatives of the latter species groups avoid the heavily urbanized areas, and prefer less urbanized areas of the city, including species such as Blackcap Sylvia atricapilla or Chiffchaff Phylloscopus collybita in the breeding season and Eurasian Tree Sparrow Passer montanus in both breeding and wintering seasons (Caula et al. 2008).

In summary, we showed that urbanization has the most detrimental effects on species showing more specialization in feeding or nesting traits (Kark et al. 2007). Insectivores especially, but also granivores, and species with open-cup nests, suffered from increasing urbanization. Hence urban habitats are most exploited by generalist species. These results were also reflected in a community composition change of the whole avifauna along an urbanization gradient, independently whether we considered breeding or wintering season. This means that encouraging insectivorous, open-cup nester species within cities might be quite challenging, because their major resources are often strongly limited. Our results suggest that green areas within city centres with characteristics that resemble suburban areas are likely to be particularly important. Such green areas, like parks, home gardens or community gardens, might provide suitable habitat even for more specialized species, if they have low disturbance, are not fully isolated fragments in the urban matrix, are sufficiently large, and do not function as an ecological trap because of increased nest predation pressure from the urban generalists (Chamberlain et al. 2009).

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SUPPLEMENTARY MATERIAL

Supplementary online appendices S1 (location of bird sampling points), S2 (full models for species richness) and S3 (table showing the abundance of each species by urbanisation category and season) can be accessed at 10.1080/00063657.2014.1000262.

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