Local quality versus regional connectivity—habitat requirements of wintering woodpeckers in urban green spaces

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Abstract

In urban landscapes, city parks represent strongholds of avian biodiversity. Hence, understanding which variables promote species richness of bird communities has major implications for urban planning in order to sustain high biodiversity in an increasingly urbanised environment. From a management perspective, three options are available: increase park area, increase habitat quality within parks and increase connectivity between parks. We used two woodpecker species, a generalist species (Great Spotted Woodpecker) and a habitat specialist (Middle Spotted Woodpecker), as indicators to identify key variables promoting biodiversity in the city parks of Vienna. Bird surveys were carried out during winter time between 2005 and 2015 in 29 urban parks. An information theoretic approach based on generalised linear models identified park area as the most relevant local variable, positively affecting the occurrence of both species. The variable was included in all best ranked models of the two woodpecker species (based on Akaike’s information criterion corrected for small-sample sizes). Other local scale variables as well as the position of city parks within the urban matrix and their connectivity were of minor importance. Our results also provide some evidence that city parks may act as refuges for birds during cold winters. The park occupancy of the Great Spotted Woodpecker increased significantly with decreasing mean winter temperatures. The management of existing parks and the planning of new parks represent opportunities to improve the ecological conditions for nature development in addition to their principal function to provide recreational, cultural and aesthetic values.

Key words: oak trees, urban parks, woodpeckers, urban development

Introduction

Parks belong to the green infrastructure of cities and provide a broad range of ecological and socio-economic goods and services such as air filtration, micro-climate regulation, noise reduction, and recreational, cultural and aesthetic values (Forman 2014). Within urbanised areas, parks are also hotspots of biodiversity (Fernández-Juricic and Jokimäki 2001; Strohbach, Lerman, and Warren 2013). Understanding which variables promote biodiversity in urban parks is crucial and a prerequisite for an adequate management focused on biodiversity persistence. Hence, it is important to identify key variables sustaining biodiversity and thereby derive management recommendations for park authorities. As species richness of woodpeckers and forest bird richness are often positively related at a local scale and at a landscape level (Mikusinski, Gromadzki, and Chylarecki 2001; Roberge and Angelstam 2006; Drever et al. 2008), we used woodpeckers to identify key variables associated with their occurrence in urban parks.
Although the general importance of woodpeckers as primary cavity producers for cavity-using vertebrates may have been overrated in the past, at least in Europe where most of the tree cavities in forests are created by fungal decay and mechanical damage (e.g. by wind) (Cockle, Martin, and Wesołowski 2011), the situation may be different in urban areas. Especially in managed city parks the formation of cavities through processes such as damage or decay may be limited, as parkland is dominated by mostly healthy trees to ensure safe visits for the public (Sandström, Angelstam, and Mikusiński 2006; Aronson 2017). Hence, woodpeckers may then provide a critical resource for obligate and facultative cavity-using species, underlining their high ecological value (Paine 1969; Bonar 2000; Boonman 2000; Martin, Aitken, and Wiebe 2004). Moreover, woodpeckers are specifically sensitive to increasing urbanisation (Sandström, Angelstam, and Mikusiński 2006; Myczko et al. 2014), thus management measures should early and significantly affect their occurrence. Furthermore, with their colourful plumage, distinctive vocalisations and their habit of drumming on wood and other surfaces, they are easily identifiable by the general public (Del Hoyo, Elliott, and Sargatal 2002). Consequently, these charismatic birds can easily be used to facilitate discussions about conservation of biodiversity and the importance of urban parks.

Biodiversity may be governed by local and regional factors. Urban bird ecology often focuses on the local scale, and park area was often found to be the most influential variable for the occurrence of species (Fernández-Juricic and Jokimäki 2001). Additionally, within urban green spaces variables related to vegetation, such as tree cover and tree species richness, were found to influence abundance and diversity of birds in general (Xie et al. 2016) and of woodpeckers in particular (Morrison and Chapman 2005; Sandström, Angelstam, and Mikusiński 2006; Drever et al. 2008; Myczko et al. 2014).

Recently, the focus of studies of urban bird ecology has shifted to the landscape scale, but the influence of factors such as landscape connectivity on bird abundance and biodiversity is still not sufficiently understood. Some studies have shown that local variables were more important than landscape variables in determining bird diversity and abundance in highly urbanised areas (Evans, Newson, and Gaston 2009; Shwartz, Shirley, and Kark 2013). While others have found that local urban bird richness strongly depended on landscape connectivity (Loss, Ruiz, and Brawn 2009; Shanahan et al. 2011). One reason for these contradictions may lie in the often used ‘urban–rural gradient’ approach. Although being intuitive, easily measurable and practical, its interpretation is often ambiguous with regard to the underlying specific features of the urbanised areas (Beninde et al. 2015).

Generally, the importance of local versus regional variables depends on the spatial scale, the connectivity variables considered and on the traits of the species studied. Concepts of connectivity differ theoretically (e.g. patch-corridor-matrix model, graph theory), and have thus different assumptions and requirements. The patch-corridor-matrix model for instance emphasises connections via corridors, whereas graph theory stresses the position of a patch in a network. Considering species traits, it has been shown for aquatic and terrestrial invertebrates, algae and plants, that generalists are governed more by regional variables than specialist species and that dispersal ability is of crucial importance (Pandit, Kolasa, and Cottenie 2009; Dapporto and Dennis 2013; Funk, Schierner, and Reckendorfer 2013).

We investigated the importance of local and regional scale variables on the park occupancy of two woodpecker species, the Great Spotted Woodpecker Dendrocopos major—one of the more generalist woodpecker species—and the Middle Spotted Woodpecker Dendrocopos medius—a habitat specialist (Mikusiński and Angelstam 1997). We expect that for the Middle Spotted Woodpecker park features (habitat quality) are more important than for the Great Spotted Woodpecker. In contrast, park occupancy of this habitat generalist may depend more strongly on regional variables (connectivity of parks).

To our knowledge until now studies testing for effects of habitat variables on the presence and diversity of woodpecker species in urban landscapes only considered conditions during the breeding season (e.g. Morrison and Chapman 2005; Sandström, Angelstam, and Mikusiński 2006; Myczko et al. 2014). As we carried out winter surveys of woodpeckers over several years, we are able to test for differences in park occupancy between winters. During winter time densities of birds can increase in urban residential areas (Tryjanski et al. 2015), providing some evidence of population shifts from rural towards urban areas in response to harsh weather conditions. By dispersing to urban landscapes, woodpeckers may find sufficient food supply even under adverse conditions due to supplementary feeding (Tryjanski et al. 2015). Furthermore, they face reduced thermoregulatory stress during long, cold winter nights because of the urban heat island phenomenon (Böhm 1998). Hence, especially during harsh winters woodpeckers may more intensely use urban areas and the probability of parks being occupied by Great and Middle Spotted Woodpeckers may increase.

Beside assessing the importance of city parks as refuges for birds during cold winters, results of this study will also contribute to our knowledge on urban bird ecology with respect to local and regional determinants and thus may help facilitating management measures.

Methods

Study area

The study was conducted in Vienna, the largest city in Austria (48°13’N, 16°22’E), with a population of 1.8 million inhabitants and an area covering 415 km² (Statistics Austria 2016). Whereas 21% of the city area are covered by densely built-up areas, around 45% are covered by green space such as forests, meadows, agricultural areas or city parks (Wichmann et al. 2009; MA 41 2014). Thereby, forests cover around 19% with contiguous broadleaved forests at the northern and western outskirts of Vienna, being dominated by oak and beech trees (Wichmann et al. 2009). Large riparian forests with a highly diverse tree species composition can also be found along the river Danube (Wichmann et al. 2009). Around 4% of Vienna are covered by city parks (MA 41 2014). Woodpecker surveys were carried out in 29 urban parks, with a mean area of 2.7 ha ranging from 0.36 ha (Börsepark) to 15.52 ha (Türkenschanzpark), and spread across the city centre of Vienna (Fig. 1 and Table 1). Beside covering a sufficient variation in park area to properly resolve the effects of this variable on woodpecker occupancy, we also chose parks in relation to their absence of connections to other remnants of greenspace via corridors. Hence, no confounding effects between connectivity via corridors and our landscape matrix connectivity measures (see below) could arise. Furthermore, for all selected parks data on their tree composition was available in the tree cadastre of Vienna (see below).

Weather conditions

Winter temperatures for our study area were derived from the BOKU-Met weather station (48°14’16.3”N, 16°19’53.8”E, 266 m
above sea level), located northwest of the Türkenschanzpark (city park code no. 27 in Fig. 1) and operated by the University of Natural Resources and Life Sciences, Vienna (https://meteo.boku.ac.at/wetter/mon-archiv, accessed 19 Aug 2017). Based on a daily 10 min interval and including the months November, December and January mean winter temperatures were calculated for each winter during which bird surveys were carried out.

Bird surveys

Study sites were visited four to eight times (four times: \( n = 1 \) city park, five times: \( n = 12 \), seven times: \( n = 1 \), eight times: \( n = 15 \)) during winter (November–January) between 2005 and 2015 (November: 2008; December: 2005, 2009, 2012, 2013; January 2009, 2013, 2015). Thereby, 16 of the 29 city parks considered in the study were surveyed two times in the winter 2008/9 (November 2008 and January 2009) and all 29 parks were surveyed two times in winter 2012/3 (December 2012 and January 2013). Woodpeckers were surveyed between 08:00 AM and 16:00 PM under favourable weather conditions (i.e. avoiding windy days and/or days of heavy rain and snowfall). Sampling effort was standardised according to park size (10 min/1 ha). The existing network of paths and roads within a park was used for survey routes, trying to cover the entire area of the park in a zigzag-manner. During surveys each woodpecker species heard or seen was recorded, not considering over-flying birds. To avoid the attraction of individuals from surrounding areas, we did not use playback techniques. Furthermore, during winter leafless trees in combination with the conspicuous foraging behaviour of woodpeckers as well as their characteristic calls ensure reliable survey results in the presence of woodpeckers within city parks, even without using playback techniques.

Local scale variables

For analysis, we considered park area and the number of woody plant species as they have been shown to influence bird abundance and diversity in parks (Fernández-Juricic and Jokimäki 2001; Shwartz, Shirley, and Kark 2008). Additionally, we included variables presumably important for woodpeckers such as basal area (Morrison and Chapman 2005). For Great Spotted Woodpeckers patch occupancy seems to be related to the density of large trees (\( >30 \) cm diameter at breast height = DBH; Barrientos 2010). The density of large Quercus trees (\( \geq 37 \) cm DBH) represents an important habitat requisite for Middle Spotted Woodpeckers during as well as outside the breeding season (Robles et al. 2007; Domínguez, Carbonell, and Ramírez 2017; Robles and Ciudad 2017). Consequently, both variables were included in our analyses to describe local habitat quality of urban city parks.

Park area was calculated in ArcGIS 10.2 (ESRI) based on Vienna land use data from the period 2009 to 2012 (City of Vienna 2016). All other local scale variables derived from data of the tree cadastre of Vienna (date of origin: October 2011), containing
information about every live tree (DBH, tree species) planted in the 29 city parks considered in the study (City of Vienna 2016). Based on these data, the amount of woody vegetation within each city park was quantified by calculating the basal area (m²/ha and as the proportion of total park area (%) for trees with DBH > 10 cm (Hedl et al. 2009). Furthermore, number of tree genera (as surrogate for structural diversity) as well as the density of large oaks and large trees were calculated for each park.

Regional scale variables

Regional scale variables were assessed for all 29 city parks in which bird surveys were carried out. For calculating the analysis of the spatial structure of the park network we delineated further 782 parks and other remnants of green space (meadows, lawns and woodlots) using Vienna land use data of the year 2009 (City of Vienna 2016). The mean size of these patches was 2.0 ha and ranged from 0.04 to 121 ha. To quantify connectivity measures we used network analysis (Minor and Urban 2007; Cuming 2010) where the landscape is represented as a set of nodes (points representing habitat patches or sampling sites) connected by edges between them. An edge between two nodes implies that there is some flux between those nodes, as in the case of dispersal between two patches (Minor and Urban 2007). The network was represented by a complete graph, i.e. every node (=park) was connected to each other. We used different network centrality measures to quantify the position of a park in the city (i.e. its connectivity to other urban green spaces), which allowed us to analyse connectivity at different spatial scales and with different focus. Three measures (CN_IDW, CN_IDW2 and CN_IDW3) focused only on the position of the parks within the network, ignoring the sizes of the areas they are connected to. Three additional measures (CA_IDW, CA_IDW2 and CA_IDW3) also took into account the size of patches they are connected to. We applied three methods of inverse distance weighting to allow for the analysis at different spatial scales. IDW gives a linear weight to distances, IDW2 a squared weight and IDW3 a cubic weight. That means that IDW3 has a stronger focus on the network configuration nearby the sampling site whereas IDW also takes into account patches further away. All connectivity measures were standardised [raw value – mean]/standard deviation]. Additionally, we also included the distance to the nearest breeding site as wintering birds may less likely occur in city parks which are further away from their breeding habitats. This may especially be the case for the Middle Spotted Woodpecker, the most resident European woodpecker (Pettersson 1985) and occupying similar home ranges during winter and breeding period (Pasinelli 2003). As available data on the breeding distribution of the two woodpecker species are based on a 618 m × 618 m grid (Wichmann et al. 2009), we calculated the nearest distance between the centroid of each of the 29 city parks and the midpoint of the grid cell showing breeding records of the respective woodpecker species.

We also analysed the landscape matrix surrounding each park in more detail based on Vienna land use data from the period 2010 to 2012 (City of Vienna 2016). Analysis was performed at a circle of 500 m radius, centred on the centroid of each city park, as the composition of the urban matrix within this radius has already been shown to have severe effects on the species richness and functional diversity of city park bird communities within our study area (Schütz and Schulze 2015). Within circles categories of the land use data describing sealed areas (e.g. roads, buildings etc.) were summarised and their areas were calculated, excluding the park areas. We hypothesis that sealed areas, especially buildings which account for most of them, impede movement of woodpeckers since they indicate a high extent of direct human disturbance and/or do not provide suitable habitat, even for dispersal movements. All spatial analyses were carried out in ArcGIS 10.2 (ESRI).

Statistical analysis

For each woodpecker species we used an information theoretic approach to test for effects of local scale predictor variables (park area, basal area, proportion of tree cover, density of large trees, density of large Quercus trees, number of tree genera), regional scale variables (proportion sealed area, distance to nearest breeding site, indices quantifying the connectivity of city parks to other green spaces) and winter in which bird surveys were carried out on the dependent variable park occupancy. Park occupancy was included in the models for each winter separately. In winters in which city parks were surveyed two times, the respective woodpecker species occupied a city park when it could be recorded at least in one of the two surveys. For model selection, we used an all-subset approach, in which all possible combinations of explanatory variables are searched and a subset of models given the most favourable values of the quantitative criterion are identified (Murtaugh 2009; Symonds and Moussalli 2011). Prior to analysis, variables that

| City park code | City park | Area (ha) | D. major | D. medius |
|---------------|-----------|-----------|----------|-----------|
| 1             | Albert-Dub-Park | 0.89      | 0        | 0         |
| 2             | Alfred Böhm Park | 2.76      | 1        | 0         |
| 3             | Alfred-Grünwald-Park | 0.81      | 1        | 0         |
| 4             | Auenbergpark | 2.86      | 1        | 1         |
| 5             | Börsepark | 0.36      | 0        | 0         |
| 6             | Bruno-Kreisky-Park | 1.32      | 0        | 0         |
| 7             | Clemens-Hofbauer-Platz | 0.59      | 0        | 0         |
| 8             | Clemens-Krauss-Park | 0.60      | 1        | 0         |
| 9             | Esterhazypark | 0.97      | 1        | 0         |
| 10            | Fridjof-Nansen-Park | 6.55      | 1        | 1         |
| 11            | Grete Rehor Park | 0.68      | 1        | 0         |
| 12            | Hügelpark | 1.15      | 1        | 0         |
| 13            | Kongresspark | 4.59      | 1        | 1         |
| 14            | Martin-Luther-King | 1.98      | 0        | 0         |
| 15            | Mährpark | 1.58      | 1        | 0         |
| 16            | Ölzeltpark | 1.10      | 1        | 0         |
| 17            | Rathauspark | 4.47      | 1        | 1         |
| 18            | Reinpark | 0.55      | 0        | 0         |
| 19            | Rohrauerpark | 1.04      | 1        | 0         |
| 20            | Rudolfspark | 0.71      | 0        | 0         |
| 21            | Schillerpark | 0.85      | 0        | 0         |
| 22            | Schönbornpark | 1.05      | 1        | 0         |
| 23            | Schubertpark | 1.32      | 0        | 0         |
| 24            | Sigmund-Freud-Park | 1.47      | 1        | 0         |
| 25            | Stadtpark | 13.39     | 1        | 1         |
| 26            | Steinbauerpark | 1.13      | 1        | 0         |
| 27            | Türkenschanzpark | 15.52     | 1        | 1         |
| 28            | Waldmüllerpark | 4.38      | 1        | 0         |
| 29            | Wilhelmsdorfer Park | 2.20      | 1        | 1         |

City park codes refer to numbers in Fig. 1. Beside park size also the presence (1) or the absence (0) of the two woodpecker species Great Spotted Woodpecker (D. major) and Middle Spotted Woodpecker (D. medius) are indicated for each park. Note that the presence of a woodpecker species indicates city parks in which the species was observed at least once during surveys.
were not normally distributed were log-transformed (park size, number of tree genera, density of large Quercus trees), arcsin-transformed (proportion of tree cover) or sqrt-transformed (distance to nearest breeding site). To minimise multi-collinearity, we identified correlated local variables using Pearson’s Correlation Coefficient. Additionally, as all six connectivity measures quantify the connectivity of city parks to other green spaces and only differ in giving different weight to distance and whether they consider the size of green spaces city parks are connected to or not, all models including more than one network variable were discarded. Each candidate model was therefore comprised of variables that were not strongly correlated ($r < 0.4$) including a maximum of one network variable. We ranked models using Akaike’s information criterion corrected for small-sample sizes ($\text{AIC}_c$). Only models that had an $\text{AIC}_c$ difference ($\Delta$) < 2 were considered in the candidate set (Richards, Whittingham, and Stephens 2011; Symonds and Moussalli 2011) and Akaike weights (=the relative likelihood of the model being the best) of these models were calculated. For all models with an $\text{AIC}_c$ difference ($\Delta$) < 2, we used model averaging to compute the average estimates for parameters of interests from all models in a candidate set. Full model averaged estimates were used for graphical representation.

All statistical analyses were carried out in R 3.0.3 (R Core Team 2014), using the R packages ggplot2 (Wickham 2009), glmulti (Calcagno 2013) and MuMIn (Barton 2015). For the whole dataset of local and regional variables used for statistical analyses see Supplementary Tables S1 and S2.

**Results**

**Local and regional scale variables**

The mean tree cover of surveyed parks was 40%, containing a mean number of 50 large trees/ha and one large oak tree/ha. The number of tree genera ranged from 1 to 68, averaging 22 tree genera per park. The basal area within city parks was on average 41 m²/ha and the mean proportion of sealed area surrounding the parks covered 80%. The distance of a park to the nearest breeding site of Great Spotted Woodpeckers reached 58 to 1280 m and to those of Middle Spotted Woodpeckers from 207 to 3845 m (Supplementary Table S3). The Sigmund Freud Park was the most central one with respect to the number of connected nodes at all three spatial scales. The area weighted connectivity was highest for the Alfreß Böhlm Park (for location of parks see Fig. 1).

**Occurrence of woodpeckers in urban parks**

When considering all surveys between 2005 and 2015 the Great Spotted Woodpecker was found in 20 of the 29 city parks considered in the study (69%), whereas the Middle Spotted Woodpecker occurred only in seven (24%) parks (Table 1). The occupancy of city parks (GLM: $F_{5,140} = 3.07, P = 0.012$) as well as the mean temperature (one-way ANOVA: $F_{5,6522} = 836, P < 0.001$) differed between winters. Highest prevalence values were observed in winter 2005/6 which was an extremely cold one (Supplementary Fig. S1). Mean winter temperature and park occupancy were negatively correlated ($r = -0.3, P < 0.001$).

**Model selection**

Being included in all of the best ranked models park size represented an important variable in describing the occupancy of city parks by the Great Spotted Woodpecker as well as by the Middle Spotted Woodpecker (Tables 2 and 3). Model averaged estimates indicate a strong positive influence of park size on the occurrence of these two woodpecker species, with much larger area requirements for the Middle compared to the Great Spotted Woodpecker (Fig. 2; Tables 4 and 5). Beside park size no

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**Table 2.** Seven best ranked models ($\Delta\text{AIC}_c < 2$) explaining the occurrence of Great Spotted Woodpecker in Vienna city parks

| Predictor variable | 1     | 2     | 3     | 4     | 5     | 6     | 7     | Relative importance of variable |
|--------------------|-------|-------|-------|-------|-------|-------|-------|--------------------------------|
| PA                 | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |      | 1                              |
| BA                 |       | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |       | 0.11                           |
| TC                 | ⬤     |       |       |       |       |       | 0.17  |                               |
| LT                 | ⬤     |       |       |       |       |       |       | 0.11                           |
| LQ                 |       | ⬤     |       |       |       |       |       |                               |
| TG                 |       |       | ⬤     |       |       |       |       |                               |
| WI                 | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     | ⬤     |      | 1                              |
| SA                 |       |       | ⬤     | ⬤     | ⬤     | ⬤     |       | 0.11                           |
| DB                 |       |       | ⬤     |       |       |       |       | 0.11                           |
| $\text{CN}_{1\text{DW}}$ | ⬤          |       |       |       |       |       |       | 0.11                           |
| $\text{CN}_{2\text{DW}}$ |       | ⬤          |       |       |       |       |       | 0.11                           |
| $\text{CN}_{3\text{DW}}$ |       |       | ⬤          |       |       |       |       | 0.11                           |
| $\text{CA}_{1\text{DW}}$ |       |       |       | ⬤          |       |       |       | 0.13                           |
| $\text{CA}_{2\text{DW}}$ |       |       |       |       | ⬤          |       |       |                               |
| $\text{CA}_{3\text{DW}}$ |       |       |       |       |       | ⬤          |       |                               |

$\text{AIC}_c$ = Akaike’s information criterion corrected for small-sample size ($\text{AIC}_c$), differences in $\text{AIC}_c$ values of each model compared with the model with the lowest $\text{AIC}_c$ value ($\Delta\text{AIC}_c$) and the Akaike weights ($\omega_i$) are listed. Grey marked rows indicate variables whose relative importance (sum of Akaike weights over all models in which variable appears) is 1. Black dots indicate variables included in each model.

PA, park area; BA, basal area; TC, proportion of tree cover; LT, density of large trees; LQ, density of large Quercus trees; TG, number of tree genera; WI, winter in which surveys were carried out; SA, proportion of sealed area; DB, distance to nearest breeding site; $\text{CN}_{1\text{DW}}$, connectivity nodes excluding area with linear-weighted distance; $\text{CN}_{2\text{DW}}$, connectivity nodes excluding area with square-weighted distance; $\text{CN}_{3\text{DW}}$, connectivity nodes excluding area with cubic-weighted distance; $\text{CA}_{1\text{DW}}$, connectivity nodes including area with linear-weighted distance; $\text{CA}_{2\text{DW}}$, connectivity nodes including area with square-weighted distance; $\text{CA}_{3\text{DW}}$, connectivity nodes including area with cubic-weighted distance.
other local scale variable had effects on the city park occupancy by Middle Spotted Woodpeckers. In Great Spotted Woodpeckers tree cover and density of large trees were at least included in the best ranked models. However, model averaged estimates did not show effects of these two variables on the occurrence of the Great Spotted Woodpecker. Basal area, density of large Quercus trees and number of tree genera were not included in any of the best ranked models.

Among regional scale variables, the distance to the nearest breeding site as well as some of the connectivity measures were included in the best ranked models of the two woodpecker species. However, they only had a minor effect on describing the occupancy of city parks (Tables 2–5). The proportion of sealed area was not included in any of the best ranked models.

The winter in which bird surveys were carried out strongly influenced encounter rates of Great Spotted Woodpeckers in city parks (Tables 2 and 4). Highest probabilities of occurrence were gained in the winter 2005/6 (Fig. 3).

### Discussion

Among local habitat variables park size was the only significant predictor for the occurrence of woodpecker species in our study. In accordance with other studies patch size had a positive effect on the occurrence of Middle Spotted Woodpecker and Great Spotted Woodpecker (Kosiński 2006; Myczko et al. 2014). Large city parks—as remnants of semi-natural green space embedded in an urban landscape—have larger core areas that are

### Table 3. Five best ranked models (ΔAIC<sub>c</sub> < 2) explaining the occurrence of Middle Spotted Woodpecker in Vienna city parks

| Predictor variable | 1   | 2   | 3   | 4   | 5   | Relative importance of variable |
|--------------------|-----|-----|-----|-----|-----|-------------------------------|
| PA                 |     |     |     |     |     | 1                             |
| BA                 |     |     |     |     |     |                               |
| TC                 |     |     |     |     |     |                               |
| LT                 |     |     |     |     |     |                               |
| LQ                 |     |     |     |     |     |                               |
| TG                 |     |     |     |     |     |                               |
| WI                 |     |     |     |     |     |                               |
| SA                 |     |     |     |     |     |                               |
| DB                 |     |     |     | 0.27|     |                               |
| CA<sub>MDW</sub>   |     |     |     |     |     | 0.13                          |
| CA<sub>IDW</sub>   |     |     |     |     |     | 0.13                          |
| CA<sub,IDW2</sub>  |     |     |     | 0.13|     |                               |
| CA<sub,IDW3</sub>  |     |     |     |     |     |                               |
| AIC<sub>c</sub>    | 55.19| 55.69| 57.09| 57.11| 57.17|                               |
| ΔAIC<sub>c</sub>   | 0.34 | 0.27 | 1.9  | 1.92 | 1.98 |                               |

Akaike’s information criterion corrected for small-sample size (AIC<sub>c</sub>), differences in AIC<sub>c</sub> values of each model compared with the model with the lowest AIC<sub>c</sub> value (ΔAIC<sub>c</sub>) and the Akaike weights (ω<sub>i</sub>) are listed. Grey marked rows indicate variables whose relative importance (sum of Akaike weights over all models in which variable appears) is 1. Black dots indicate variables included in each model. For abbreviations of predictor variables see Table 2.
unaffected by edge effects associated with the surrounding matrix, such as higher levels of car and pedestrian traffic (Fernández-Juricic 2001). Woodpeckers may then find suitable habitats in the more undisturbed core areas of large city parks. Moreover, a study on patch-occupancy dynamics of Middle Spotted Woodpeckers demonstrated a higher persistence in larger forest fragments (Robles and Ciudad 2012). Further, local extinctions can be buffered by floaters. Such non-breeding birds

| Predictor variable | Estimate | SE  | Adjusted SE | 95% CI       |
|--------------------|----------|-----|-------------|--------------|
| Intercept Winter 2005/6 | -2.03 | 0.98 | 0.99        | -3.98 to 0.09 |
| Winter 2008/9      | -1.63   | 0.96 | 0.97        | -3.54 to 0.27 |
| Winter 2009/10     | -3.27   | 1.01 | 1.02        | -5.27 to -1.26 |
| Winter 2012/3      | -1.32   | 0.84 | 0.85        | -2.99 to 0.34 |
| Winter 2013/4      | -1.55   | 0.85 | 0.86        | -3.23 to 0.14 |
| Winter 2014/5      | -2.96   | 0.96 | 0.97        | -4.85 to -1.06 |
| Park area          | 3.13    | 0.57 | 0.57        | 2.02 to 4.26 |
| Prop. of tree cover| 0.42    | 1.29 | 1.3         | -2.12 to 2.95 |
| CAIDW2             | -0.03   | 0.12 | 0.12        | -0.26 to 0.20 |
| Distance nearest breeding site | -0.02 | 0.01 | 0.01 | -0.04 to 0.02 |
| CNIDW2             | -0.01   | 0.09 | 0.09        | -0.18 to 0.15 |
| Density of large trees | 01   | 05   | 05          | -0.01 to 0.01 |

Table 4. Full model averaged estimates of parameters explaining the occupancy of Vienna city parks by the Great Spotted Woodpecker

Estimates whose confidence intervals do not contain zero are printed in bold. For abbreviations of connectivity measures see Table 2.

| Predictor variable | Estimate | SE  | Adjusted SE | 95% CI       |
|--------------------|----------|-----|-------------|--------------|
| Intercept          | -6.1     | 1.8 | 1.81        | -9.63 to 2.55 |
| Park area          | 2.79     | 0.59| 0.59        | 1.63 to 3.96  |
| Distance nearest breeding site | -0.01 | 0.03 | 0.03 | -0.11 to 0.03 |
| CAIDW             | -0.02    | 0.15| 0.15        | -0.91 to 0.58 |
| CAIDW2            | -0.03    | 0.24| 0.24        | -1.47 to 0.98 |

Table 5. Full model averaged estimates of parameters explaining the occupancy of Vienna city parks by the Middle Spotted Woodpecker

Estimates whose confidence intervals do not contain zero are printed in bold. For abbreviations of connectivity measures see Table 2.

Figure 3. Predicted relationships between winter in which bird surveys were carried out and occurrence of the Great Spotted Woodpecker. Predictions are based on model averaged estimates. For a better comparison between severity of winter and probability of woodpecker occurrence also mean winter temperatures (±SE) are indicated.
capable of replacing lost territorial individuals were more abundant in larger high-quality patches (Robles and Ciudad 2017). As woodpeckers are territorial species and can occupy home-ranges almost year-round, these described metapopulation dynamics may also be applied to woodpeckers inhabiting green space remnants embedded in an urban matrix (Myczko et al. 2014). Hence, the higher occurrence probability of woodpeckers in large city parks may be the result of a higher persistence caused by a lower extinction risk within these patches.

Great Spotted Woodpeckers, representing by far the most abundant woodpecker species of Vienna, showed higher probabilities of occurrence in smaller parks compared to the Middle Spotted Woodpecker, classified as forest insectivorous specialist and having situated its population stronghold in mature woodlands on the outskirts of Vienna (Mikusiński and Angelstam 1997; Wichmann et al. 2009). This is in accordance with a study carried out in Poland showing that the mean size of forest plots occupied by Middle Spotted Woodpeckers were larger than that of Great Spotted Woodpeckers, underlining the area-demanding character of this species (Kosiński 2006).

Beside park size other local scale variables were of minor importance in explaining the occurrence of the two woodpecker species. For the Middle Spotted Woodpecker the density of large trees has often been stressed to be a key requisite in its habitat (Pasinelli 2003; Robles and Ciudad 2012; Robles and Ciudad 2017). This was not supported by the results of our study, with density of large oaks not even being included in the best ranked models. However, Middle Spotted Woodpeckers are not only associated with mature stands of oaks, but with large deciduous trees in general (Kosiński 2006; Roberge, Angelstam, and Villard 2008). As city parks considered in this study are dominated by deciduous tree species, covering on average 85 (±16) % of large trees (>30 cm)—a variable included in our analyses—we did not incorporate the density of large deciduous trees as additional separate variable. Despite being considered as a more generalist species also Great Spotted Woodpeckers show a marked habitat selection, preferring well forested habitat patches with a high diversity of tree species and a high density of large trees (Barrientos 2010; Segura 2017). Although the proportion of tree cover as well as the density of large trees were included in the best ranked models of this species, model-averaged estimates did not show a strong effect of these variables on the species’ occurrence in our study. That no effect (Middle Spotted Woodpecker) or only a weak one (Great Spotted Woodpecker) of large trees on the occurrence of woodpeckers could be detected may be related to (1) the small variation in large tree density between studied city parks and/or (2) to their generally high density. Hence large trees may not represent a limiting structure for foraging woodpeckers.

Studies on habitat preferences of woodpeckers predominately focused on the breeding season, but differences in habitat selection between breeding season and winter months could already be observed. Between October and December Middle Spotted Woodpeckers for example showed an expansion into less mature forest areas (lower forest cover and fewer large trees) with a greater abundance of dead trees (Domínguez, Carbonell, and Ramírez 2017). The density of dead trees also promotes the occurrence of the Great Spotted Woodpecker (Segura 2017). However, almost every park considered in this study is open to public. Consequently, due to potential safety and aesthetic reasons the removal of standing dead wood is forced by city authorities (Sandström, Angelstam, and Mikusiński 2006; Aronson 2017). Because of these park management measures dead wood within city parks may be a limited resource being of minor importance in determining the occurrence of the two woodpecker species.

At a regional scale neither network connectivity assessed at three spatial scales, nor patch isolation, quantified as the distance to the nearest breeding site, had an effect on the presence of woodpeckers. Also the proportion of sealed area surrounding each city park did not influence the occupancy of city parks by the two woodpecker species. Hence, the permeability of the urban matrix appears being neglectable for explaining the winter distribution of both woodpecker species in city parks in our study area. This is in accordance with theoretical predictions that specialist species with specific habitat needs are predominately governed by local variables as they tend to monopolise restricted resources in fragmented habitats (Pandit, Kolasa, and Cottenie 2009; Dappporto and Dennis 2013; Funk, Schiemer, and Reckendorf 2013). Hence, local scale park variables rather than regional scale landscape variables may be linked to the probability of park occupancy. In contrast, generalists benefit from using any suitable resources (Dappporto and Dennis 2013). Consequently, regional scale variables may be of major importance when occupying city parks. Based on these theoretical assumptions, we expected some association with variables operating on a regional scale, such as landscape permeability and connectivity, at least for the Great Spotted Woodpecker, the most widely distributed and one of the least specialised woodpecker species (Mikusiński and Angelstam 1997). However, also other studies provided only weak evidence, that woodpeckers may be governed by regional variables. In Örebro in Sweden the number of woodpecker species as well as the number of individuals increased from the city centre to the periphery, supposing some influence of regional landscape configuration on species distribution (Sandström, Angelstam, and Mikusiński 2006). Similar results were reported by Myczko et al. (2014) who found a comparable trend with woodpeckers to be less common and abundant in the city centre. But in both studies the spatial configuration of the landscape only explained a small proportion of variability in the data. Furthermore, regional and habitat variables could not be properly disentangled. For example, in Myczko et al. (2014) the regional urbanisation index was correlated with deciduous forest and patch area.

A meta-analysis of factors determining intra-urban biodiversity of different taxonomic groups (including birds) also found only weak support for the significance of connectivity variables, but a strong effect of functional corridors (Beninde et al. 2015). A positive effect of corridors on birds of the urban landscape has regularly been reported (Fernández-Juricic and Jakimäki 2001). Shanahan et al. (2011) for instance reported significant effects of revegetated areas directly connected with remnant vegetation (i.e. a maximum gap width <50 m to the analysed patch) on bird diversity and abundance. The small gap width was presumably chosen because many forest birds are reluctant to leave the forest, and even small gaps seem to hinder movement on a short-term basis (Bélisle and Desrochers 2002). On a larger temporal scale such gaps may be irrelevant for dispersal, i.e. there is no apparent dispersal limitation (Whittaker and Marzluff 2012). Dispersal limitation is a function of scale (temporal and spatial) and the species under consideration. When considering breeding dispersal for instance, inter-patch distances <3.5 km have no significant influence on the distribution of the nuthatch (Sitta europaea). Only if inter-patch distances increased above 3.5 km dispersal limitation were evident (Van Langevelde 2000). The Nuthatch has similar breeding dispersal abilities such as the investigated woodpeckers with median values of 1.67 km (Matthysen, Adriaensen, and Dhondt 1995). For juvenile
Middle Spotted Woodpeckers dispersal distances range from 0.9 to 4.8 km in fragmented landscapes (Ciudad, Robles, and Matthysen 2009) and in Great Spotted Woodpeckers the median natal dispersal is estimated 6 km (Gil-Tena et al. 2013). Furthermore, woodpeckers are not strictly sedentary species, but rather show nomadic migration movements. The intensity of these movement patterns is predominantly triggered by food shortage and high population densities (Newton 2006; Linden et al. 2011). Adverse circumstances can cause individuals to disperse even hundreds of kilometres (Newton 2006). Given these high dispersal abilities of birds and the low explanatory power of direct connectivity measures, it seems unlikely that dispersal limitation plays a significant role in structuring bird communities in cities with a high amount of green space such as Vienna. For the investigated parks, the minimum distance to the next green space remnant averages 334 m (minimum: 119 m, maximum: 546 m), which is significantly less than the reported dispersal potential of the two woodpecker species.

The reported positive effects of corridors and surrounding green space are presumably a surrogate for the enlargement of the patch area itself. The effects of corridors in promoting biodiversity may be based on an enlargement of patch area or on an increase of connectivity between patches, i.e. the effects of area and corridors are difficult to disentangle, what was also pointed out by Shanahan et al. (2011).

Beside corridors, also percentage of surrounding green space was revealed as an important parameter in determining urban biodiversity (Beninde et al. 2015). Depending on the dispersal ability of different species, again surrounding green space can act as a landscape variable related to connectivity or simply as an extension of the patch area under consideration.

Our results point out the importance of city parks as refuges for birds during cold winters. For Great Spotted Woodpeckers the winter in which bird surveys were carried out was an important variable in explaining the encounter rates of this species in city parks. Highest probabilities of occurrence were recorded in the winter 2005/6, which also was the coldest one among survey years. During winter time birds face high thermoregulatory costs emerging especially from long, cold nights (Pinowski et al. 2006). As the time window available for foraging is shortened at this time of the year and resources are depleted, compensating these metabolic losses is challenging. By dispersing from rural to urban areas woodpeckers may find sufficient food supply even under adverse circumstances (Tryjanowski et al. 2015). Indeed, decreasing temperatures lead to higher encounter rates of Great Spotted Woodpeckers at artificial bird feeders (Chamberlain et al. 2005). Additionally, higher artificial light levels in urban areas may enable birds to prolong their diurnal foraging activity (Russ, Rüger, and Klenke 2015). Furthermore, due to the urban heat island phenomenon built up areas of the city centre of Vienna show higher air temperatures than the surrounding rural areas, being most noticeable during summer and winter (Bohm 1998). Hence, thermoregulatory stress during cold winter nights may be reduced by inhabiting urban areas. A more intense use of urban areas during winter time may increase the probability of park occupancy by Great Spotted Woodpeckers. There was no effect of survey winter on the park occupancy by Middle Spotted Woodpeckers maybe due to low sample size.

In conclusion, it seems that the size of habitat patches rather than their position within the landscape matrix is important for birds in general and woodpeckers in particular. We thus recommend park areas >4 ha to promote woodpecker habitats. This is in the range of threshold values reported to promote generalist bird species in cities (1–10 ha), but far below values recommended to promote area-sensitive species (20–140 ha) (Beninde et al. 2015). Nevertheless, this size will allow the occurrence of the two woodpecker species and thereby foster facultative and obligatory cavity-using species such as passersines, mammals and insects as at least the Great Spotted Woodpecker—being widely distributed across the city of Vienna and even inhabiting heavily built-up areas (Wichmann et al. 2009)—might use some of the city parks also for breeding and thereby ensures nest availability. As in big cities an enlargement of city parks is difficult to realise, the implementation and maintenance of corridors such as alley trees along roads or scattered greenery of public space—especially among city parks of high quality—may be a cost efficient alternative (Fernández-Juricic and Jokimäki 2001). At least corridors being wisely designed and managed may then disproportionally enlarge the patch area of remnant green spaces, as the size of the new patch area equals the sum of two patches plus corridor area. This may also be a first approach to promote area-sensitive species in cities.

The fact that large trees are still a prominent feature in most city parks of Vienna and that their density is fairly similar between parks, may additionally promote the importance of park size in explaining the occurrence of the two woodpecker species because in larger parks they have better chances to meet their foraging and shelter requirements. But this also means that a loss of large trees—even if the size of the habitat patch remains stable—can cause severe declines in woodpecker populations inhabiting fragmented landscapes (Pasinelli 2000). Hence, beside the implementation and maintenance of ‘green’ corridors to enlarge the size of remnant habitat patches, care must be also taken to preserve large trees within city parks in order to promote woodpecker occurrence in urban landscapes.

**Data availability**

All woodpecker data used in this study are available as Supplementary data.

**Supplementary data**

Supplementary data are available at JUECOL online.

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