UNIVERSITY OF HELSINKI

Local and landscape-scale drivers of bird diversity across the greenspace network of the city of Lahti

University of Helsinki
Master's Programme in Ecology and Evolutionary Biology
Master's thesis
Meri Back
05/2023

Supervisor:
Professor Ian MacGregor-Fors

Faculty: Faculty of Biological and Environmental Sciences
Degree programme: Master's Programme in Ecology and Evolutionary Biology
Study track: Ecology and Evolutionary Biology
Author: Meri Back
Title: Local and landscape-scale drivers of bird diversity across the greenspace network of the city of Lahti
Level: Master's thesis
Month and year: 05/2023
Number of pages: 39 + 3 (Appendices)
Keywords: urban greenspace; urban birds; species richness; point count; local-scale; landscape-scale
Supervisor or supervisors: Ian MacGregor-Fors
Where deposited: HELDA – Digital Repository of the University of Helsinki
Additional information:
Abstract: Cities are novel and fragmented environments that offer a wide range of habitats and resources for urban dwellers, such as birds. Previous work shows that the size and vegetation structure of urban forest patches and parks play an important role in urban bird abundance and diversity. The aim of the thesis was to find out the role of major urban greenspaces and which local and landscape-scale drivers in the urban greenspace network are influencing bird species richness and composition in the city of Lahti.

A breeding bird survey was conducted in Lahti, including 60 survey points and 15 urban greenspaces. A total of 41 bird species were observed, and the most common species were Fieldfare, Common Chaffinch, and Great Tit. On the local-scale, the size of trees was positively correlated with bird species richness, indicating that bigger and older trees support higher bird diversity in urban greenspaces. On the landscape-scale, I found that the size of the greenspace, its distance to the urban continuum border, and the amount of green neighbouring the greenspace were the significant drivers explaining bird species richness.

The findings indicate that both local and landscape-scale drivers are significant for urban bird communities in Lahti. Furthermore, to better understand the resources that urban communities need, a comprehensive study of different urban dweller species is important – not just the few sensitive species – to achieve effective management. Urban greenspaces host most of the urban bird species in the city; thus, it is important to preserve these urban greeneries as well as protect the green areas around the city proactively to sustain them while the urban development continues sprawling.

Tiedekunta: Bio- ja ympäristötieteellinen tiedekunta
Koulutusohjelma: Ekologian ja evoluutiobiologian maisteriohjelma
Opintosuunta: Ekologia ja evoluutiobiologia
Tekijä: Meri Back
Työn nimi: Paikalliset ja alueelliset ympäristötekijät, jotka vaikuttavat linnuston monimuotoisuuteen Lahden kaupungin viheralueverkostossa
Työn laji: Maisterintutkielma
Kuukausi ja vuosi: 05/2023
Sivumäärä: 39 + 3 (liitteet)
Avainsanat: kaupungin viheralue; kaupunkilinnusto; lajirikkaus; pistelaskenta; paikallinen taso; alueellinen taso
Ohjaaja tai ohjaajat: Ian MacGregor-Fors
Säilytyspaikka: HELDA – Helsingin yliopiston digitaalinen arkisto
Muita tietoja:
Tiivistelmä: Kaupungit ovat uudenlaisia ympäristöjä, jotka tarjoavat monipuolisen valikoiman elinympäristöjä sekä resursseja kaupungin eliöyhteisöille kuten linnuille. Aiemmat tutkimukset osoittavat, että kaupunkimetsien ja puistojen koko ja kasvillisuuden rakenne ovat merkittäviä tekijöitä lintujen määrän ja monimuotoisuuden kannalta. Tutkielman tavoite oli selvittää kaupungin isojen viheralueiden rooli sekä mitkä paikalliset ja alueelliset ympäristötekijät vaikuttavat lintujen lajiston monimuotoisuuteen ja kokoonpanoon Lahden kaupungin viheralueverkostossa.

Pesimälinnuston pistelaskenta Lahdessa sisälsi yhteensä 60 tutkimuspistettä ja 15 viheraluetta. Lintulajeja havaittiin yhteensä 41, joista yleisimpiä olivat räkättirastas, peippo sekä talitiainen. Paikallisella tasolla puiden koko korreloi positiivisesti linnuston lajirikkauden kanssa viitaten siihen, että isommat ja siten vanhemmat puut ylläpitävät monimuotoisempaa linnustoa kaupungin viheralueilla. Alueellisella tasolla viheralueen koko, sen etäisyys kaupunkialueen rajasta sekä viheralueita ympäröivien viherlaikkujen koko olivat merkittäviä ympäristötekijöitä linnuston monimuotoisuuden kannalta.

Tutkielman tulokset viittaavat siihen, että sekä paikalliset että alueelliset ympäristötekijät ovat merkittäviä Lahden kaupungin linnustolle. On tärkeää tutkia kattavasti kaupungistuneita lajeja eikä vain muutamaa erityisherkkää lajia, jotta tiedetään eliöyhteisön tarvitsemat resurssit ja kaupunkiympäristöä voidaan hoitaa tehokkaasti. Kaupungin viheralueet tarjoavat elinympäristön suurimmalle osalle kaupungin lintulajeista, joten niiden suojeleminen, kuten myös kaupunkia ympäröivien viheralueiden ennakoiva suojelu on tärkeää kaupungin kehittyessä ja kasvaessa.

Table of content

1 Introduction 5

1.1 Urbanisation 5

1.2 Cities as environments 6

1.3 Urban avian community 7

1.4 Urban greenspaces 9

1.5 Aims of the study 11

2 Materials and methods 13

2.1 Study area 13

2.2 Bird survey 15

2.3 Habitat characterisation 15

2.4 Statistical analysis 16

3 Results 19

3.1 Bird species and habitat composition 19

3.2 Species richness 21

3.3 Landscape-scale 22

4 Discussion 26

4.1 Bird species and habitat composition across the greenspace network 26

4.2 The importance of urban remnant trees 27

4.2.1 Kariniemi Park as an urban bird hotspot 29

4.3 Bird diversity on the landscape-scale 29

5 Conclusions 32

5.1 Suggestions for urban planning and management 32

Acknowledgements 34

References 35

Appendices 40

1 Introduction

1.1 Urbanisation

Urban areas are very important drivers globally of ongoing environmental change and biodiversity loss (Tryjanowski *et al.* 2017). Over half of the human population lives in cities, which still occupy less than 3% of the terrestrial area (Aronson *et al.* 2014). As urbanisation increases and human population growth is rapid, cities are pressured to sprawl into the surrounding areas, which then increases material consumption and the need for natural resources (Turner *et al.* 2003; Tryjanowski 2017).

Urban development and sprawl increase the risk of fragmentation and isolation of natural habitats and disrupt natural nutrient and hydrological cycles, even resulting in a simplified species composition (Alberti and Marzluff 2004). The sprawl of cities into surrounding areas is necessary for getting enough resources for the growing population (Gavrilidis *et al.* 2019). To manage the continuous disturbance, urban ecosystems must have resilience, meaning they must be able to tolerate alterations and preserve their stable state. With urban planning and conservation actions towards the current urban habitats, we could increase the resilience of the cities and make them less vulnerable to unexpected changes that will occur due to the ongoing climate warming (Alberti and Marzluff 2004).

Cities were often established in regions with rich biodiversity and good transportation routes. The most suitable transportation routes are located along the seacoast or along rivers; thus, their surroundings offer naturally diverse habitats (Arson *et al.* 2014; Jokimäki *et al.* 2018). Native species face many threats in urban environments due to anthropogenic factors like the loss of natural habitats, disturbances, and introduced alien species (Aronson *et al.* 2014). Furthermore, the impacts of urbanisation are very persistent, as natural succession cannot occur in these highly managed habitats and urban areas keep expanding (McKinney 2002). A key factor in sustaining the native plant and animal communities is increasing the available habitats for them (Turner 2003). Preserving urban nature can change people's attitudes towards conservation issues and increase their appreciation for biodiversity (Shwartz *et al.* 2008). We need an understanding of urban species

composition and global patterns for sustainable urban planning (Aronson *et al.* 2014).

1.2 Cities as environments

Urban areas are novel and continuously disturbed environments. Urban environments offer a wide variety of different habitats with different disturbance levels: highly built areas, urban parks, cemeteries, roadside corridors, unmanaged urban woodlots, and residential areas with gardens (Jokimäki *et al.* 2014). These different habitats are often fragmented and separated with human-built cover and impervious surfaces (Marzluff and Ewing 2001; Jokimäki *et al.* 2014) that increase run-off, alter natural hydrological and nutrient cycles, and retain heat efficiently, causing the urban heat island phenomenon (Oke 1973; Alberti 2007). Cities are a global threat to biodiversity when taking into account their development history, spatial structure, and rapid urbanisation, in addition to the human-mediated spread of alien species and the increase of extinctions due to the loss of natural habitats (Aronson *et al.* 2014).

The urbanisation of a species often includes three phases. The first is the arrival of a few individuals in the area. The probability of it arriving in a certain area depends on the proportion of urban areas inside the species' geographical range, the age of the city, and how long it has been available. Secondly, surviving in the newly urbanised area requires adjusting to very different environmental circumstances, such as highly fragmented habitats as well as physical and chemical traits. Lastly, after spreading and adjusting to the urban area, the populations start to spread within the area and to neighbouring cities, but the dispersal depends on the species and the specific dispersal distance. Dispersal might follow either the stepping-stone model, spreading to the nearby cities first, or new cities are occupied independently from the previous dispersal. This might be, for example, due to increased population density in one area (Fey *et al.* 2015).

Species can be classified according to their tolerance of anthropogenic changes and human presence. Urban avoiders require more natural habitats with very little or no human-induced disturbance or management, but they can persist in the more natural areas surrounding the urban continuum depending on the possible connectivity of these natural areas (McKinney 2002; Fischer 2015). Urban utilisers thrive in the

suburban areas where there are some remnant forest patches available as well as some built cover and managed vegetation, but the group is very flexible with their breeding habitat. Finally, the urban dweller group consists of very few species that are adapted to the modified environment and strongly dependent on the resources that are only available in cities, independent from natural areas (McKinney 2002; Fischer 2015).

Urban dwellers encounter many risks in an urban environment despite their ability to adapt to human-induced disturbances. Santiago-Alarcon and Delgado-V (2017) established that in Canada, the USA, and Latin America, the most significant causes of bird mortality in urban environments are predation by cats, collisions with buildings (especially windows) and vehicles, and alterations in host-parasite interactions. Moreover, other predators, such as raptors, can be found in increasing numbers in urban areas compared to rural areas, possibly because of the concentrated number of prey species in a fragmented environment (Sorace 2002). In addition, non-native and invasive species are also spreading and competing for available resources, eventually even replacing native populations (McKinney 2002).

1.3 Urban avian community

Birds are a common urban dweller group to study in urban ecology. They are proposed to be an indicator taxon for other species that are less easy to observe since they are easy to detect and identify because of their conspicuous presence and vocalisation (Turner 2003). Since birds are mobile species, they can be very sensitive to environmental changes and respond to them by dispersing to a more suitable habitat (Guo *et al.* 2019). Their tolerance to habitat fragmentation varies depending on their home range, ability to disperse, anti-predator behaviour, and foraging habits. Tolerant species can broaden their territory in small, fragmented habitats by visiting neighbouring habitats (Newton 1998). On the other hand, habitat fragmentation is part of a natural ecosystem as well, and birds have adapted to habitat changes and learned to utilise novel habitats in consequence of disturbances such as a forest fires (Marzluff and Ewing 2001). However, travel between possible habitats has costs for the individual, and to find out the effects of fragmentation on the species, breeding success needs to be studied, not just composition (Newton 1998).

Species-specific behavioural characteristics affect their ability to inhabit urban areas, such as behavioural flexibility in novel habitats (Sol *et al.* 2002), interaction with other species, and the available resources (Jokimäki 1999; Shwartz *et al.* 2008). Often, native bird abundance and diversity decrease in urban areas, except for a few synanthropic species that benefit from the resources that cities offer (Turner 2003). On the other hand, Marzluff (2005) stated that, in fact, moderately urbanised and forested suburban areas host the most diverse bird communities compared to urban and even rural areas (Sol *et al.* 2002). Suburban areas provide attractive wintering habitats as well due to the bird feeders that citizens afford (Sandström *et al.* 2006).

Despite the strong anthropogenic disturbance in urban environments, threatened bird species have also been observed in the urban cores, indicating that urban avian communities are very diverse. In addition to the naturally high biodiversity in the area, especially for cavity and building nesters, there are many nesting sites available. Jokimäki and others (2018) found a total of 26 threatened breeding bird species in European towns, including seven towns in Finland. Species found in most of the study towns were House Sparrow (*Passer domesticus)*, Common House Martin (*Delichon urbica)*, Barn Swallow (*Hirundo rustica)*, Spotted Flycatcher (*Muscicapa striata)*, Common Kestrel (*Falco tinnunculus)*, Eurasian Tree Sparrow (*Passer montanus)*, and Common Redstart (*Phoenicurus phoenicurus)*. Some building and cavity nesting bird species, such as the Common House Martin, have been urbanised a long time ago, but other species are nesting in the buildings frequently as well. Actually, the number of building nesting bird species is positively correlated with the number of inhabitants in the city, population density, and distance from the city centre. Urban species richness is found to be positively correlated with the number of threatened species in the city, and consequently, the overall species richness could be considered a surrogate factor in the conservation of threatened species. However, a high abundance of threatened species, for example, in urban areas of Australia might be due to their extinction delay since urbanisation is a relatively new phenomenon, whereas in Europe many species have already disappeared from cities (Jokimäki *et al.* 2018).

Studies have found that urban forest patches and parks play an important role in urban bird abundance and diversity, for example, through their size and vegetation structure (Shwartz *et al.* 2008). Jokimäki and others (2014) documented those

unmanaged wooded urban green areas in Northern Finland had more bird species, a higher total number of pairs, more pairs belonging to coniferous forest, and an increased abundance of Common Chaffinch (*Fringilla coelebs)* and Willow Warbler (*Phylloscopus trochilus)* compared to highly managed areas. Consequently, old and dead trees offer important nesting sites and food for cavity nesting birds, and the overall vegetation cover protects ground nesting species by decreasing predator visibility (Jokimäki *et al.* 2014). Especially woodlands near the urban edge have more dead wood than the ones closer to the city centre. Moreover, there are more forest species because there are more gardens with planted trees compared to the city centre, where most of the surfaces are impervious (Aronson *et al.* 2014). However, urban woodland management often aims to maintain quite open woodlands with very little understory vegetation for aesthetic and safety reasons (Hedblom and Söderström 2010). The intensity of park management should be studied more at small spatial scales and how it affects the local bird community. It is important to take these factors into account in land use planning in order to preserve native biodiversity in urban environments (Shwartz *et al.* 2008).

1.4 Urban greenspaces

Urban greenspaces are often suggested to be the most heterogeneous habitats in urban ecosystems, as the vegetation is relatively diverse, especially in the larger greeneries. However, the intensity of park management influences diversity (Shwartz *et al.* 2008). Often, the greenspaces closer to the city centre are smaller than the ones closer to the urban edges. When considering urban bird populations, 10-35 hectares have been stated to be enough to sustain most urban dwellers (Fernández-Juricic and Jokimäki 2001; Lepczyk *et al.* 2017). It has been stated that bird species richness increases with the size of a greenspace in urban environments due to their greater habitat diversity, available niches, and ability to support larger populations (Donnelly and Marzluff 2004). Major urban greenspaces offer a variety of different environments for people as well; they have different functions such as sports, recreational areas, and sub-natural areas for hiking. Hence, they are very important study subjects (Shwartz *et al.* 2008).

The biodiversity of a greenspace is higher when there are more different habitat types available inside the greenery (Shwartz et al. 2008). Urban avian communities require

greenspaces with remnant older and bigger trees that offer diverse resources for feeding, perching, and nesting to sustain their population in the city (Barth *et al.* 2015). The number of trees in urban greenspaces and surrounding areas has a positive effect, especially on woodland bird species (Ferenc *et al.* 2014). Novel, highly-built urban areas tend to replace the remnant vegetation with planted bushes and trees, which host lower biodiversity and take time to mature (Barth *et al.* 2015).

Increasing fragmentation of natural habitats is a great risk for biodiversity as the area available for native species reduces due to urban development and, most importantly, reduces and isolates the native vegetation (Marzluff and Ewing 2001; Oliver *et al.* 2011). Fragmented urban greenspaces are referred to as urban habitat islands surrounded by highly built areas where biodiversity is concentrated (Oliver *et al.* 2011). Urban populations are isolated from each other, which decreases their chance of survival as the individuals cannot access more resources, such as food or nesting sites, from other habitats. Furthermore, the smaller the fragmented habitats are, the more they are exposed to human disturbance and altered conditions due to an increased edge effect (Haddad *et al.* 2015). The ability to cross these dense and highly built areas to access another greenspace depends on the characteristics of a species; if it is easy to move via flying, it can utilise human-built green corridors, or it is able to adapt to the built environment (Schneider *et al.* 2014).

However, the edge effect has also been documented to have positive effects on animal diversity, abundance, fitness, and behaviour (Schneider *et al.* 2014). Especially edge species prefer habitats with edges of remnant forests and other greenspaces surrounded by more open urban environments since they can access both the resources in the forest and the city. The additional food available in human settlements enables the populations to increase more than they would in a natural habitat. In addition, human presence can protect them from their natural predators (McKinney 2002).

To conserve current urban biodiversity, it is necessary to increase the connectivity between these fragmented habitats and preserve the existing remnant greenspaces (Ferenc *et al.* 2014; Von Thaden *et al.* 2021). The shapes and sizes of urban greenspaces, together with their location and the network they form, influence species abundance and their ability to distribute between them (Von Thaden *et al.* 2021). It has been stated that connectivity between fragmented habitats increases

biodiversity and decreases the risk of reduced gene flow between urban populations. Moreover, smaller green patches can support highly mobile populations in the urban core even if their main habitat is in the peri urban (Lepczyk *et al.* 2017). However, it is difficult to balance sustaining the existing urban green network with urban development. Expanding greeneries at the expense of built areas and transport infrastructure is difficult.

Urban populations require individuals to disperse from other habitats to sustain vitality in a fragmented environment. To understand the characteristics of these urban greeneries that are attracting individuals requires both local and landscape-scale perspective to find out the important drivers of diversity (Marzluff and Ewing 2001; Lepczyk *et al.* 2017). Lancaster and Rees (1979) stated that vegetation complexity, especially foliage height, is an important local factor sustaining bird diversity in an urban greenspace. In addition, Evans and others (2009) found that local-scale drivers were more important factors for bird species richness than landscape-scale factors. However, in the study of Donnelly and Marzluff (2004), both local and landscape-scale variables were correlated with bird diversity in the study area. In addition to the bird species richness increasing with the size of the studied greenery, they also found that the bird species abundance increased in urban and suburban greenspaces compared to rural areas.

1.5 Aims of the study

Conservation actions towards the remnants as well as the highly managed urban greenspaces are crucial as urbanisation is sprawling and threatening biodiversity. It is essential to increase research-based knowledge of urban ecosystems and their dwellers to understand which characteristics of urban habitats attract them and how this knowledge could improve land management.

In this study, I examine the diversity of urban avian communities at two different levels in the city of Lahti. Furthermore, I focus on the greenspace network inside the urban continuum. My objective is to identify local-scale drivers, such as the structure of the vegetation, and landscape-scale drivers such as the location and connectivity of the greenspace network, that are influencing bird species diversity. I expect bird species richness to be higher in greenspaces with a more diverse vegetation structure, including large trees. In addition, I predict the size of a greenspace will have a

positive correlation with bird species richness. My goals are to assess the role of major greenspaces in an urban environment and what the differences are between the greenspaces in Lahti. Since more greenspaces are located in the northern parts of the urban continuum and they are closely grouped together, I assume the greenspace network is more connected there than in the southern parts, thus having a more diverse bird community. Finally, I discuss possible urban planning and management actions for sustaining the avian community in the city of Lahti.

2 Materials and methods

2.1 Study area

The urban bird survey was conducted in the city of Lahti, capital of Päijät-Häme municipality in southern Finland (60˚57´14¨N, 25˚44´37¨E). It was established as a city in 1905. There are ~120 000 inhabitants in Lahti, and the population density is 1,016 inhabitants per km² (Tilastokeskus 2021). Furthermore, Lahti was nominated as the European Green Capital of 2021. As a former industrial city, it was quite polluted in the 1970s, including the lake Vesijärvi. However, huge conservation efforts have been made ever since to restore the lake, and many changes towards more sustainable actions have been implemented in the city (MacGregor-Fors *et al.* 2021).

The Salpausselkä ridge divides the city of Lahti geographically into four different landscapes with distinctive features, including the lake towards the north, a valley towards the south, forested Salpausselkä ridge towards the west, and Luhtaanmaa towards the east. Salpausselkä is a major groundwater catchment area across southern Finland, and its highest points are located in Lahti. It affects the topography and waterbodies of the region, as well as the soil and vegetation. The city centre is located at the junction of these areas. The centre is affected by an auspicious microclimate and hosts a diverse environment (Neuvonen *et al.* 2013).

The urban continuum consists of clearly connected inner and outer urban areas of the city, covering a total of 54 km². According to Helminen and others (2020) from the Finnish Environment Institute, the definition of the Finnish urban area is that there are over 15 000 inhabitants, and the area is divided into an inner urban area with dense, continuous, and efficiently built structures and an outer urban area with a still continuous built-up environment and city-like efficiency and resources. To have comparable knowledge of urban ecology, there is a need to establish global guidelines and standards on how to define urban gradients and separate the peri-urban (Hedblom and Söderström 2010). My study of the greenspace network inside the urban continuum consists of 15 separate urban greeneries > 10 hectares, including urban parks, forests, and cemeteries. Characteristics of the greenspaces are seen in Table 1.

Table 1. Characteristics of the studied fifteen greenspaces.

Characteristics	Mean	SD	Min.	Max.
Greenspace size (ha)	21.6	7.65	10.4	34.7
Distance from the urban continuum centre (m)	2310.5	1157.9	665.8	4257.1
Distance from the urban continuum border (m)	745.6	438.0	241.2	1612.7
Total bird species richness	-	-	4	26

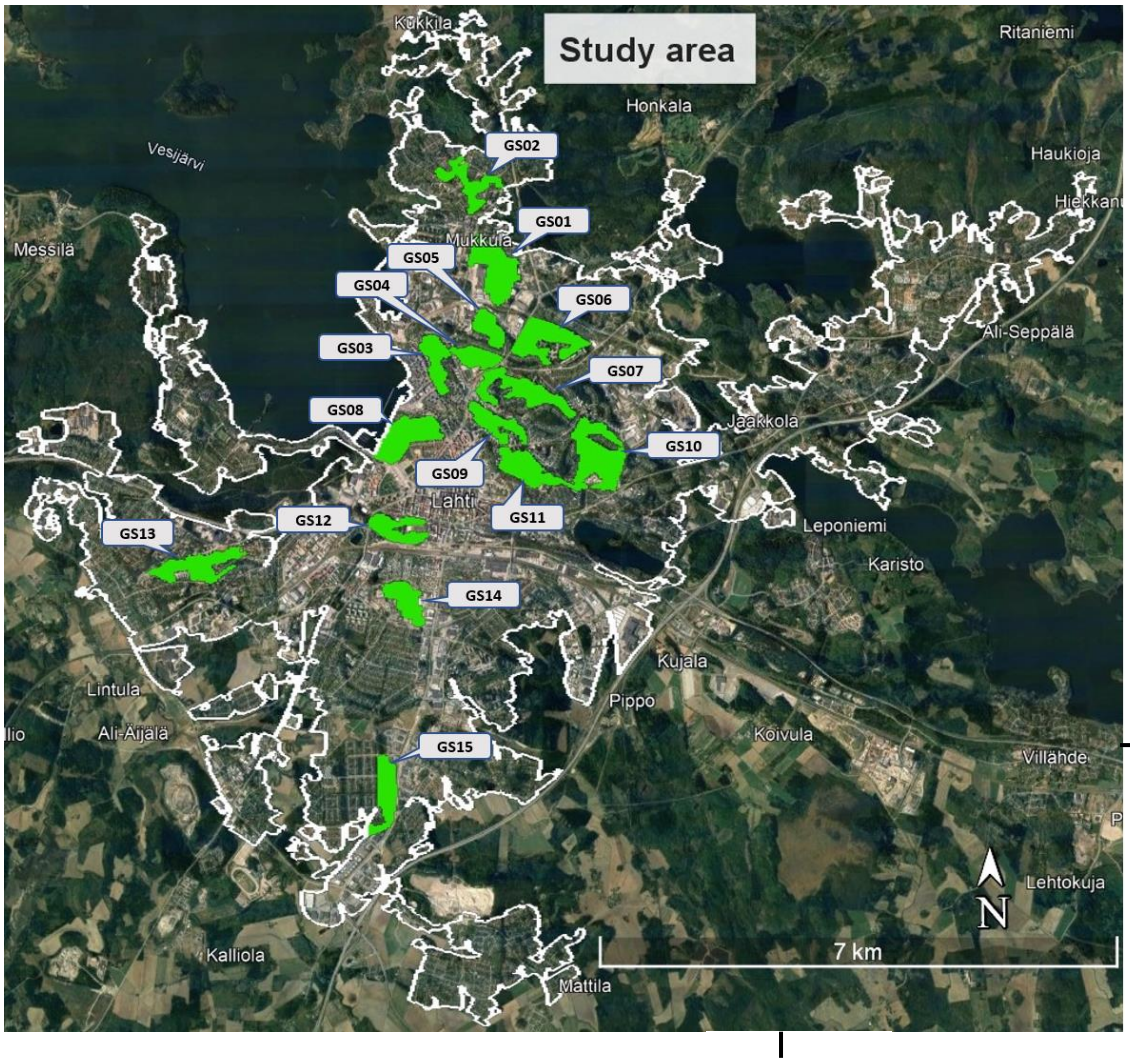


Figure 1. Map of the study area.

The white polygon is the urban continuum of Lahti, and the 15 studied greenspaces are numbered and marked in green. A satellite image was captured in Google Earth (v. 7.3).

2.2 Bird survey

The survey of the breeding birds in Lahti was carried out from May 15th to June 11th, 2021, during which the migratory species arrived to breed. The point count followed the Methods of bird monitoring described by LUOMUS (Hilden *et al.* 1991; Ralph *et al.* 1995). The census was conducted between sunrise and five hours onward (from 4 a.m. to 9 a.m.), when the birds were the most active. The observing period for each point count was 5 min + 5 min to maximise species richness and increase the chance of detecting rare or inconspicuous species at the site. To avoid double observations, I used the 50-metre radius. I recorded every observed individual perching, nesting, or foraging, but did not record overflying individuals to ensure all observed individuals were using the survey site and not the surrounding habitats. All individuals seen or heard inside the 50-metre radius were recorded and included in the analyses. Birds were recorded in pairs in the order they were observed, and the distance from the observer to the birds was measured with a laser rangefinder. The point counts were not conducted on very rainy or windy mornings. The point count included a total of 60 survey sites, and each site was visited once by the same observers, except for 12 sites, which were visited twice as they were validation points. The distance between survey sites was a minimum of 200 metres to avoid observing the same individuals at the neighbouring sites. The average temperature during the censusing period was 15 °C (SD 5.9), and the average wind speed was 0.5 m/s (SD 0.4).

2.3 Habitat characterisation

A total of 26 habitat variables were measured within the same 50-metre radius at each survey site in all the urban greeneries. The measurements were conducted immediately after the census period without disturbing the birds, except for the number of pedestrians, which was counted during the count. The habitat characteristics included 12 variables related to the vegetation cover and structure (such as tree abundance, tree cover, maximum and average diameter at breast height (DBH from here on)), maximum and average height of herbaceous plants and shrubs, seven variables related to possible hazards for birds (such as maximum building height, number of pedestrians, path width, and maximum noise), and five variables measuring the location of a survey site or greenspace (such as the distance from the point to the centre of the urban continuum and the distance from the greenspace

centre to the edge of the urban continuum). In addition, the wind and temperature were measured during each census period.

2.4 Statistical analysis

I performed analyses on two different levels: 1) the local habitat variables to assess bird species richness on the study site level, and 2) the landscape variables to assess bird species richness on the greenspace level. For the local level, I assessed the composition of estimated bird species richness and habitat, and for both levels, I performed generalised linear regressions. All statistical analyses were performed using R Statistical Software (v. 4.2.2; R Core Team 2022).

Explanatory variables related to each other may cause multicollinearity in a regression model. It can alter the statistical significance of the variables and the outcome of which variables best explain the bird species richness in my data, especially with a small data set like the greenspaces (n=14). To assess possible multicollinearity between the explanatory variables in my generalised linear models (GLM from here on), I used the variance inflation factor (VIF from here on), which is one of the commonly used methods (O'Brien 2007; Thompson *et al.* 2017). The dependence between explanatory variables increases when the VIF increases; hence, I extracted the variables with the highest VIF one by one from the GLM. I considered multicollinearity a problem in the models if the VIF-value of a variable was > 3 to be more conservative due to the many variables in my data (Thompson *et al.* 2017).

Firstly, I established which habitat variables were significantly correlating with the species richness at each survey site by fitting a GLM with a Poisson distribution and a log link using the bird species richness as a response variable in R. I included 28 explanatory variables and extracted the variables with the highest VIF-values from the model. I chose the model with the lowest Akaike Information Criterion (AIC-value from here on) and checked for possible statistically significant explanatory variables (p-value < 0.05).

Secondly, to assess and compare species richness in each greenspace, I changed the varying sampling sizes to be equal to each other. Thus, I conducted a rarefaction analysis using estimates and confidence intervals generated in software EstimateS (v. 9.1.0; 2013). The estimated number of species was calculated by resampling recorded

observations seven times for each greenspace, and then the estimations were plotted in R. One greenspace with just one survey site was excluded from the analysis as the sampling size was so small and the estimation would have been unreliable. Finally, I measured the Bray-Curtis similarity index of both the habitat variables and the bird species richness for each greenspace to see which greenspaces resemble each other.

The landscape-level analysis was more complex, including four models. I analysed a total of nine landscape-scale variables to see if they were correlating with the bird species richness in the 14 studied greenspaces. I used the same estimations of species richness as before (generated in EstimateS). I used the metrics of three different-sized buffers around the greenspaces (50-metre, 100-metre, and 200-metre buffers) generated by our group member in Fragstats (v. 4.2.1; 2015). The metrics generated in Fragstats included 1) LPI (largest patch index; the percentage that the largest green patch occupies inside the buffer), 2) CI (connectance index; percentage of joinings between green patches inside the buffer that are under the specified distance criterion; I used a 20-metre threshold due to the 10-metre pixel size in the raster file), 3) TA (total area of green inside the buffer), 4) NP (number of green patches inside the buffer), 5) ratio (TA / NP), and 6) SI (shape index of the greenspace; perimeter (m) / area (m2)). Other variables I included in the analysis were also used in the previous GLM: 7) size (the size of the greenspace), 8) DC (distance from the centre of the greenspace to the centre of the urban continuum), and 9) DB (distance from the centre of the greenspace to the border of the urban continuum).

Firstly, for each buffer (50m, 100m, and 200m), I fitted GLMs with a Gamma distribution and an inverse link using bird species richness as a response variable in R. In addition, I fitted a fourth GLM with landscape variables with the highest Pearson correlation values (r-values) from each buffer, generating a model with size, NP for a 100-metre buffer, LPI for a 50-metre buffer, ratio for a 200-metre buffer, SI, and DB. I excluded the same greenspace with only one study site from the analysis as the sampling size was so small and the estimation would have been unreliable.

Secondly, I compared the AIC-values of the four models with different buffer variables and distinguished models for 50-metre buffer and for chosen r-values to be better fitted than models for 100-metre and 200-metre buffers, thus excluding them (see Appendix Table 5). Again, to assess possible multicollinearity between the explanatory variables, I used VIF with a threshold of 3. I removed variables with the

highest VIF-values one by one from the models, resulting in the GLM for a 50-metre buffer with an AIC-value of 79.968 and the GLM for r-values with an AIC-value of 72.629. Consequently, I interpreted that the model for r-values is a better fit for explaining bird species richness in the 14 greenspaces.

Finally, to confirm the most significant landscape variables that better explained species richness, I fitted the GLM for r-values by reducing the model (Crawley 2007: 434-448). I extracted the landscape variables with the highest p-values one by one from the model until only one variable remained. In addition, I checked for possible interactions between the landscape variables.

3 Results

3.1 Bird species and habitat composition

I recorded a total of 41 bird species within a 50-metre radius at 60 survey sites in the city of Lahti. The highest species richness in a survey site was 12, and the lowest was four. The most common species observed were Fieldfare (*Turdus pilaris)* in 48 sites, Common Chaffinch in 47 sites, and Great Tit (*Parus major)* in 45 sites. The most abundant species were Common Chaffinch (73 pairs), Fieldfare (61 pairs), and Willow Warbler (53 pairs). Species that were observed in every greenspace were the Great Tit, Willow Warbler, and Fieldfare. The species that were observed only in one greenspace were Common Rosefinch (*Carpodacus erythrinus),* Lesser Spotted Woodpecker *(Dendrocopus minor),* Yellowhammer *(Emberiza citrinella),* Common Reed Bunting *(Emberiza schoeniclus),* Eurasian Jay *(Garrulus glandarius),* Icterine Warbler *(Hippolais icterina),* Common Gull *(Larus canus),* Lesser Black-backed Gull *(Larus fascus),* Thrush Nightingale *(Luscinia luscinia),* Eurasian Bullfinch *(Pyrrhula pyrrhula),* and Lesser Whitethroat (*Sylvia curruca)*. The species list and abundance per greenspace can be found in the appendices (Table 4).

The highest recorded species richness in a greenspace was 26 species (GS08 with seven survey sites), and the lowest was four species (GS12 with just one survey site). Figure 2 illustrates the estimated species richness in each greenspace if the sampling size had been equal (seven re-samplings generated with EstimateS, GS12 with just one sampling excluded) and the ±84% confidence intervals of the estimates. The letters A, B, and C describe the similarity between greenspaces in relation to bird species richness. Greenspaces with the letter A have statistically higher bird species richness than those with the letters B or C. The highest estimated bird species richness was found in GS08 (26 ± 4.46), GS15 (21.6 ± 9.88), and GS01 (21 ± 5.65). The lowest species richness was found in GS04 (10.7 ± 0.57), GS09 (12.88 ± 4.23), and GS14 (13.13 ± 3.27). GS08 is the only greenspace in category A. Greenspaces GS03, GS06, and GS10 are in category B, differing significantly from GS08. And finally, GS04 differs significantly from every other greenspace as it is the only one in category C. Other parks fall between the mentioned greenspaces.

The Bray-Curtis dendrograms of ecological distances in Figure 3 present the similarities in a) habitat composition and b) bird species composition between all 15

greenspaces. Greenspaces with more similar habitats or species composition are clustered closer together. Considering habitats (3a), ecological dissimilarity is < 40% and bird species composition (3b) has an ecological dissimilarity of < 80%. Figure 3a illustrate that the greenspaces are divided into three distinct clusters according to their habitat composition. However, bird species composition does not follow the same structure and is more complex (3b). I found that only GS07, GS09, and GS11 are clustered together, considering both habitat and species compositions.

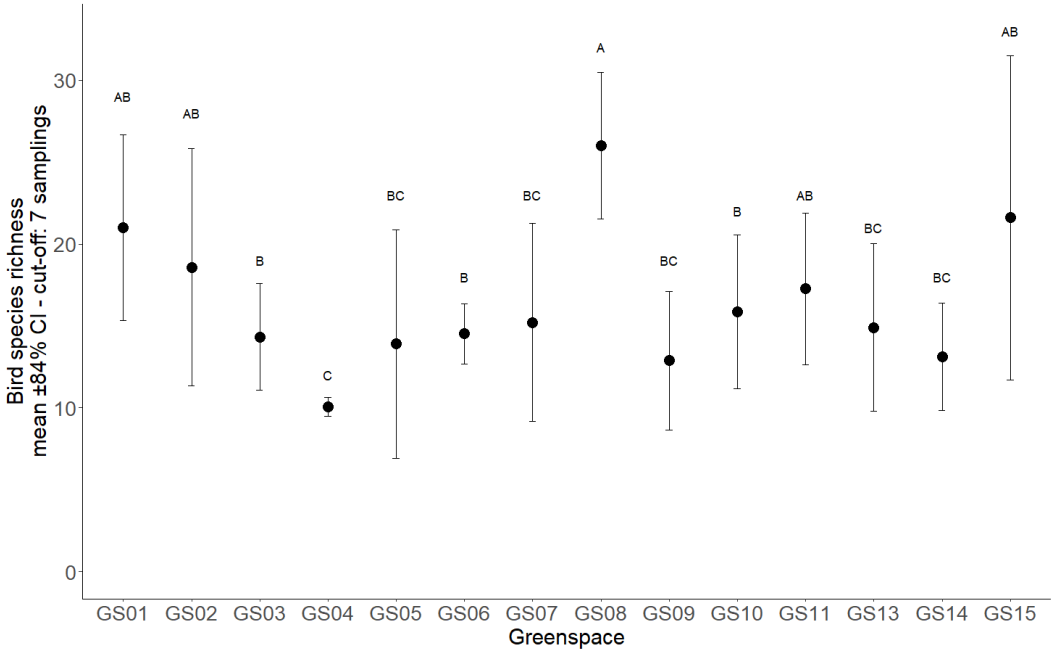


Figure 2. Estimated bird species richness in each greenspace with the ±84% confidence intervals of the estimates and description of the similarity between greenspaces marked with letters A, B, and C. The cut-off in EstimateS was seven samplings.

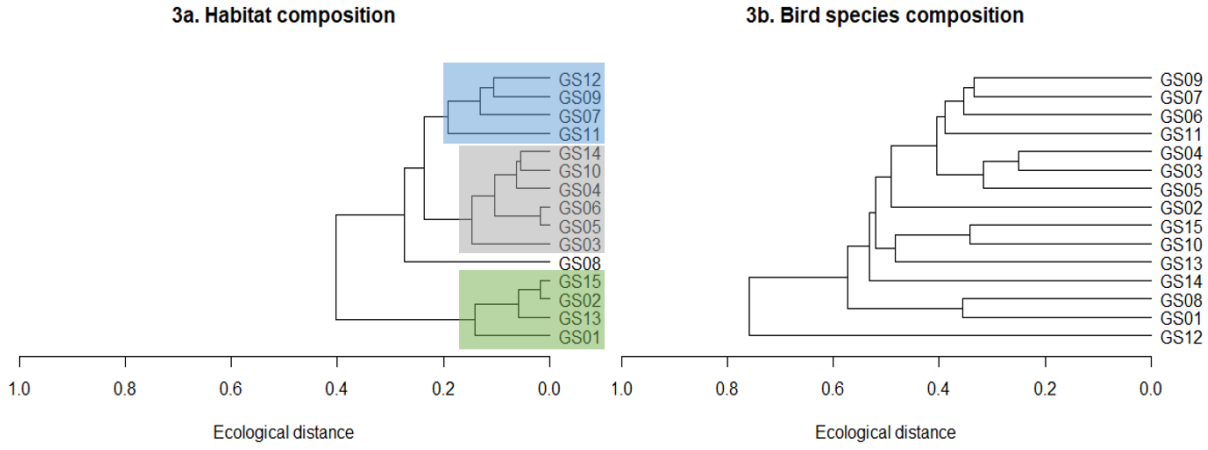


Figure 3. Bray-Curtis ecological distances between greenspaces. 3a represents the similarity between the habitat compositions of the greenspaces, and 3b represents the similarity of the bird species composition.

3.2 Species richness

I employed a generalised linear model with a total of 17 explanatory variables (Table 2), which resulted in maximum DBH being the significant factor correlating positively with bird species richness (p-value 0.027). The VIF-values of the explanatory variables in the GLM were < 3 to avoid multicollinearity between variables. Other variables were not recorded as being significant in this analysis.

According to the results, the bird species richness increases as the maximum DBH increases. Figure 4 shows the relationship between overall bird species richness and the maximum DBH of trees (metres) in the survey sites. Only in three sites (s23, s26, and s22) the maximum DBH exceeds one metre, and furthermore, the species richness is relatively high in those sites as well, from 10 to 12 species. The maximum DBH is noticeably smaller in other sites (varying from 0.3 to 0.7 metres), and species richness varies from four to 10. One survey site with nine species has a maximum DBH of zero because there are no trees present.

Table 2. Ranking the models to explain species richness according to the AIC-values.

AIC-values as well as the change in AIC (Δ AIC) of the models are also shown in the table. (sp=species richness, a=distance from survey point to urban centrum, b=distance from survey point to urban edge, c=distance from survey point to patch edge, size=greenspace size, DC=distance from greenspace to urban centrum, DB=distance from greenspace to urban border, g=survey point on avenue, h=tree abundance, i=herbaceous plant cover, j=shrub cover, k=tree cover, l=max. height of herbaceous plants, m=average height of herbaceous plants, n=max. shrub height, o=average shrub height, p=max. tree height, q=average tree height, r=max. building height, s=max. DBH, t=average DBH, u=pathwidth, v=pedestrians, w=min. noise, x=max. noise, y=average noise, z=final noise, long=longitude, lat=latitude).

Number	Model	AIC	Δ AIC
11	**sp~c+size+DC+g+h+i+j+l+n+q+r+s+u+v+w+z+lat**	**288.19**	**0**
10	sp~c+size+DC+DB+g+h+i+j+l+n+q+r+s+u+v+w+z+lat	288.19	1.84
9	sp~c+size+DC+DB+g+h+i+j+l+n+q+r+s+u+v+w+z+long+lat	288.19	1.94
8	sp~c+size+DC+DB+g+h+i+j+l+n+o+p+q+r+s+u+v+w+z+long+lat	288.19	4.32
7	sp~c+size+DC+DB+g+h+i+j+l+n+o+p+q+r+s+u+v+w+z+long+lat	290.18	6.31
6	sp~c+size+DC+DB+g+h+i+j+l+m+n+o+p+q+r+s+u+v+w+x+z+long+lat	290.69	6.82

Number	Model	AIC	∆ AIC
5	sp~c+size+DC+DB+g+h+i+j+k+l+m+n+o+p+q+r+s+u+v+w+x+z+long+lat	291.46	7.59
4	sp~c+size+DC+DB+g+h+i+j+l+m+n+o+p+q+r+s+u+v+w+z+long+lat	292.11	8.24
3	sp~c+size+DC+DB+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+z+long+lat	293.24	9.37
2	sp~b+c+size+DC+DB+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+z+long+lat	294.4	10.54
1	sp~b+c+size+DC+DB+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+y+z+long+lat	296.09	12.22
0	sp~a+b+c+size+DC+DB+g+h+i+j+k+l+m+n+o+p+q+r+s+t+u+v+w+x+y+z+long+lat	297.8	14.01

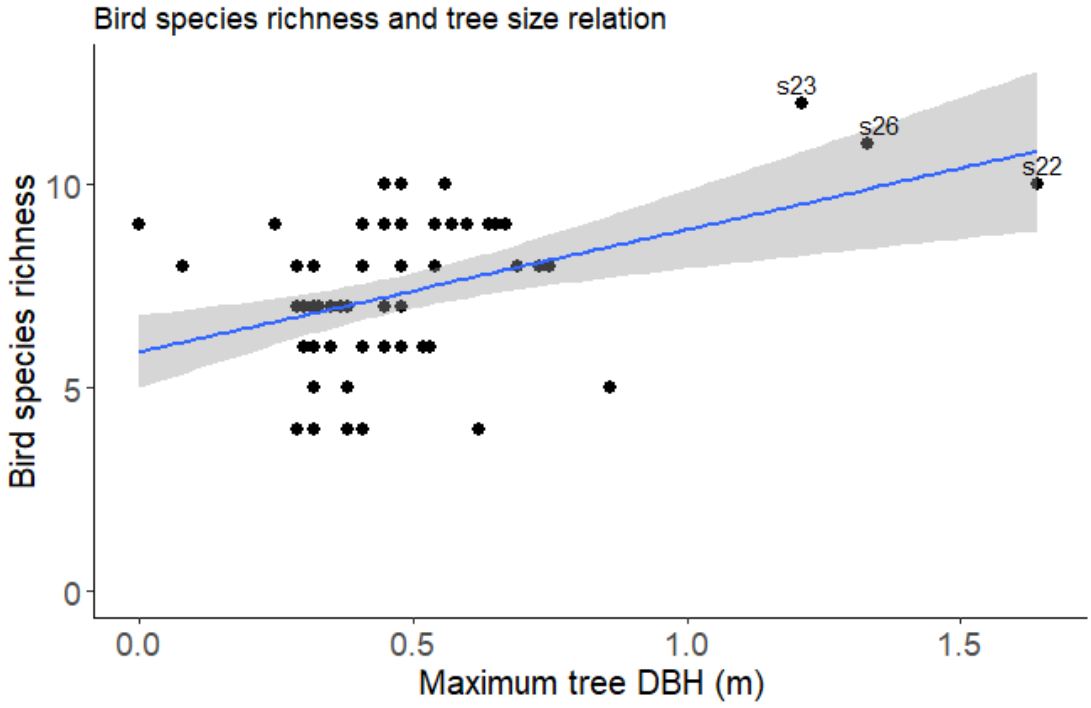


Figure 4. Correlation between overall bird species richness and the maximum tree DBH (metres) in 60 survey sites.

3.3 Landscape-scale

Estimated bird species richness in the 14 studied greenspaces varied from 10 to 26 species. GLMs with the metrics from the different buffers are presented in the appendices (Table 5). According to the lowest AIC-values, I tested both models 1 and 4 as their ΔAIC-values differed by < 2, so I could not say which model better

explained bird species richness and discarded models 2 and 3. The analyses of both models 1 and 4 with the rest of the landscape variables indicated that the model best explaining the bird species richness in the greenspaces was the GLM with the best r-values (AIC 72.629) which explained 87% of the variance (see Appendices Table 6). According to the results, the significant landscape variables correlating with the species richness are the distance from the greenspace to the border of the urban continuum (DB) (p-value 0.006), the size of the greenspace (p-value 0.013), and the LPI50 (largest patch index) (p-value 0.021) (Table 3). There were no significant interactions between these landscape variables.

I found the bird species richness to be higher in those greenspaces close to the urban continuum borders and decreasing closer to the urban centre (Figure 5). Three greenspaces (GS08 n=26, GS15 n=22, and GS01 n=21) with the highest species richness are all located 150-300 metres from the closest border. The greenspace with the lowest species richness (GS04 n=11) is located 1,000 metres from the border. The distance from the greenspace to the city border varied from 150 metres to 1,600 metres.

The results state that bird species richness increases with the size of the greenspace, as seen in Figure 6. The highest species richness was found in a 28-hectare-sized greenspace, and the lowest species richness was observed in an 11-hectare-sized greenspace. Other greenspaces with over 20 species (GS15 and GS01) varied from 16 hectares to 29 hectares. The size of the greenspace varies from ten hectares to 35 hectares.

Finally, I found that the species richness was negatively correlated with the largest patch index of the 50-metre buffer (Figure 7). In other words, there was a higher species richness in those greenspaces that have smaller green patches neighbouring them in relation to the buffer area. The highest species richness (n=26) was found in GS08, with a green patch vacating only < 30% of the 50-metre buffer area. On the other hand, the lowest species richness (n=11) was found in GS04, with a green patch vacating > 60% of the 50-metre buffer area. The buffer with the highest LPI (GS03) included a green patch vacating 89% of the buffer. LPI varied from 23% to 89%.

Table 3. Significance of the variables in explaining the bird species richness in the greenspaces.

Variable	p-value
DB	**0.006**
size	**0.013**
LPI50	**0.021**
ratio200	0.096
NP100	0.512
shape	0.681

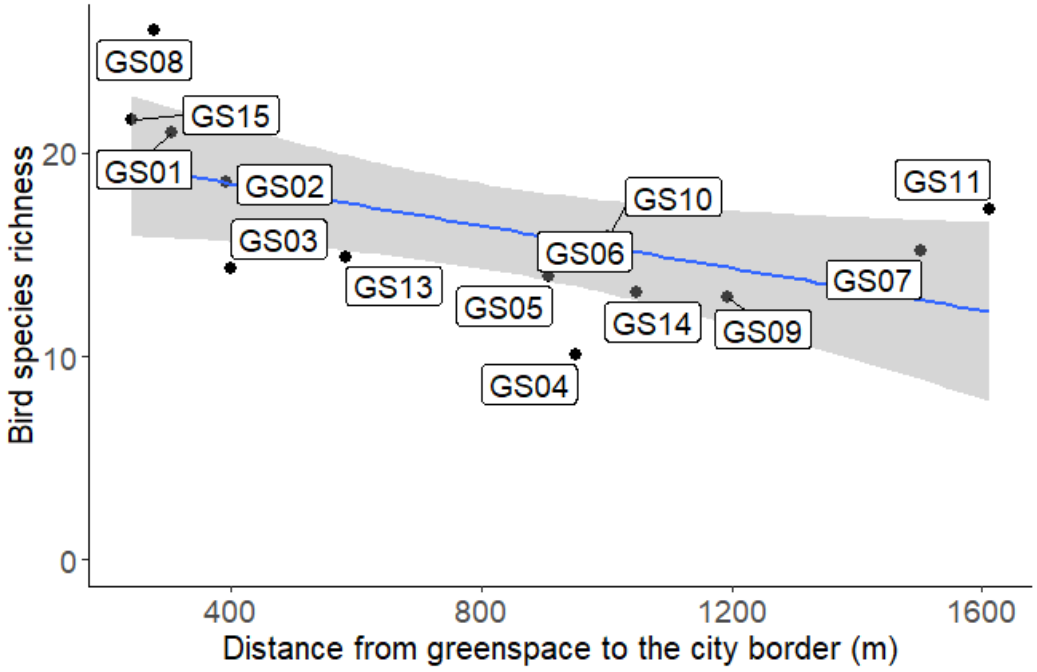


Figure 5. Correlation between overall bird species richness and the distance of the greenspaces to the border of the urban continuum (metres).

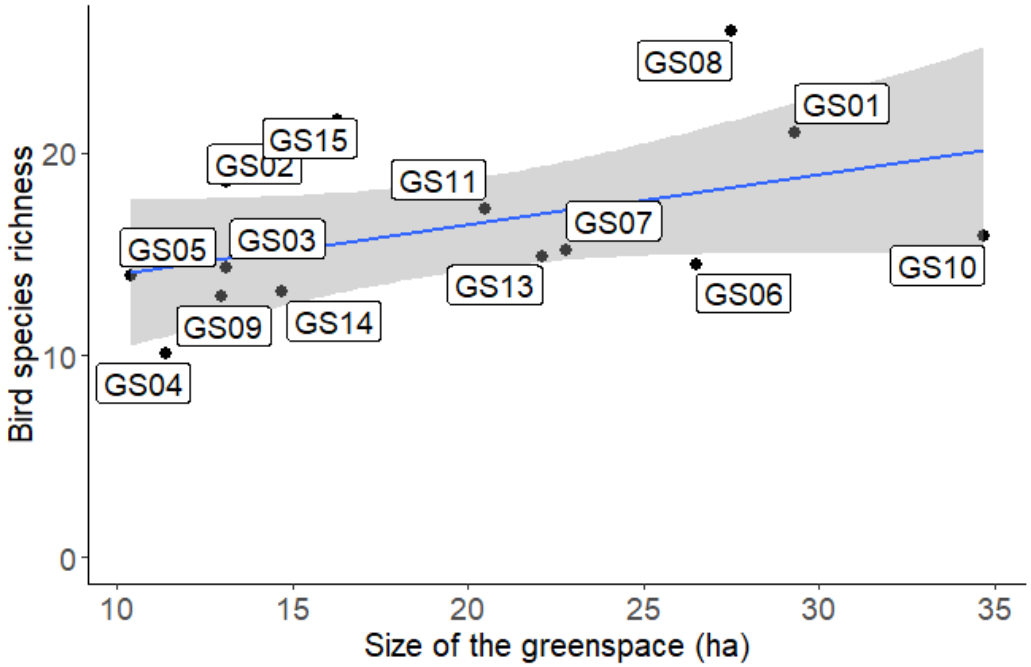


Figure 6. Correlation between overall bird species richness and the size of the greenspaces (hectares).

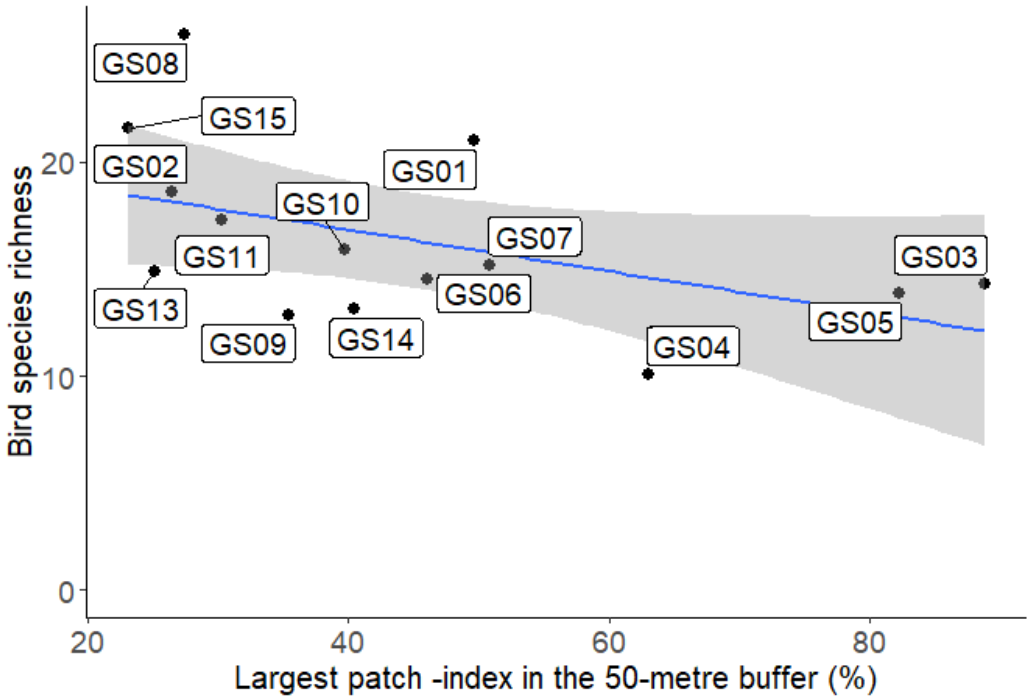


Figure 7. Correlation between overall bird species richness and the largest patch index of the 50-metre buffer (percentage). The percentage illustrates the area that is occupied by the biggest green patch inside the buffer.

4 Discussion

4.1 Bird species and habitat composition across the greenspace network

My objective was to identify local and landscape-scale drivers across the greenspace network of Lahti that are influencing bird species diversity and to assess the role of major greenspaces in an urban environment. This study found evidence of them both influencing bird species richness in Lahti. The vegetation structure inside the greenspace (especially the size of the trees) had a significant positive correlation with bird diversity. In addition, the distance from the greenspace to the urban continuum border, the size of the greenspaces, and the amount of green neighbouring the greenspaces are significant factors explaining bird diversity. One greenspace (GS08) in particular stood out, hosting a diverse bird community while being located right in the city centre.

I recorded a total of 41 bird species in the urban greenspace network of Lahti. According to the Birdlife Päijät-Häme ornithological society (2023), there were 183 breeding bird species recorded in 2018. Thus, around 22 percent of the total breeding bird species were observed in the 15 urban greenspaces. According to Komi and others (2012), there were a total of 144 breeding bird species in the Lahti region that were recorded in the Bird Atlas of Lahti during the years 2009-2011. In addition, the number of species in Lahti does not differ much from the total of recorded species in the city of Helsinki, which was 151 species in 2019 (Helsingin kaupunki 2019).

The estimated bird species richness in each greenspace varied from 11 to 26. GS08 had the highest species richness differing significantly from every other greenspace. On the other hand, the other two most diverse greenspaces GS01 and GS15 did not differ much from the other greenspaces implying that GS08 is very significant habitat maintaining the urban bird community diversity. When comparing the overall habitat and bird species composition, the greenspaces that are visibly the most similar in habitat and bird species composition are GS07, GS09, and GS11. They are all located close to each other in a moderately urban area, and they are part of the bigger network of urban greeneries in the northern part of Lahti. It can be easier for birds to travel between greenspaces that are close to each other, making it possible to find more resources and consequently creating more united urban bird communities. However, I did not find a significant correlation between the connectedness of the

greenspaces and bird species richness as I expected, but the results show that GS05 and GS06 resemble each other closely in habitat composition. This can be due to their connectedness, as I found that their connectance indeces generated with Fragstats are higher than the other greenspaces (GS05 CI100 5.7%, GS06 CI100 3.3%). In contrast, other greenspaces have connectance indices varying from 0% to 2%.

The studied greenspaces are clearly clustered in three groups according to their habitat composition, meaning that these large urban greeneries are divided into three different types of habitats. On the other hand, bird species composition does not share this structure; in fact, the bird species composition structure between greenspaces differs a lot from the more distinct habitat composition structure. Birds can utilise these varying urban greeneries and maintain a rich community. In addition, there is less ecological dissimilarity in the habitat compositions (40%) compared to the ecological dissimilarity of the bird species compositions (80%). Urban greeneries can resemble each other due to the continuous disturbance, altered vegetation, and common management actions (Shwartz *et al.* 2008) across the greenspace network in Lahti. In contrast, a very high dissimilarity in bird species richness between greenspaces states that at least these big urban greeneries can host a diverse urban dweller community and, furthermore, they are essential to sustain the populations in the city (Shwartz *et al.* 2008).

4.2 The importance of urban remnant trees

I expected the bird species richness to be higher in those greenspaces with a more diverse vegetation structure, including large trees. I found that the maximum DBH of trees in my survey sites was the one significant habitat variable correlating positively with bird species richness. Species richness was higher when the trees at the study site were larger. The maximum DBH varied around 0.3 to 0.7 metres in most of the sites, and only three sites had trees with a DBH over one metre (sites s22, s23, and s26). Those sites are located inside GS08, right in the city centre, next to Lake Vesijärvi, which I found to be the most species-rich greenspace, as mentioned in Section 3.1. From the larger DBH, I can assume the trees are older, indicating that the overall vegetation is at the older end of the succession and the habitat is stabilised.

Therefore, the avian community has been established, and the habitat fits more species in different niches.

Greenspace with a diverse vegetation structure offers a variety of resources to hole-nesting species as well as ground-nesting species and raptors. Jokimäki and others (2014) found that the height of a dominant tree species in Finnish urban greenspaces was the main factor increasing the breeding bird species richness, total number of species, and total number of pairs belonging to different forest habitats. The tree height could be related to the selection of a safe nesting place and predator avoidance, as Jokimäki and others (2014) also documented that urban birds prefer nesting higher in the tree than rural individuals. Consequently, bigger trees across the greenspace network of Lahti can offer safe breeding habits and thus attract more species than other greeneries.

However, single remnant trees can be important to the urban bird community as well. Barth and others (2015) found that novel urban areas in a city in Australia with single remnant trees increased bird species richness and abundance compared to the ones without fully grown trees. Furthermore, their results stated that the species composition was significantly different to those areas without trees and resembled the species composition in urban parks. Similarly, Fernández-Juricic and Jokimäki (2001) established that trees along the streets of Madrid can provide the necessary resources for urban birds during breeding season, especially for species that feed on the ground but nest in the trees. Leaving remnants, even single native trees, in urban developments can be a valuable resource for urban birds and increase connectivity between habitats by working as ecological corridors if there is density-dependent pressure to disperse within the urban greenspace network (Fernández-Juricic and Jokimäki 2001; Barth *et al.* 2015).

The positive correlation between bird species richness and maximum DBH of the trees that I found should be interpreted with caution, as the increase seen in Figure 4 is visible only in the three survey sites with species richness varying from 10 to 12 (maximum DBH > one metre). The species richness of the other 57 survey sites is clustered between four and 10, with maximum DBH varying from 0.25 to 0.75 metres. A wider and longer-term survey is needed to determine if the DBH is the only significant environmental variable on a local-scale correlating with bird species richness in the urban greenspaces of Lahti.

4.2.1 Kariniemi Park as an urban bird hotspot

I observed the highest species richness in GS08 (Kariniemi Park), which is located in the city centre and is a very popular recreation area in Lahti. It is also a relatively large greenspace with a total of 27,5 hectares, and it includes seven of my study sites. This finding could be partly explained by the unique topography of the area – a combination of forests, lowlands, fields, and a waterbody. The greenspace includes a small nature conservation area, and the vegetation overall is diverse with tall deciduous and coniferous trees (Kekki et al. 2019; Lahden karttapalvelu 2023). According to Neuvonen and others (2013), the greenspace has been considered a significant bird nesting site. Furthermore, due to the unique shape of the urban continuum in Lahti, Kariniemi Park is located right next to Lake Vesijärvi, which can benefit the urban dweller community. The freshwater offers safe drinking water and bathing areas to water-related species as well as forest species. Xie and others (2021) found that waterbodies within and outside urban greeneries increase bird species richness and abundance in the city of Beijing, more specifically forest species that are not directly dependent on aquatic habitats. Callaghan and others (2021) stated that waterbodies within the city can even increase bird species richness compared to more rural areas. My observations support the fact that with a diverse vegetation structure including remnant trees and the neighbouring lake, Kariniemi Park hosts a rich bird community, including one of the area's typical dwellers, the Icterine Warbler (Kekki et al. 2019).

4.3 Bird diversity on the landscape-scale

Firstly, I found that bird species richness was higher in those greenspaces closer to the border of the urban continuum. Furthermore, three greenspaces (GS08, GS01, and GS15) with the highest bird species richness were the closest to the border as well. GS08 was the closest greenspace to the city centre, as I discussed earlier, and this intriguing feature is due to the particular shape of the city caused by the lake Vesijärvi. However, GS01 and GS15 are located in suburban areas on opposite sides of Lahti. Actually, urban bird species have been found to prefer suburban habitats over urban habitats, at least in Sweden (Sandström *et al.* 2006). Suburban areas often include gardens and other diverse greenery suitable for bird habitats. Private gardens can support high biodiversity and be considerable habitats for a large number of

urban populations due to their varying vegetation structure, including different tree species, diverse nesting sites, and improved primary production (Sandström *et al.* 2006; Ferenc *et al.* 2014). In addition, predation risk can be lower when there are other prey species available besides birds (Sandström *et al.* 2006).

Often, the size of a greenspace is an important factor explaining bird species richness in an urban environment (Jokimäki 1999). Larger urban greenspaces have more breeding bird species than smaller ones (Donnelly and Marzluff 2004; Evans *et al.* 2009; Jokimäki *et al.* 2014). Following this theory, I predicted that the size of the greenspaces in Lahti would have a positive correlation with the bird species richness. According to the analysis, together with the habitat variables, the size of the greenspace did not have a significant correlation with bird species richness on a local scale. However, on the landscape-scale, the results state that size was one of the significant landscape variables correlating positively with species richness. Similarly, Evans and others (2009) stated that bird species richness is likely to increase with the size of urban greenery.

Supporting my findings on the landscape-scale, Jokimäki and others (2014) conducted an urban bird survey in the city of Rovaniemi, where they found that the size of an urban wooded green area was the most important environmental factor explaining the overall bird abundance. The size correlated positively with the bird species richness, the total number of abundant pairs, the total number of pairs belonging to different ecological groups, and the total number of pairs of the most common species. Especially the Common Chaffinch, Willow Warbler, Great Tit, and Redwing (*Turdus iliacus)* increased in numbers with the increasing greenspace size. However, their study area included greenspaces that were 0.3-10.9 hectares in size, whereas my greenspaces varied from 10.4 to 34.7 hectares. The difference between 0.3 and 10-hectare urban greenery can be huge considering their habitat suitability for urban dwellers and result in significant differences in biodiversity.

Finally, I found that the largest patch index of the 50-metre buffer (LPI50) was the only significant Fragstats metric explaining bird species richness in my results. My results indicate that greenspaces with smaller green patches (in relation to the 50-metre buffer) around them have higher bird species richness. Three greenspaces (GS03, GS05, and GS04) with the highest LPI varied from 60 to 90%. Consequently,

these three greenspaces form part of the close greenspace network in the northern parts of Lahti.

Cities are very fragmented areas, and the built structures such as roads and tall buildings divide the remaining greenspaces into smaller greeneries than in a natural habitat outside urban settlements, creating isolated habitat islands (Oliver *et al.* 2011). GS08 is an example of an isolated urban greenspace that is mostly surrounded by highly built areas in the centre of the city, yet it still has the highest bird species richness in my study. Oliver and others (2011) stated that these habitat islands can host a diverse bird community because most of the species in the area are concentrated in this one greenery, which has suitable habitats that the built environment does not offer. If there are other green patches neighbouring the bigger greenspaces, it increases the connectivity between habitats, so urban dwellers have more space to move around, disperse, and utilise a wider range of resources.

In addition, low LPI might be a typical characteristic of the overall fragmented urban environment, and most of the urban greeneries are surrounded by just small green patches (LPI < 50%). Thus, these three greenspaces with a higher LPI are exceptions to the urban greenspace network surrounded by sealed and built surfaces. Furthermore, this conclusion supports the findings I discussed earlier in Section 4.2, that even single remnant trees on the sides of the streets are important to bird diversity. Single trees and small green patches can offer necessary resources, such as foraging and nesting sites, to breeding birds.

5 Conclusions

A total of 22% of the breeding birds recorded in the Päijät-Häme region were observed in these 15 urban greenspaces. Both local and landscape-scale drivers were found to influence the bird species richness across the urban greenspace network of the city of Lahti. On the local scale, study sites with larger trees had a higher bird species richness, supporting previous work stating that remnant trees in urban environments are important to sustaining bird diversity. On the landscape-scale, three significant environmental variables were found to correlate with bird species richness. Species richness increased with the size of the greenspace, as expected; however, it decreased in greenspaces further away from the urban continuum border and when the surrounding 50-metre buffer included bigger green patches neighbouring the greenspace. Urban greenspaces are fragmented habitat islands, which induces risks for urban dwellers, but bigger greeneries with diverse habitats, including remnant trees, can host a number of species as long as they are conserved.

However, there are some difficulties in studying urban greenspaces and making the information comparable. There are limitations in data collection and generalising information because of spatial and temporal scale since studies include varying numbers of greenspaces, surveys are conducted only during breeding season, or they are carried out only during one year, such as my study (Callaghan *et al.* 2018). One possible solution is to use citizen science as a data collection method because it would maximise the available data in different areas and temporal recurrence.

5.1 Suggestions for urban planning and management

The survey included a total of 217 study sites across the urban continuum of Lahti, but I focused on the greenspace network. I observed a total of 58 bird species across the city, including green and grey areas. Consequently, these 15 studied urban greenspaces host 70 percent of the bird species I observed in Lahti. Greenspaces are essential to conservation and preserving avian communities in urban environments.

The effects of different environmental variables on the bird community are often species-specific. Species-specific responses are, for example, related to food and breeding habits and adaptation to anthropogenic disturbance (Ortega-Álvarez and MacGregor-Fors 2010). To understand the resources that urban communities need, a

comprehensive study of different urban dweller species is important – not just the few sensitive species – to achieve effective management (Marzluff and Ewing 2001). Unfortunately, applying species-specific management suggestions to urban management is difficult (Ortega-Álvarez and MacGregor-Fors 2010). Officials have to consider many other aspects in addition to the ecological information. According to an interview conducted by Yli-Pelkonen (2008), housing and other economic and social well-being-related issues tend to weigh more in the decision-making process than ecological information, and conservation of urban greenspaces is considered important but not ‘’a ruling factor’’ in land use.

My results indicate that in urban planning and management, it is important to consider both local characteristics and the landscape-scale to understand bird-habitat relationships, as also stated by Jokimäki (1999). Often, the proposed management action is to increase the number of old trees to attract individuals, enabling new populations to inhabit urban areas (Ortega-Álvarez and MacGregor-Fors 2010). Moreover, my findings support Jokimäki and others (2014) suggestion that it is important to promote conservation actions in urban green areas that are already large and areas with remnant dominant trees. Overall, a sufficient amount of natural and diverse vegetation with multiple layers, and old and big trees can host a more diverse bird community in an urban greenspace (Sandström *et al.* 2006). Jokimäki and others (2014) state that it would be good to observe the surroundings, such as buffer zones of urban greenspaces, which I found to have significant correlations with bird species richness as well. To have more remnant and diverse habitats, it is essential to conserve green areas outside cities before they are urbanised so the vegetation remains and trees do not have to be planted from the beginning.

In addition to the survey data scholars are conducting, utilising citizen science in urban ecology research can offer broad survey data and enable a more comprehensive analysis of the relationships between urban avian communities and greenspaces (Callaghan *et al.* 2018). Citizens are able to observe ecological processes and changes, including habitat fragmentation and biodiversity loss, which can raise awareness of environmental and climate issues (Yli-Pelkonen and Niemelä 2005). The city has to ensure all essential environmental information is produced and available for planning and decision-making, conserving ecologically the most important areas (Yli-Pelkonen 2008).

Acknowledgements

A thank you to Ian MacGregor-Fors for supervising this thesis; his exceptional guidance throughout the process made this project possible. A special thank you to Michelle García-Arroyo for assisting with data analysis. And thank you to both Michelle García-Arroyo and Miquel Gómez-Martínez for the great and successful field work in Lahti and their irreplaceable support throughout the project. A thank you to the Master's Programme in Ecology and Evolutionary Biology for the financial support that made the field work in Lahti possible. Finally, thank you to all the friends and family for their mental support on this journey.

References

Alberti, M. & Marzluff, J.M. 2004: Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. – *Urban Ecosystems* 7: 241–265.

Alberti, M. 2007: The Urban Ecosystem. – In: Alberti, M., *Advances in Urban Ecology*: 1-26. Springer, Seattle, Washington.

Aronson, M.F.J., Frank A. La Sorte, Charles H. Nilon, Madhusudan Katti, Mark A. Goddard, Christopher A. Lepczyk, Paige S. Warren, Nicholas S. G. Williams, Sarel Cilliers, Bruce Clarkson, Cynnamon Dobbs, Rebecca Dolan, Marcus Hedblom, Stefan Klotz, Jip Louwe Kooijmans, Ingolf Ku ¨hn, Ian MacGregor-Fors, Mark McDonnell, Ulla Mo ¨rtberg, Petr Pys ˇek, Stefan Siebert, Jessica Sushinsky, Peter Werner and Marten Winter 2014: A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. – *Proceedings of the Royal Society B: Biological Sciences* 281: 20133330.

Barth, B.J., FitzGibbon, S.I. and Wilson, R.S. 2015: New urban developments that retain more remnant trees have greater bird diversity. – *Landscape and Urban Planning* 136: 122-129.

Callaghan, C.T., Major, R.E., Lyons, L.B., Marin, J.M. and Kingsford, R.T. 2018: The effects of local and landscape habitat attributes on bird diversity in urban greenspaces. – *Ecosphere* 9(7): e02347.

Callaghan, C.T., Poore, A.G.B., Major, R.E., Cornwell, W.K., Wilshire, J.H. and Lyons, M.B. 2021: How to build a biodiverse city: environmental determinants of bird diversity within and among 1581 cities. – *Biodiversity and Conservation* 30: 217–234.

Carral-Murrieta, C.O., García-Arroyo, M., Marín-Gómez, O.H., Sosa-López, J.R. and MacGregor-Fors, I. 2020: Noisy environments: untangling the role of anthropogenic noise on bird species richness in a Neotropical city. – *Avian Research* 11: 32.

Colwell, R.K. 2013. EstimateS v.9.1.0: Statistical estimation of species richness and shared species from samples. Available at: robertkcolwell.org.

Crawley, M.J. 2007: Regression. – In: Crawley, M.J., *The R Book*: 434-448. Wiley, Chichester.

Donnelly, R. and Marzluff, J.M. 2004: Importance of Reserve Size and Landscape Context to Urban Bird Conservation. – *Conservation Biology* 18: 733-745.

Evans, K.L., Newson, S.E. and Gaston, K.J. 2009: Habitat influences on urban avian assemblages. – *Ibis* 151: 19-39.

Ferenc, M., Sedláček, O. and Fuchs, R. 2014: How to improve urban greenspace for woodland birds: site and local-scale determinants of bird species richness. – *Urban Ecosystems* 17: 625–640.

Fernández-Juricic, E. and Jokimäki, J. 2001: A habitat island approach to conserving birds in urban landscapes: case studies from southern and northern Europe. – *Biodiversity and Conservation* 10: 2023–2043.

Fey, K., Vuorisalo, T., Lehikoinen, A. and Selonen, V. 2015: Urbanisation of the wood pigeon (*Columba palumbus*) in Finland. – *Landscape and Urban Planning* 134: 188-194.

Fischer, J.D., Schneider, S.C., Ahlers, A.A. and Miller, J.R. 2015: Categorizing wildlife responses to urbanization and conservation implications of terminology. – *Conservation Biology* 29: 1246-1248.

Gavrilidis, A.A., Niţă, M.R., Onose, D.A., Badiu, D.L. and Năstase, I.I. 2019: Methodological framework for urban sprawl control through sustainable planning of urban green infrastructure. – *Ecological Indicators* 96: 67-78.

Google Earth 7.3, 2023. *Finland, 60. 571417, 25.443674*. Available at: earth.google.com (Accessed 2.5.3023).

Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D., Lovejoy, T.E., Sexton, J.O., Austin, M.P., Collins, C.D., Cook, W.M., Damschen, E.I., Ewers, R.M., Foster, B.L., Jenkins, C.N., King, A.J., Laurance, W.F.,Levey, D.J., Margules, C.R., Melbourne, B.A., Nicholls, A.O., Orrock, J.L., Song, D.X. and Townshend, J.R. 2015: Habitat fragmentation and its lasting impact on Earth's ecosystems. – *Advancement for Science* 1: e1500052.

Hedblom, M. & Söderström, B. 2010: Landscape effects on birds in urban woodlands: an analysis of 34 Swedish cities. – *Journal of Biogeography* 37: 1302-1316.

Helminen, V., Nurmio, K. and Vesanen, S. 2020: Kaupunki-maaseutu-alueluokitus 2018. – *Suomen ympäristökeskuksen raportteja 21*. Suomen ympäristökeskus (SYKE), Helsinki.

Helsingin kaupunki 2023: Helsingin pesimälintulajit 2019. Available at: hel.fi (Accessed 18.4.2023).

Hilden, O., Koskimies, P. and Väisänen, R.A. 1991: Point Count of Breeding Land Birds. – In: Koskimies, P. and Väisänen, R.A., *Monitoring Bird Populations*: 27-32. Zoological Museum, Finnish Museum of Natural History, University of Helsinki.

Hunt, M.L., Blackburn, G.A., Siriwardena, G.M., Carrasco, L. and Rowland, C.S. 2022: Using satellite data to assess spatial drivers of bird diversity. – *Remote Sensing in Ecology and Conservation*. [Online]

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

Jokimäki, J., Kaisanlahti-Jokimäki, M-L. and Carbó-Ramírez, P. 2014: The importance of wooded urban green areas for breeding birds: a case study from Northern Finland. – In: Brumm, H. and Gil, D., *Avian Urban Ecology: behavioural and physiological adaptations*: 201-213. Oxford University Press, Oxford.

Jokimäki, J., Suhonen, J. and Kaisanlahti-Jokimäki, M-L. 2018: Urban core areas are important for species conservation: A European-level analysis of breeding bird species. – *Landscape and Urban Planning* 178: 73-81.

Kekki, I., Kuhno, P., Lammi, E. and Metsänen, T. 2019: *Päijät-Hämeen lintupaikkaopas*. – Päijät-Hämeen Lintutieteellinen Yhdistys ry, Lahti.

Komi, P., Kuhno, P., Metsänen, T. and Selin, M. 2012: *Lahden II lintuatlas 2009-2011*. 1. p. [Lahti]: Lahden seudun ympäristöpalvelut.

Lahden kaupunki 2023: Lahden karttapalvelu. Available at: kartta.lahti.fi (Accessed 7.1.2023).

Lancaster, R.K. and Rees, W.E. 1979: Bird communities and the structure of urban habitats. – *Canadian Journal of Zoology* 57: 2358–2368.

Lepczyk, C.A., Aronson, M.F.J., Evans, K.L., Goddard, M.A., Lerman, S.B. and Macivor, J.S. 2017: Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. – *BioScience* 67: 799-807.

MacGregor-Fors, I., García-Arroyo, M., Kotze, J., Ojala, E., Setälä, H. and Vauramo, S. 2021: A more sustainable urban future calls for action: the city of Lahti as European Green Capital 2021. – *Journal of Urban Ecology* 7: 1-6.

Marzluff, J.M. and Ewing, K. 2001: Restoration of Fragmented Landscapes for the Conservation of Birds: A general Framework and Specific Recommendations for Urbanizing Landscapes. – *Restoration Ecology* 9: 280-292.

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

McKinney, M. 2002: Urbanization, Biodiversity, and Conservation. – *BioScience* 52: 883-890.

McGarigal K., Cushman, S.A. and Ene, E. 2023. FRAGSTATS v4.2.1: Spatial Pattern Analysis Program for Categorical Maps. Computer software program produced by the authors. Available at: fragstats.org.

Neuvonen, H., Särkkä, A-M., Kujala, K., Palojärvi, E., Niemelä, M., Asikainen, R., Varso, K., Uronen, C., Karvinen-Jussilainen, A., Palomäki, J., Silvast, M., Rope, A-M., Riihelä, A., Karu-Hanski, T., Malin, I., Sivonen, M., Ojala, M., Utter, P., Lanki, T. and Vauramo, S. 2013: Lahden viheralueohjelma 2013-2025. – Lahden kaupunki, Lahti. Available at: lahti.fi (Accessed 1.2.2023).

Newton, I. 1998: Habitat Fragments and Metapopulations. – In: Newton, I., *Population Limitation in Birds*: 123-142. Academic Press, Amsterdam.

O'Brien, R.M. 2007: A Caution Regarding Rules of Thumb for Variance Inflation Factors. – *Quality & Quantity* 41:673–690.

Oke, T.R. 1973: City size and the urban heat island. – *Atmospheric Environment* 7: 769-779.

Oliver, A.J., Hong-Wa, C., Devonshire, J., Olea, K.R., Rivas, G.F. and Gahl, M.K. 2011: Avifauna richness enhanced in large, isolated urban parks. – *Landscape and Urban Planning* 102: 215-225.

Ortega-Álvarez, R. and MacGregor-Fors, I. 2010: What matters most? Relative effect of urban habitat traits and hazards on urban park birds. – *Ornitologia Neotropical* 21: 519–533.

Päijät-Hämeen lintutieteellinen yhdistys – Birdlife Päijät-Häme 2023: Kuntien lajimäärät. Available at: phly.fi (Accessed 18.4.2023).

Ralph, C.J., Sauer, J.R. and Droege, S., technical editors 1995: *Monitoring Bird Populations by Point Counts*. – General Technical Report PSW-GTR-149. Pacific Southwest Research Station, Forest Service, US. Department of Agriculture, Albany CA.

R Core Team 2022: R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: r-project.org.

Sandström, U.G., Angelstam, P. and Mikusinski, G. 2006: Ecological diversity of birds in relation to the structure of urban green space. – *Landscape and Urban Planning* 77: 39-53.

Santiago-Alarcon, D. and Delgado-V., C.A. 2017: Warning! Urban Threats for Birds in Latin America. – In: MacGregor-Fors, I. and Escobar-Ibáñez, J., *Avian Ecology in Latin American Cityscapes*: 125–142. Springer, Cham.

Schneider, S.C., Fischer, J.D. and Miller, J.R. 2014: Two-sided edge responses of avian communities in an urban landscape. – *Urban Ecosystems* 18: 539–551.

Shwartz, A., Shirley, S. and Kark, S. 2008: How do habitat variability and management regime shape the spatial heterogeneity of birds within a large Mediterranean urban park? – *Landscape and Urban Planning* 84: 219–229.

Sol, D., Timmermans, S. and Lefebvre, L. 2002: Behavioural flexibility and invasion success in birds. – *Animal Behaviour* 63: 495-502.

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

Thompson, C.G., Kim, R.S., Aloe, A.M. and Becker, B.J. 2017: Extracting the Variance Inflation Factor and Other Multicollinearity Diagnostics from Typical Regression Results. – *Basic and Applied Social Psychology* 39: 81-90.

Tilastokeskus: Väestörakenne. – Helsinki: Tilastokeskus. Available at: stat.fi/StatFin (Accessed 2.5.2023)

Tryjanowski, P., Morelli, F., Mikula, P., Krištín, A., Indykiewicz, P., Grzywaczewski, G., Kronenberg, J. and Jerzak, L. 2017: Bird diversity in urban green space: A large-scale analysis of differences between parks cemeteries in Central Europe. – *Urban Forestry & Urban Greening* 27: 264–271.

Turner, W.R. 2002: Citywide biological monitoring as a tool for ecology and conservation in urban landscapes: the case of the Tucson Bird Count. – *Landscape and Urban Planning* 65: 149–166.

Von Thaden, J., Badillo-Montaño, R., Lira-Noriega, A., García-Ramírez, A., Benítez, G., Equihua, M., Looker, N. and Pérez-Maqueo, O. 2021: Contributions of green spaces and isolated trees to landscape connectivity in an urban landscape. – *Urban Forestry & Urban Greening* 64: 127227.

Xie, S., Marzluff, J.M., Su, Y., Wang, Y., Meng, N., Wu, T., Gong, C., Lu, F., Xian, C., Zhang, Y. and Ouyang, Z. 2021: The role of urban waterbodies in maintaining bird species diversity within built area of Beijing. – *Science of the Total Environment* 806: 150430.

Yli-Pelkonen, V. and Niemelä, J. 2005: Linking ecological and social systems in cities: urban planning in Finland as a case. – *Biodiversity and Conservation* 14: 1947–1967.

Yli-Pelkonen, V. 2008: Ecological information in the political decision making of urban land-use planning. – *Journal of Environmental Planning and Management* 51: 345-362.

Appendices

Table 4. List of bird species that contributed to differences in species composition in the city of Lahti.

The table presents all the observed bird species in the survey sites within the 50-metre radius. The x marks whether the species was observed in the greenspace.

Species	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**
Acrocephalus dumetorum	x							x							
Anas platyrhynchos								x							x
Apus apus		x											x	x	x
Branta leucopsis								x							
Carpodacus erythrinus	x														
Certhia familiaris								x							x
Chloris chloris	x	x					x	x					x		
Chroicocephalus ridibundus	x							x							
Columba palumbus	x	x	x	x	x	x		x		x	x			x	x
Corvus cornix			x			x	x	x	x		x			x	
Corvus monedula							x	x						x	
Cyanistes caeruleus	x	x	x	x	x		x	x	x		x		x		x
Dendrocopos major		x				x				x	x				
Dendrocopos minor			x												
Emberiza citrinella															x
Emberiza schoeniclus		x													
Erithacus rubecula										x	x				x
Ficedula hypoleuca	x	x	x		x			x	x			x	x		
Fringilla coelebs	x	x	x	x	x	x	x	x	x	x	x		x	x	x

Species	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
Garrulus glandarius	x														
Hippolais icterina								x							
Larus canus								x							
Larus fuscus								x							
Luscinia luscinia															x
Motacilla alba	x	x						x							
Parus major	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Passer montanus								x						x	
Phoenicurus phoenicurus	x		x			x		x		x	x		x	x	
Phylloscopus sibilatrix	x		x	x	x	x	x	x	x		x				
Phylloscopus trochilus	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Pica pica	x						x			x	x			x	
Pyrrhula pyrrhula										x					
Regulus regulus	x			x	x	x	x			x					
Sylvia atricapilla		x						x		x			x		x
Sylvia borin	x					x		x	x		x		x	x	
Sylvia curruca											x				
Troglodytes troglodytes										x					
Turdus iliacus	x	x	x	x	x	x	x	x	x	x	x		x	x	
Turdus merula	x		x	x		x	x	x	x	x			x		x
Turdus philomelos	x					x									x
Turdus pilaris	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table 5. Four generalised linear models, their AIC- and Δ AIC-values with the metrics from each of the buffers (50-metre, 100-metre, and 200-metre), the model with the best r-values, and r-squared of the models.

Number	Model	AIC	Δ AIC	r^2
1	**sprich ~ TA50 + NP50 + LPI50 + CI50 + ratio50**	**83.39**	**0**	**0.2954968**
4	**sprich ~ TA200 + NP100 + LPI50 + CI200 + ratio200**	**84.35**	**0.967**	**0.4571708**
3	sprich ~ TA200 + NP200 + LPI200 + CI200 + ratio200	87.347	3.957	0.2822104
2	sprich ~ TA100 + NP100 + LPI100 + CI100 + ratio100	88.035	4.645	0.2020944

Table 6. Results of the reduced generalised linear model for the best r-values.

Model	AIC	Δ AIC	r^2
sprich ~ size + NP100 + LPI50 + ratio200 + shape + DB	72.629	0	0.872841
sprich ~ size + LPI50 + DB	72.632	0.003	0.724941
sprich ~ size + LPI50 + ratio200 + DB	74.329	1.7	0.763932
sprich ~ size + DB	74.533	1.904	0.600312
sprich ~ size + NP100 + LPI50 + ratio200 + DB	75.338	2.709	0.805198
sprich ~ DB	77.168	4.539	0.433129