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Bird diversity in urban green space: A large-scale analysis of differences between parks and cemeteries in Central Europe

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ABSTRACT

Urbanization is a permanent and still continuing expansion of human settlements and is responsible for dramatic changes of natural areas to urban areas. In traditional view, urbanization is often blamed for the loss of biodiversity and biotic homogenization of natural communities. However, for some species, urban areas, can represent suitable environment for life and even enable them to maintain stable and abundant populations. Urban ecosystems are not homogenous; within human settlements we can find several different habitats which can be occupied by species with different tolerance to certain aspects of urban life. This diversity can be exhibited by interhabitat changes in species richness, diversity and abundances of local communities. Here, we investigated biodiversity patterns in bird communities of two urban habitats, parks and cemeteries, in three Central European countries. Data on species richness, diversity and abundances of birds were collected from published papers as well as unpublished sources. Our analyses revealed that bird species richness was positively correlated with area and age of trees in both habitat types. There was however no significant relationship between species diversity and area in both habitat types. Moreover, species composition of bird communities significantly varied between cemeteries and parks with strong preference for one of habitat types in several species. Predominant occupancy of habitat type by certain species could be linked to interhabitat differences in vegetation structure, human behaviour and management. Interestingly, several bird species often recognised as urban avoiders were detected in surveyed cemeteries and parks.

1. Introduction

Urbanization involves a permanent and ongoing expansion of human settlements and is responsible for dramatic changes of natural areas in cities (Grimm et al., 2008; McDonald, 2008). Because of continuing and rapid increase of human population which entails growth of material consumption demand, urbanized areas represent hotspots driving local as well as global environmental changes and influences biodiversity on multiple scales (Kareiva et al., 2007; Grimm et al., 2008). The most noted local effects of urbanization are related to the loss of biodiversity and biotic homogenization (Chace and Walsh, 2006; Clavero and Brotons, 2010; Clavero et al., 2011; Morelli et al., 2016).

Bird communities are important components of biodiversity in urban ecosystems. Birds also represent a suitable and frequent model for the evaluation of environmental changes in urban areas (Marzluff, 2005) due to their relatively easy detectability and identification in the field and complexity of responses to environmental alterations (Croci et al., 2008). Although some species known as "urban avoiders" seems to be intolerant to urban areas, such environment offers suitable habitats for species which are able to cope with novel conditions (Croci et al., 2008; Maklakov et al., 2011). Urban heat island effect, as well as humans providing food to birds might cause even the expansion of some

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species (Croci et al., 2008; Møller et al., 2014; Fisher et al., 2015). On the other hand, avian survivorship in urban areas can be influenced by risk of collision with human-made objects, mainly buildings and cars (Klem, 1990), predators, including these ones directly connected with human like cats and dogs (Sorace, 2002), and disease (Delgado-V and French, 2012).

Successful colonization of urban ecosystems is often linked to biological traits of each species (Croci et al., 2008; Maklakov et al., 2011). Unequal susceptibility of species to urban conditions indicates that urban areas may act as an environmental filter (Tscharntke et al., 2012; Aronson et al., 2014) that influences species composition, community richness and population sizes of birds. However, urban ecosystems are not homogenous; within human settlements we can find different habitat subtypes which can be occupied by species with different tolerance to certain aspects of urban life (Jokimäki and Kaisanlahti-Jokimäki, 2003; Møller et al., 2012; Aronson et al., 2014; Fischer et al., 2015).

Species richness is often used as an operational variable reflecting the state of biological diversity (Jiguet et al., 2005) and constituting one of the most useful measures of biodiversity, mainly in birds (Gotelli and Colwell, 2001; Ricklefs, 2012; Morelli, 2013; Young et al., 2013). The main factor implicated in variation of species richness is habitat size, followed by spatial heterogeneity of area, its isolation, productivity and age (MacArthur and Wilson, 1967; Fernández-Juricic and Jokimäki, 2001; Mittelbach et al., 2001; Pautasso et al., 2011). Furthermore, for birds, species richness and abundance are often correlated (Ferenc et al., 2014; Jokimäki et al., 2016). Urbanization is obviously linked to an increased accumulation of avian biomass but a reduction in species richness (Chace and Walsh, 2006). Additionally, bird abundance trends have been correlated with specific patterns of urban-related habitat changes (Germaine et al., 1998; Jokimäki et al., 2016). Urbanization process endangers species in many ways: a) by removal of native habitats because of development on the urban–rural fringe, and b) by indirect effects, due to the fact that urbanization can deplete the resources in surrounding areas (Czech et al., 2000). Moreover, human presence can reduce breeding abundance, affecting also the foraging strategies of urban birds (Fernández-Juricic et al., 2001).

Parks and cemeteries are known as biodiversity islands in urban ecosystems (Jokimäki, 1999; Fernández-Juricic and Jokimäki, 2001). They can stabilize species richness and population structures of several animal groups, and their value as refuges for birds has been underlined (Lussenhop, 1977). Parks and cemeteries belong to the best recognized and studied types of urban green space, along with urban woodlands (forests) and gardens (Luniak and Pisarski, 1982; Jokimäki 1999; Low et al., 2009). They differ significantly in terms of how they are managed and perceived by their users and are associated with different sets of values revealed by urban inhabitants. Proximity to parks tends to be perceived as an amenity, while proximity to cemeteries as a disamenity, by apartment buyers (Tudor et al., 2013; Czembrowski and Kronenberg, 2016). Although cemeteries are used for recreational purposes in Central and Eastern Europe (Jakóbczyk-Gryszkiewicz et al., 2008), they are far less visited than parks. Indeed, similar reluctance to use cemeteries for recreational purposes (compared to positive attitudes towards visiting parks) can also be observed in other regions and continents (Huang, 2007; Kjøller, 2012). One more important aspect of urban parks and cemeteries is that they are usually managed in a top-down manner by local managers (in general these are local authorities in the case of parks and church authorities in the case of cemeteries). This changed their ecological features and usually support lower biodiversity than in the case of green spaces where a bottom-up management practice is followed, such as allotment gardens (Andersson et al., 2007).

The main aim of this study was to compare the biodiversity of bird communities in two urbanized habitats: parks and cemeteries in Central Europe. First, bird species richness and diversity composition were analysed. Then, we focused on the differences between bird species most characteristic of both types of urban green space.

2. Methods

2.1. Data collection

In this study, we focused on bird communities of parks and cemeteries in three Central European countries: Poland, Slovakia and Czech Republic. The data were collected by literature review based on a search (key words: park* OR cemeter* AND cit* OR town*) of scientific databases (Scopus; Web of Science and JSTOR); an internet search (Google/Google Scholar); as well as published and unpublished ornithological bibliographies and other sources (see Fig. A; ESM for data sources distribution). When papers with relevant information on our topic were selected; their references (backward search) and citation records (forward search) were searched for other articles that could provide relevant data.

Data for parks and cemeteries were used only if breeding bird community was established by territory mapping method (Tomiałojć, 1980). Such collected data were then treated as paired couples meaning that we included only sources where both habitats types were studied simultaneously in the same city/town. This approach eliminated many studies on parks from our sampling, but we obtained a more balanced geographic record. We extracted from these publications basic data on geographic location (latitude and altitude), habitat type (park or cemetery), number of breeding pairs, as well as total number of breeding species (for full index of sites see Supplementary Table 1). Furthermore, each sampling site (park or cemetery) was described by set of environmental variables. We used remote sensing and field information, available from the authors. The environment was described using the following variables: area (ha), age of trees (in years, an estimation of maximum age of the oldest trees within the area), canopy coverage (%), building coverage (%), level of fragmentation (ranked from 1 (minimum), to 4 (maximum)), distance to nearest urban area (meters), distance to nearest natural area (meters), presence or absence of artificial lights, amount of shrubs (ranked from 1 (minimum) to 4 (maximum)).

2.2. Statistical analyses

In this study, species richness was used as a main descriptor of breeding avifauna because provides one of the simplest and univariate measures of community diversity (Magurran, 2004). The number of species present in a given area is often used as an operational variable reflecting the state of biological diversity (Jiguet et al., 2005). We intentionally decide not to work with number of breeding pairs and density because in the relatively small cemeteries and parks, many bird species foraged outside breeding place, and many nested colonially and semicolonially (e.g. *Corvus frugilegus, Columba palumbus*, *Turdus pilaris*, Carduelidae) which makes studies on density irrelevant (Luniak, 1981; Tomialojc, 1970, 1980; Jokimäki and Kaisanlahti-Jokimäki, 2003). Bird richness was calculated as the number of bird species recorded in each site (park or cemetery). The bird species diversity was calculated for each site using the Shannon–Weaver diversity index. We used linear regression to calculate the correlation between biodiversity measures (bird species richness and diversity), and biodiversity measures with the size of cemeteries or parks. A comparison of the area size of cemeteries and parks was performed using Welch two sampling *t*-test.

We used non-metric multidimensional scaling (NMDS) to perform a preliminary comparison between cemeteries and parks, based on environmental characteristics used to describe the sampling sites (area, canopy, shrub and building coverage, distance to nearest urban area, distance to nearest natural area, presence of artificial lights) and bird species composition (number of individuals per species in each sampling site). The NMDS is an indirect gradient analysis approach which produces an ordination based on a distance or dissimilarity matrix, that collapse information from multiple dimensions (e.g, from multiple communities, sites, etc.) into two dimensions (Kenkel and Orloci, 1993;

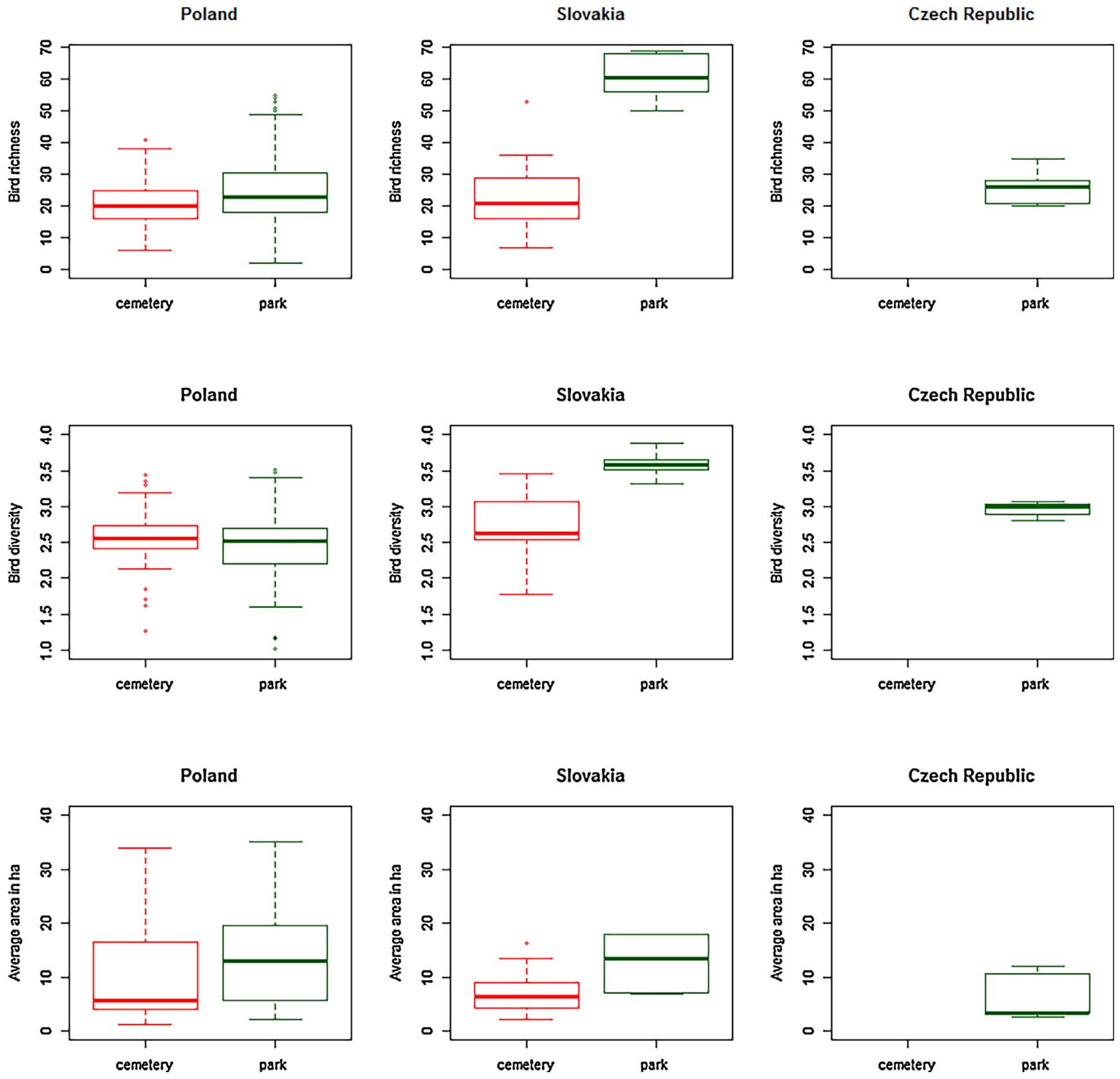

Fig. 1. Bird species richness and diversity and area (ha) in parks and cemeteries in three countries of Central Europe. The box plots show medians, quartiles, 5- and 95-percentiles and extreme values.

Sreekar et al., 2015). The values of stress of the NMDS ≤ 0.2 provides a good representation of data (Kenkel and Orloci, 1993).

We used Mantel tests to check for spatial autocorrelation issues in dataset (Mantel, 1967). This test evaluates the similarity between two matrices: one measuring ecological distance (e.g. differences in bird species richness) and one as geographical distance (Legendre and Legendre, 2012). We used Monte Carlo permutations with 9999 randomizations to test for significance (Oksanen, 2014). Generalized Linear Mixed Models (GLMMs) were used to study the associations between pattern of bird species richness and diversity (response variables) in parks or cemeteries and the area, environmental characteristics (age of trees, canopy coverage, building coverage, level of fragmentation, distance to urban, distance to nearest natural area, presence of artificial lights and shrubs, modelled as fixed effects (modelled as predictor variables). Also possible interactions between area and habitat type were included during model procedure. Sampling site (plot identity) (groups = 89), year of record (groups = 41) and country (groups = 3) were added as a random factors in the model, to account for potential differences related to these variables. Bird species richness was assumed as Poisson distribution, while species diversity was modelled as a Gaussian family. Because our data showed slight evidence of spatial autocorrelation for bird species richness, we proceed by resolving the problem including the interaction term latitude/longitude into the model specification (Dormann et al., 2007). Models were fitted by maximum likelihood (Laplace Approximation), using the package ‘lme4′ (Bates et al., 2014), and Akaike’s Information Criterion (AIC) was used to determine the model that ‘best’ explained variation in the data (Burnham and Anderson, 2002).

Finally, in order to study the bird species typical for parks and cemeteries, the indicator value method was used (IndVAL analysis) (De Cáceres et al., 2010; De Cáceres and Jansen, 2012). The IndVAL analysis is based on specificity, which is the conditional probability of a positive predictive value of a given species as an indicator of the target plot group and sensitivity (or fidelity), which is the conditional probability that the given species will be found in a newly surveyed plot belonging to the same plot group (Dufrene and Legendre, 1997), producing a percentage indicator value (IndVAL) for each species. To be characteristic of a certain habitat type, a species has to be found reliably and almost exclusively within that habitat. Therefore, only bird species having a value of IndVAL statistic higher than 20% and a p value lower than 0.05 were considered as indicator species for each habitat type (Della Rocca et al., 2014).

All statistical analyses were performed with R ver. 3.1.0 (R Core Team, 2014).

3. Results

In total of 4270 observations of 110 different breeding bird species were collected during studies of urban parks and cemeteries in Poland, Slovakia and Czech Republic. Altogether, we obtained data for 170 sampling sites (142 in Poland, 22 in Slovakia and 6 in Czech Republic), distributed in 36 different cities and towns. The oldest data collected were from 1952, and the newest from 2012 (see Supplementary Table 1). The sampling sites were distributed among 120 parks and 50 cemeteries. The size of both green space types ranged between 1.2–42 ha for cemeteries, and 1.2–47.8 ha for parks. Based on all data collected, the average area was similar for both green space types (10.8 for cemeteries and 13.0 for parks, t = 1.23, df = 74.5, p = 0.22).

The NMDS ordination plot for environmental variables (Fig. B, ESM) showed a relative small separation between cemeteries and parks. On the other hand, for bird species composition, the NMDS ordination (Fig. B, ESM) shows plots less compact in the space of ordination. These results suggest that cemeteries and parks are both similar in terms of environmental characteristics as well as in terms of bird composition, but the overall bird species composition is more variable than environmental characteristics.

Bird species richness ranged from 2 to 68 species among studied sites, with an average of 25 species per sampling sites. The species diversity was significantly correlated with bird species richness ($r^2 = 0.41$, F = 118.2, df = 168, $p < 0.001$). However, patterns of bird species richness, species diversity and area of parks and cemeteries, were slightly different among countries (Fig. 1). On country level, we found several differences in species richness and diversity between parks and cemeteries (Fig. 2). Although no differences in area size between parks and cemeteries were revealed when all records were putted together, we found significant differences on country level (Fig. 2). Furthermore, the positive significant relationship between species richness and area was found in both parks and cemeteries ($r^2 = 0.20$, F = 30.27, df = 118, $p < 0.001$ and $r^2 = 0.11$, F = 5.31, df = 45, p = 0.02, respectively). The correlation between species diversity and area was non-significant in both parks and cemeteries ($r^2 = 0.02$, F = 2.84, df = 118, p = 0.06, $r^2 = 0.009$, F = 0.64, df = 65, p = 0.42, respectively).

Table 1
Fixed-effect parameters in GLMM, accounting for variation in bird species richness and species diversity in relationship to area (ha), habitat type (park or cemetery), age of trees, canopy coverage, building coverage, level of fragmentation, distance to nearest urban area, distance to nearest natural area, presence of artificial lights and abundance of shrubs. The full model is based on 150 observations and it is the result of an automated model selection procedure including possible interactions between covariates (area and habitat type). SamplingSampling site (plot identity) (groups = 89), year of record (groups = 41) and country (groups = 3) were added as a random factors in the model. Only significant variables (at $P < 0.05$) selected in the best model are shown in the table.

Fixed effects/Response variable	Estimate	SE	z value	P
Species richness				
(Intercept)	2.843	0.270	10.522	< 0.001
Age of trees (100–250 years)	0.223	0.109	2.029	0.042
Canopy coverage	0.030	0.010	2.067	0.038
Area (ha): Habitat(Park)	0.112	0.058	1.925	0.049
Species diversity				
(Intercept)	2.659	0.432	6.152	< 0.001
Area (ha)	0.014	0.006	0.245	0.050

The results of GLMM procedures showed a positive correlation between bird species richness and the age of oldest trees in the site, the

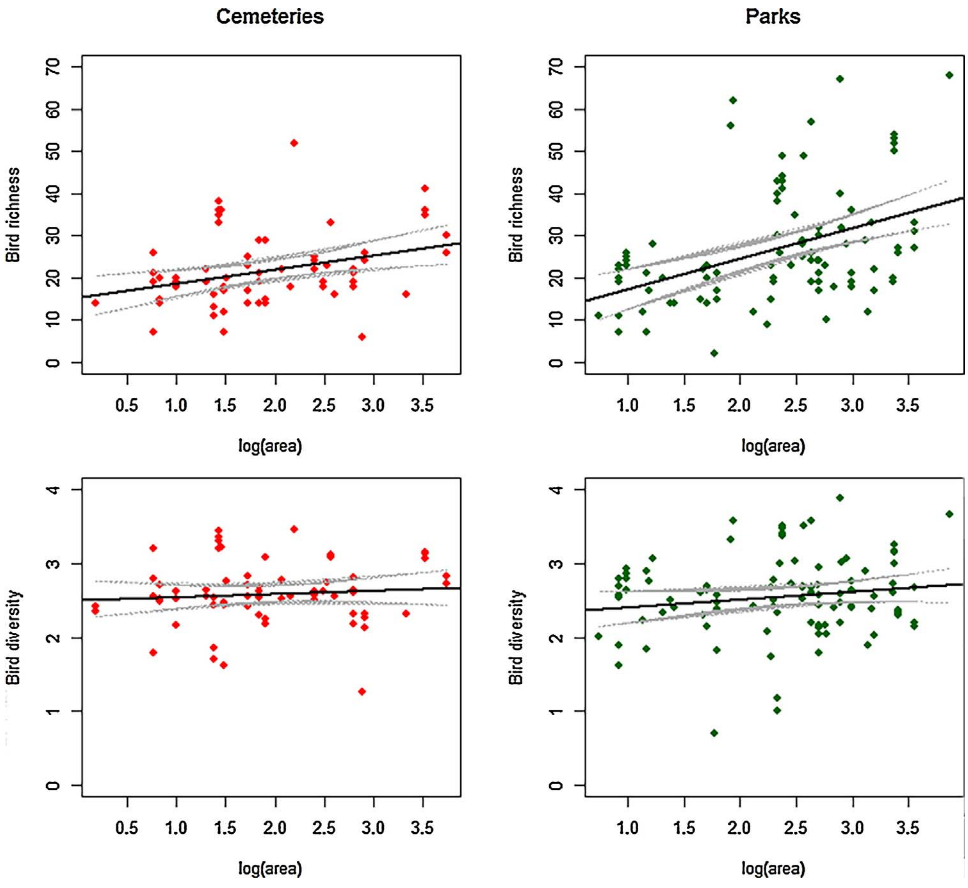

Fig. 2. Relationship between bird species richness, bird diversity and area in parks and cemeteries.

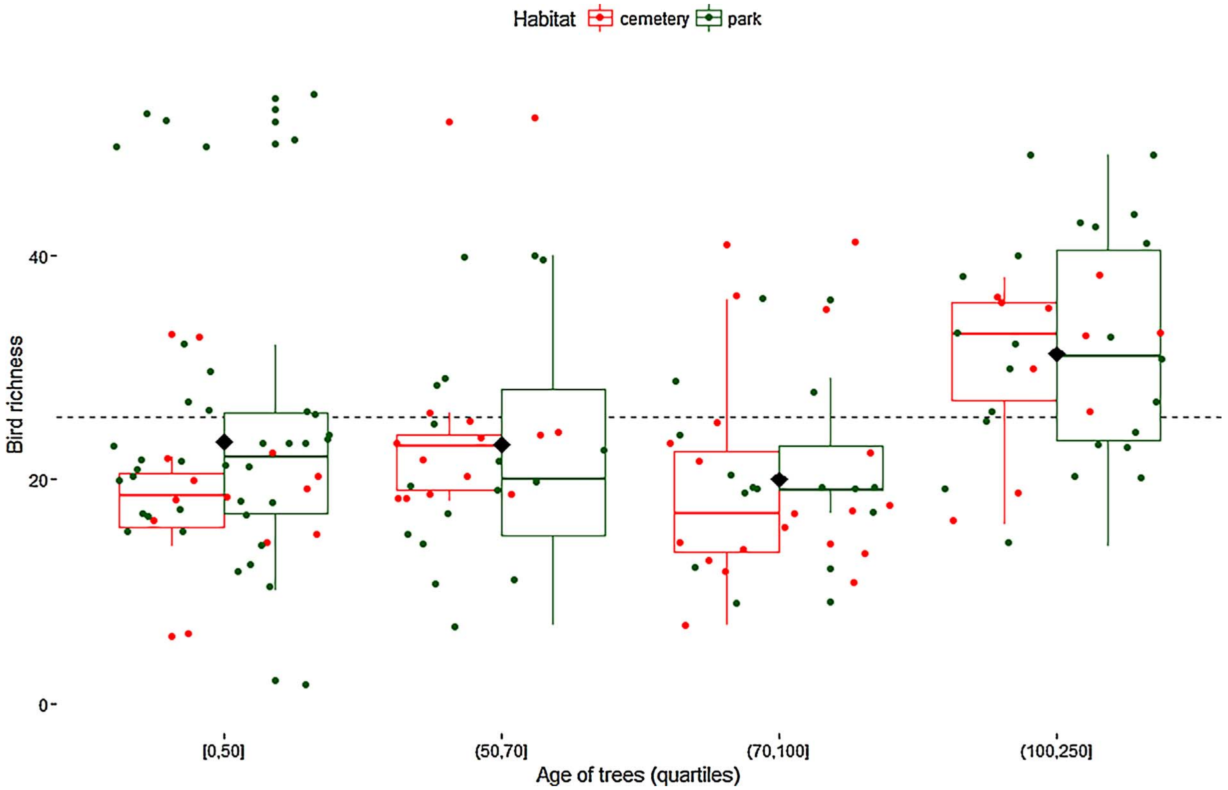

Fig. 3. Comparison of bird species richness between parks and cemeteries, in a gradient of trees classified by age. The y-axis represents the estimated variable. The box plots show medians, mean (black rhombus), quartiles, 5- and 95-percentiles and extreme values.

coverage of canopy and the area size in parks (Table 1). The Fig. 3 show the differences in bird species richness in both habitat (cemeteries and parks) in a gradient of the age of trees, classified in quartiles. Bird species diversity was weakly but positively linked only to the size of cemeteries and parks. Interestingly, habitat type did not play important role in predicting bird species richness or diversity (Table 1).

We further revealed differences in the species composition of bird communities between cemeteries and parks. IndVAL analysis provided the list of species which describe and are representative for one of the habitat types and the responses of each bird species to each habitat type, in terms of specificity (component "A" of IndVAL) and fidelity (component "B" of IndVAL) (Table 2). In addition, the "multipatt" function produced, at the first level, the representative species for particular sites. Of them, 12 bird species were significantly diagnostic for parks, while only five bird species for cemeteries (Table 2).

Table 2
Results of the IndVAL analysis on bird species from cemeteries and parks. The component A is referred to the specificity, while the component B is referred to the fidelity of the species to each habitat type. Only species with 'stat' values higher than 0.20 were selected at 0.05 *p*-level.

Species	A	B	stat	p
Cemetery				
Dryobates minor	0. 5791	0.8600	0. 706	0.002
Columba palumbus	0. 5454	0.8600	0.6850	0.037
Phoenicurus phoenicurus	0.6512	0.5600	0.6040	0.001
Oenanthe oenanthe	0.9438	0.1400	0.3640	0.002
Serinus serinus	1.0000	0.0600	0.2450	0.019
Park				
Sylvia atricapilla	0.6010	0.7833	0.6860	0.010
Carduelis carduelis	0.6044	0.6417	0.6230	0.028
Phylloscopus collybita	0.6757	0.5000	0.5810	0.022
Strix aluco	0.7692	0.4000	0.5550	0.003
Phylloscopus sibilatrix	0.8304	0.3917	0.5700	0.002
Coccothraustes coccothraustes	0.6989	0.3250	0.4770	0.046
Anas platyrhynchos	0.9055	0.1917	0.4170	0.004
Luscinia luscinia	0.8929	0.1667	0.3860	0.024
Columba livia	0.8065	0.1667	0.3670	0.040
Leiopicus medius	1.0000	0.1333	0.3650	0.022
Ficedula albicollis	1.0000	0.0917	0.3030	0.034
Regulus regulus	1.0000	0.0917	0.3030	0.029

4. Discussion

Although our review study based on data collected by different observers, with different time regime and small differences in methodology, as normally biased in this kind of study we obtained very strong findings. Our results highlighted differences in species composition between cemeteries and parks, which is novel in broad temporal and spatial scale (*cf*. Ferenc et al., 2014; Fernández-Juricic and Jokimäki, 2001; Gaston, 2010). We further revealed impact of canopy and age of trees on avian bird communities, supporting other studies highlighting urban greenery and tree effects on composition of bird communities (Morelli et al., 2017; Schütz and Schulze, 2015).

While bird species richness and diversity was greater in cemeteries than in parks in Slovakia, we found the opposite trend in Poland; however, these differences are not statistically significant (Table 1). Slight differences in species richness could be due to species–area relationship (Luniak 1981; Marzluff 2005) because parks are larger than cemeteries in Poland, but are quite similar in Slovakia. Besides area size, habitat heterogeneity is one of best predictors of variability in species richness (Roth, 1976; Atauri and de Lucio, 2001; Reif, 2007). Therefore, it is possible that Polish parks and Slovak cemeteries provide more diversified structure of vegetation than other urban green spaces (Pauleit and Duhme, 2000) and thus offer life space for wider community of birds. Also other factors, like location area within the city (centre *vs*. periphery) and therefore access to open space with food can be crucial to occurrence and population size of many species, especially pigeons, doves, corvids and some thrushes and finches (Fernández-Juricic and Jokimäki, 2001; Biadun and Zmihorski, 2011; Ferenc et al., 2014; Mikula et al., 2014), however it not influenced significantly park and cemetery avian communities. On the other hand, also more detailed factors describing green patches like age of trees and canopy cover affect bird communities in parks and cemeteries, and importance of both factors are already well documented generally for avian communities (Wiens, 1992) and particularly in urban areas (Luniak, 1981; Jokimäki. 1999). Results of analysis underline especially positive function of very old trees (older than 100 years), what was documented to many functional group of organisms (Stagoll et al., 2012).

We further found that bird community composition differed between parks and cemeteries. Whereas average area did not significantly differ between both habitat types, we assumed that differences in species composition are linked to species-specific habitat selection, although, other factors, such as land use patterns and human behaviour differences, can play role as well. Cultural and behavioural differences of human behaviour between parks and cemeteries can also explain the differences. Human activity is more tangible in parks where people play, practice sports or walk (including with pets), often in larger groups; whereas cemeteries are quieter and only occasionally visited with pets. Consequent factors, such as human density, speed of approach, encounter group size or presence of pet while walking, seem to have an impact on animal risk level perception (Fernández-Juricic et al., 2001; Miller et al., 2001; Liao et al., 2005). Moreover, land uses and management practices in parks and cemeteries can explain some differences in bird community composition as well. For instance, a recent trend of removing trees and other forms of vegetation can be observed particularly in cemeteries, which is mostly related to the perceived need for ensuring public safety. This reflects one of the important barriers to urban greening and urban green space preservation − that trees and urban vegetation in general are often perceived as a nuisance (Kronenberg, 2015). Clearly, this also has an impact on bird species diversity.

We indeed found differences in distribution of several species with quite narrow habitat requirements between parks and cemeteries. For instance, *Phoenicurus phoenicurus* was typical for cemeteries, especially in Poland. In sympatry with *Phoenicurus ochruros*, the former species inhabits habitats with higher proportion of trees and lower proportion of buildings (Sedláček et al., 2004). Pauleit and Duhme (2000) showed that cemeteries can be characterized by higher coverage of woody vegetations than parks and can thus provide a more suitable habitat for *Phoenicurus phoenicurus*. Also *Columba palumbus* is reaching highest densities in habitats with sufficient tree coverage (Palomino and Carrascal, 2006), small sacral architecture and can therefore prefer cemeteries over parks. Different environmental conditions could also play a role in distributional patterns of some woodpeckers. Our analysis revealed that *Dryobates minor* was typical in cemeteries, whereas *Leiopicus medius* predominantly inhabited parks. Again, this could be linked to different habitat preferences between species as site occupancy in *Dryobates minor* is positively affected by woodland area and shrub cover, and negatively by urbanization; while *Leiopicus medius* strongly prefers mature oak dominated stands (Myczko et al., 2014) the proportion of which is higher in several Central European parks than cemeteries (e.g. Reháčková and Pauditšová, 2004; Kopij, 2014). Priority distribution of *Strix aluco* and *Ficedula albicollis* in parks can be connected with higher availability of old trees with cavities in park habitat (Tomialojc, 1970). Surprising is the lack of other owls, especially *Athene noctua* that can breed at the hollows of old trees that can be found in parks and cemeteries (Grzywaczewski, 2009). Preference of other species for parks could be related to the higher proportion of shrubs (*Sylvia atricapilla*, *Luscinia luscinia*), fruit trees (*Coccothraustes coccothraustes*), ponds or water streams (*Anas platyrhynchos*) and intentional feeding by people (*Columba livia*). On the other hand, amount of rock-like structures could be responsible for *Oenanthe oenanthe* preference for cemeteries rather than parks.

We further confirmed that parks and cemeteries are important biodiversity hotspots, mainly in urbanized environments (Fernández-Juricic and Jokimäki 2001). In general, urban adapters prefer tree-rich habitats, are omnivorous and granivorous, sedentary and higher nested (Chace and Walsh, 2006; Croci et al., 2008). However, our findings indicate possibility that parks and cemeteries can represent suitable breeding habitats also for urban avoiders due to their specific environmental characteristics. We found that numerous passerine species which were previously recognised as urban avoiders in Central and West European cities (Croci et al., 2008; Maklakov et al., 2011) can actually successfully inhabit these sites. These species can be classified in several ecological groups (categories based on mixed traits − see: Tomialojc, 1970; Croci et al., 2008), such as mainly insectivorous: *Lanius* (*collurio* and *excubitor*), *Oriolus oriolus*, *Certhia familiaris*; ground or low nesting: *Alauda arvensis*, *Emberiza citrinella*, *Miliaria calandra*, *Sylvia* (*curruca* and *communis*), *Anthus trivialis*, *Motacilla flava*, *Oenanthe oenanthe*, *Lucustella fluviatilis*, both *Saxicola*, and all *Acrocephalus* species, and expanding species: *Turdus pilaris*. Moreover, majority of these birds are migrants. Insectivorous, ground and low nesting and migratory bird species are traditionally viewed as the bird groups most sensitive to environmental quality (Clergeau et al., 1998; McKinney, 2002). Parks and cemeteries can thus provide suitable habitat for these birds in urban environments (Lussenhop 1977; Miller and Hobbs, 2002) and serve as important points of local invasions for urban exploiting or refugees for urban less tolerant species (Blair and Johnson, 2008).

Finally, we found that bird species richness for both habitats and diversity for parks was positively correlated with area size. Moreover, species composition of bird assemblages significantly differed between parks and cemeteries with several species strongly preferring one of habitat types. Unequal distribution of these species could be linked to different habitat structure (e.g. age and density of vegetation), human behaviour and land use patterns between parks and cemeteries. Confirmed presence of numerous bird species, up to now known as urban avoiders, indicates important role of parks and cemeteries as a refuges for urban intolerant birds which has several implications for urban green space management practices.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ufug.2017.08.014.

References

Andersson, E., Barthel, S., Ahrné, K., 2007. Measuring social–ecological dynamics behind the generation of ecosystem services. Ecol. Appl. 17, 1267–1278. http://dx.doi.org/10.1890/06-1116.1.

Aronson, M.F.J., La Sorte, F.A., Nilon, C.H., Katti, M., Goddard, M.A., Lepczyk, C.A., Warren, P.S., et al., 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proc. R. Soc. Lond. B 281, 20133330.

Atauri, J.A., de Lucio, J.V., 2001. The role of landscape structure in species richness distribution of birds, amphibians, reptiles and lepidopterans in Mediterranean landscapes. Landsc. Ecol. 16, 147–159.

Bates, D., Maechler, M., Bolker, B., Walker, S., 2014. Lme4: Linear Mixed-effects Models Using Eigen and S4, R Package. (Available at: http://cran.r-project.org/package=lme4).

Biadun, W., Zmihorski, M., 2011. Factors shaping a breeding bird community along an urbanization gradient: 26-year study in medium size city (Lublin, SE Poland). Pol. J. Ecol. 59, 381–389.

Blair, R.B., Johnson, E.M., 2008. Suburban habitats and their role for birds in the urban–rural habitat network: points of local invasion and extinction? Landsc. Ecol. 23, 1157–1169.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, 2nd edition. Springer Verlag, New York, NY, USA.

Chace, J.F., Walsh, J.J., 2006. Urban effects on native avifauna: a review. Landsc. Urban

Plan. 74, 46–69.

Clavero, M., Brotons, L., 2010. Functional homogenization of bird communities along habitat gradients: accounting for niche multidimensionality. Glob Ecol Biogeogr 19, 684–696. http://dx.doi.org/10.1111/j. 1466-8238.2010.00544. x.

Clavero, M., Brotons, L., Herrando, S., 2011. Bird community specialization, bird conservation and disturbance: the role of wildfires. J. Anim. Ecol. 80, 128–136. http://dx.doi.org/10.1111/j. 1365-2656.2010.01748. x.

Clergeau, P., Savard, J.P.L., Mennechez, G., Falardeau, G., 1998. Bird abundance and diversity along an urban-rural gradient: a comparative study between two cities on different continents. Condor 100, 413–425.

Croci, S., Butet, A., Clergeau, P., 2008. Does urbanization filter birds on the basis of their biological traits. Condor 110, 223–240.

Czech, B., Krausman, P.R., Devers, P.K., 2000. Economic associations among causes of species endangerment in the United States. Bioscience 50, 593–601.

Czembrowski, P., Kronenberg, J., 2016. Hedonic pricing and different urban green space types and sizes: insights into the discussion on valuing ecosystem services. Landsc. Urban Plan. 146, 11–19. http://dx.doi.org/10.1016/j.landurbplan.2015.10.005.

De Cáceres, M., Jansen, F., 2012. Functions to assess the strength and significance of relationships of species site group associations. In: In: De Cáceres, M., Legendre, P., Moretti, M. (Eds.), Improving Indicator Species Analysis by Combining Groups of Sites 119. Oikos, pp. 1674–1684. http://dx.doi.org/10.1111/j. 1600-0706.2010. 18334. x.

Della Rocca, F., Stefanelli, S., Pasquaretta, C., Campanaro, A., Bogliani, G., 2014. Effect of deadwood management on saproxylic beetle richness in the floodplain forests of northern Italy: some measures for deadwood sustainable use. J Insect Conserv. 18, 121–136. http://dx.doi.org/10.1007/s10841-014-9620-1.

Dormann, C.F., McPherson, J.M., Araújo, M.B., et al., 2007. Methods to account for spatial autocorrelation in the analysis of species distributional data: a review. Ecography 30, 609–628. http://dx.doi.org/10.1111/j.2007. 0906-7590.05171. x.

Dufrene, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67, 345–366.

Ferenc, M., Sedláček, O., Fuchs, R., 2014. How to improve urban greenspace for woodland birds: site and local-scale determinants of bird species richness. Urban Ecosyst. 17, 625–640. http://dx.doi.org/10.1007/s11252-013-0328-x.

Fernández-Juricic, E., Jokimäki, J., 2001. A habitat island approach to conserving birds in urban landscapes: case studies from southern and northern Europe. Biodiv. Conserv. 10, 2023–2043. http://dx.doi.org/10.1023/A:1013133308987.

Fernández-Juricic, E., Jimenez, M.D., Lucas, E., 2001. Bird tolerance to human disturbance in urban parks of Madrid (Spain): Management implications. In: Marzluff, J., Bowman, R., Donnelly, R. (Eds.), Avian Ecology and Conservation in an Urbanizing World. Springer, US, New York, pp. 259–273.

Fischer, J.D., Schneider, S.C., Ahlers, A.A., Miller, J.R., 2015. Categorizing wildlife responses to urbanization and conservation implications of terminology. Conserv. Biol. 29, 1246–1248. http://dx.doi.org/10.1111/cobi.12451.

Gaston, K.J., 2010. Urban Ecology. Cambridge University Press, Cambridge UK.

Germaine, S.S., Rosenstock, S.S., Schweinsburg, R.E., Richardson, W.S., 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson. Arizona Ecol. Appl. 8, 680–691. http://dx.doi.org/10.1890/1051-0761(1998)008[0680:RABBHA]2.0. CO;2.

Gotelli, N.J., Colwell, R.K., 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. Ecol. Lett. 4, 379–391. http://dx.doi.org/10.1046/j. 1461-0248.2001.00230. x.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., Briggs, J.M., 2008. Global change and the ecology of cities. Science 319, 756–760.

Grzywaczewski, G., 2009. Home range size and habitat use of the little owl *Athene noctua* (Scopoli 1769) in lublin region (East Poland). Ardea 97, 541–545.

Huang, S.C.L., 2007. Intentions for the recreational use of public landscaped cemeteries in Taiwan. Landsc. Res. 32, 207–223. http://dx.doi.org/10.1080/01426390701231614.

Jakóbczyk-Gryszkiewicz, J., Dyba, W., Marcińczak, S., Tanaś, S., 2008. Zagospodarowanie Terenów Rekreacyjnych W Łodzi: Plany, Perspektywy. Łódzkie Towarzystwo Naukowe, Łódź.

Jiguet, F., Renault, O., Petiau, A., 2005. Estimating species richness with capture—recapture models: choice of model when sampling in heterogeneous conditions. Bird Study 52, 180–187.

Jokimäki, J., Kaisanlahti-Jokimäki, M.L., 2003. Spatial similarity of urban bird communities: a multiscale approach. J. Biogr 30, 1183–1193.

Jokimäki, J., Suhonen, J., Kaisanlahti-Jokimäki, M.L., 2016. Urbanization and species occupancy frequency distribution patterns in core zone areas of European towns. Eur. J. Ecol. 2, 23–43.

Jokimäki, J., 1999. Occurrence of breeding bird species in urban parks: effects of park structure and broad-scale variables. Urban Ecosyst. 3, 21–34.

Kareiva, P., Watts, S., McDonald, R., Boucher, T., 2007. Domesticated nature: shaping landscapes and ecosystems for human welfare. Science 316, 1866–1869.

Kenkel, N.C., Orloci, L., 1993. Applying metric and nonmetric multidimensional scaling to ecological studies: some new results. Ecology 67, 919–928.

Kjøller, C.P., 2012. Managing green spaces of the deceased: characteristics and dynamics of Danish cemetery administrations. Urban For. Urban Green 11, 339–348. http://dx.doi.org/10.1016/j.ufug.2012.02.002.

Klem Jr., D., 1990. Collisions between birds and windows: mortality and prevention (Colisiones de pájaros con ventanas: mortalidad y prevención). J. Field Ornithol. 61, 120–128.

Kopij, G., 2014. Distribution and abundance of the Red Squirrel *Sciurus vulgaris* in an urbanised environment. Acta Musei Silesiae Sci. Nat. 63, 255–262.

Kronenberg, J., 2015. Why not to green a city? Institutional barriers to preserving urban ecosystem services. Ecosyst. Serv. 12, 218–227. http://dx.doi.org/10.1016/j.ecoser.2014.07.002.

Legendre, P., Legendre, L., 2012. Numerical Ecology, 3rd edn. Elsevier, Amsterdam.

Liao, J., Blumstein, D.T., Libby, S., Geist, C., 2005. Does intruder group size and orientation affect flight initiation distance in birds? Anim. Biodivers. Conserv. 28, 69–73.

Low, S., Taplin, D., Scheld, S., 2009. Rethinking Urban Parks: Public Space and Cultural Diversity. University of Texas Press, Austin.

Luniak, M., Pisarski, B., 1982. Animals in Urban Environment. Wydawnictwo Polskiej Akademii Nauk, Warszawa.

Luniak, M., 1981. The birds of the park habitats in Warsaw. Acta Ornithol. 18, 335–370.

Lussenhop, J., 1977. Urban cemeteries as bird refuges. Condor 79, 456–461.

Møller, A.P., Diaz, M., Flensted-Jensen, E., et al., 2012. High urban population density of birds reflects their timing of urbanization. Oecologia 170, 867–875.

Møller, A.P., Jokimäki, J., Skorka, P., Tryjanowski, P., 2014. Loss of migration and urbanization in birds: a case study of the blackbird (*Turdus merula*). Oecologia 175, 1019–1027. http://dx.doi.org/10.1007/s00442-014-2953-3.

MacArthur, R.H., Wilson, E.O., 1967. The Theory of Island Biogeography. Princeton University Press, Princeton.

Magurran, A., 2004. Measuring Biological Diversity. Blackwell Science, Oxford, UK.

Maklakov, A.A., Immler, S., Gonzalez-Voyer, A., Rönn, J., Kolm, N., 2011. Brains and the city: big-brained passerine birds succeed in urban environments. Biol. Lett. 7, 730–732.

Mantel, N., 1967. The detection of disease clustering and a generalized regression approach. Cancer Res. 27, 209–220.

Marzluff, J.M., 2005. Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. Urban Ecosyst. 8, 157–177.

McDonald, R.I., 2008. Global urbanization: can ecologists identify a sustainable way forward? Front. Ecol. Environ. 6, 99–104.

McKinney, M.L., 2002. Urbanization, biodiversity, and conservation. Bioscience 52, 883–890. http://dx.doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0. (CO;2).

Mikula, P., Hromada, M., Albrecht, T., Tryjanowski, P., 2014. Nest site selection and breeding success in three *Turdus* thrush species coexisting in an urban environment. Acta Ornithol. 49, 83–92.

Miller, J.R., Hobbs, R.J., 2002. Conservation where people live and work. Conserv. Biol. 16, 330–337.

Miller, S.G., Knight, R.L., Miller, C.K., 2001. Wildlife responses to pedestrians and dogs. Wildl. Soc. Bull. 29, 124–132.

Mittelbach, G.G., Steiner, C.F., Scheiner, S.M., et al., 2001. What is the observed relationship between species richness and productivity? Ecology 82, 2381–2396.

Morelli, F., Benedetti, Y., Ibáñez-Álamo, J.D., Jokimäki, J., Mänd, R., Tryjanowski, P., Møller, A.P., 2016. Evidence of evolutionary homogenization of bird communities in urban environments across Europe. Glob. Ecol. Biogeogr. 25, 1284–1293. http://dx.doi.org/10.1111/geb.12486.

Morelli, F., Benedetti, Y., Su, T., Zhou, B., Moravec, D., Šímová, P., Liang, W., 2017. Taxonomic diversity, functional diversity and evolutionary uniqueness in bird communities of Beijing's urban parks: effects of land use and vegetation structure. Urban For. Urban Green. 23, 84–92. http://dx.doi.org/10.1016/j.ufug.2017.03.009.

Morelli, F., 2013. Quantifying effects of spatial heterogeneity of farmlands on bird species richness by means of similarity index pairwise. Int. J. Biodivers. 2013, 1–9. http://dx.doi.org/10.1155/2013/914837.

Myczko, L., Rosin, Z.M., Skórka, P., Tryjanowski, P., 2014. Urbanization level and woodland size are major drivers of woodpecker species richness and abundance. PLoS One 9, e94218.

Oksanen, J., 2014. Multivariate Analysis of Ecological Communities in R: Vegan Tutorial. (Available at: http://cc.oulu.fi/∼jarioksa/popular.html).

Palomino, D., Carrascal, L.M., 2006. Urban influence on birds at a regional scale: a case study with the avifauna of northern Madrid province. Landsc. Urban Plan. 77, 276–290.

Pauleit, S., Duhme, F., 2000. Assessing the environmental performance of land cover types for urban planning. Landsc. Urban Plan. 52, 1–20.

Pautasso, M., Böhning-Gaese, K., Clergeau, P., et al., 2011. Global macroecology of bird assemblages in urbanized and semi-natural ecosystems. Glob. Ecol. Biogeogr. 20, 426–436.

Core Team, R., 2014. R: A Language and Environment for Statistical Computing. (Vienna, Austria).

Reháčková, T., Pauditšová, E., 2004. Evaluation of urban green spaces in Bratislava. Boreal Environ. Res. 9, 469–477.

Reif, J., 2007. Factors affecting local bird species richness patterns in the Czech Republic: an analysis of the Breeding Bird Monitoring Programme data. Sylvia 43, 31–43.

Ricklefs, R.E., 2012. Species richness and morphological diversity of passerine birds. Proc. Natl. Acad. Sci. U.S.A. 109, 14482–14487. http://dx.doi.org/10.1073/pnas.1212079109.

Roth, R.R., 1976. Spatial heterogeneity and bird species diversity. Ecology 57, 773–782.

Schütz, C., Schulze, C.H., 2015. Functional diversity of urban bird communities: effects of landscape composition, green space area and vegetation cover. Ecol. Evol. 5, 5230–5239. http://dx.doi.org/10.1002/ece3.1778.

Sedláček, O., Fuchs, R., Exnerová, A., 2004. Redstart *Phoenicurus phoenicurus* and black redstart *P. ochruros* in a mosaic urban environment: neighbours or rivals? J. Avian Biol. 35, 336–343.

Sorace, A., 2002. High density of bird and pest species in urban habitats and the role of predator abundance. Ornis Fennica 79, 60–71.

Sreekar, R., Zhang, K., Xu, J., Harrison, R.D., 2015. Yet another empty forest: considering the conservation value of a recently established tropical nature reserve. PLoS Biol. 10, e0117920. http://dx.doi.org/10.5061/dryad.76mg6.

Stagoll, K., Lindenmayer, D.B., Knight, E., Fischer, J., Manning, A.D., 2012. Large trees are keystone structures in urban parks. Conserv. Lett. 5, 115–122.

Tomialojc, L., 1970. Quantitative studies on the synanthropic avifauna of Legnica and its environs. Acta Ornithol. 22, 293–392.

Tomialojc, L., 1980. The combined version of the mapping method. Bird Census Work and Nature Conservation. EBCC, Goettingen, pp. 92–106.

Tscharntke, T., Tylianakis, J.M., Rand, T.A., et al., 2012. Landscape moderation of biodiversity patterns and processes-eight hypotheses. Biol. Rev. 87, 661–685.

Tudor, C.A., Ioja, I.C., Hersperger, A., Patru-Stupariu, I., 2013. Is the residential land use incompatible with cemeteries location? Assessing the attitudes of urban residents. Carpathian J. Earth Environ. Sci. 8, 153–162.

Wiens, J.A., 1992. The Ecology of Bird Communities. Cambridge University Press, Cambridge, UK.

Young, J.S., Ammon, E.M., Weisberg, P.J., et al., 2013. Comparison of bird community indices for riparian restoration planning and monitoring. Ecol. Indic. 34, 159–167. http://dx.doi.org/10.1016/j.ecolind.2013.05.004.