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Winter field survey of bird feeders in two Hungarian cities

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Abstract Bird feeding by people is one of the most popular human-wildlife interactions globally. Urban ecology studies generally recognize that cities offer a more favourable habitat for many wintering birds compared to natural areas, primarily due to the increased availability of the winter food sources provided by people. However, actual field surveys about the residents' bird feeding activity are rare. Here we surveyed bird feeders during the winter of 2021–2022 at 5-5 locations in two cities in Hungary. We recorded the number and type of bird feeders, the type of food offered, the number of bird species and individuals visiting the feeders. The density of feeders was higher in Veszprém, a middle-sized city (range: 60.1–206.1 bird feeders/km^2) compared to Budapest, the capital city of Hungary (23.3–83.0 bird feeders/km^2). The most frequent food types were fat balls, seed mix, and sunflower seeds in both cities. We registered a total of 516 individuals of 24 species on the feeders, and found that the type of the feeder, but not the city, significantly affected both the number of individuals and species visiting bird feeders. These results help to get a more complete picture of how the winter food supplies of birds are shaped by urbanization.

Keywords: urbanization, wildlife feeding, supplementary feeding, human-wildlife interaction, Central Hungary

Összefoglalás Az emberek szerte a világon, így Magyarországon is előszeretettel helyeznek ki eleséget a madarak számára. A városökológiai kutatásokban általánosan elfogadott nézet, hogy az így megnövekedett téli táplálékmennyiség kedvezőbb élőhellyé teheti a madarak számára a városokat a természetes területeknél, legalábbis a téli időszakban. Azonban arról, hogy milyen típusú és mennyiségű madáreleséget helyeznek ki a lakosok, ritkák a tényleges terepi felméréseken alapuló vizsgálatok a szakirodalomban. Ezért jelen vizsgálatunkban ismételt terepi bejárások során mértük fel a madáretetőket 2021–2022 telén, 5 budapesti és 5 veszprémi helyszínen. Feljegyeztük a madáretetők számát és típusát, a kihelyezett táplálék típusát, továbbá azt, hogy milyen madárfajok és mekkora egyedszámban látogatták az etetőket. Az aktív etetők sűrűsége a veszprémi területeken általában magasabbnak bizonyult (60,1–206,1 madáretető/km^2 között mozgott), mint a budapesti helyszíneken (23,3–83,0 madáretető/km^2). Az etetőkön leggyakrabban megfigyelt tápláléktípus mindkét városban a cinkegolyó, a magkeverék és a napraforgómag volt. Összesen 24 faj 516 példányát figyeltük meg. Az etető típusa szignifikáns hatást gyakorolt az azt látogató madarak egyed- és fajszámára, míg a két város között ezekben nem találtunk különbséget. A jelen vizsgálatunkban gyűjtött adatok segítségével pontosabb képet kaphatunk arról, hogy miként alakítja át az urbanizáció a telelő madarak táplálék forrásait.

Kulcsszavak: urbanizáció, madáretetés, téli élelem, ember-vadvilág kapcsolat, Közép-Európa

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Introduction

Food availability stands out as one of the primary regulatory factors shaping avian communities in all types of habitats (Payne & Wilson 1999, Ferger *et al.* 2014). At the same time, the fluctuations of food availability exert a significant influence on birds, at both individual and population levels, particularly in seasonal environments (Diggs *et al.* 2011, Elo *et al.* 2012). Thus, birds have historically adapted to the natural variations in food supplies, which is particularly notable in temperate zones where seasonal changes in food, such as seeds and arthropods, fundamentally influence birds' foraging behaviour, overwinter survival, and distribution (Roberts 1979, Diggs *et al.* 2011, Pekarsky *et al.* 2021). However, human activities are increasingly altering the natural abundance of these food sources and, consequently, may disrupt the associated ecological processes (Chamberlain *et al.* 2005, Johnson & Munshi-South 2017).

The practice of bird feeding has emerged as a widespread and increasingly popular activity in human settlements, especially as more and more people are living in urban areas worldwide (Reynolds *et al.* 2017). This trend is reflected by the growing market for bird food production and sales (Orros & Fellowes 2015, Plummer *et al.* 2019), establishing bird feeding as probably the most popular form of human-wildlife interactions (Jones *et al.* 2008, Baverstock *et al.* 2019). Typically, people provide food for birds not solely for welfare reasons or to aid conservation efforts, but also for aesthetic enjoyment, with many food-providing nature enthusiasts eager to discover the most preferred types of food to attract more birds to their bird tables (Cox & Gaston 2015, Galbraith *et al*. 2015, Dayer *et al.* 2019). The practice of bird feeding is often encouraged by nature conservation organizations in many countries, particularly those in the Northern Hemisphere (Baverstock *et al.* 2019). This is not different in Hungary either, where urban residents commonly engage in bird feeding, especially during the winter months.

Considering the widespread occurrence of bird feeding, urban ecology studies generally recognize cities as more favourable habitats for many wintering birds compared to natural areas, primarily due to the increased availability of food sources during winter (Robb *et al.* 2008, Chamberlain *et al*. 2009, Evans *et al.* 2015). Beyond this, however, bird feeding has several further potential biological and ecological implications for feeder-visiting birds. Previous research on this topic has largely focused on how winter feeding influences avian community composition at feeding sites (Ferger *et al*. 2014, Galbraith *et al.* 2015, Pierret & Jiguet 2018), health risks including pathogen exposure (Lawson *et al.* 2012, but see: Frątczak *et al.* 2021), mortality factors associated with feeding sites (Robb *et al.* 2008, Lawson *et al.* 2018, Tryjanowski *et al.* 2018), and occasionally the potential impacts of winter feeding on birds' physiology and reproductive success (Plummer *et al.* 2013, Plummer *et al.* 2018). These studies are very important by providing a more comprehensive understanding of the myriad effects of bird feeding on urban bird populations. However, many of these studies, being feeding experiments, may not necessarily provide insights into the prevalence and characteristics of local bird feeding practices. While there have been efforts to assess the extensive scale of bird feeding (Horn & Johansen 2013, Dayer *et al.* 2019) or estimate bird feeder densities and the types of food provided at bird tables in urban environments (Orros & Fellowes 2015, Plummer *et al.* 2019), actual field surveys and studies investigating human residents' bird feeding practices remain rare. Moreover, there is a notable gap in our understanding regarding the structural types and densities of bird feeders (Amrhein 2014, but see: Tryjanowski *et al.* 2015), factors critical in determining the number of bird species and individuals that can effectively utilize these resources. This is particularly true for regions beyond the USA and the UK (Reynolds *et al.* 2017, Baverstock *et al.* 2019), where bird feeding has been a longstanding tradition for decades and is studied most frequently (Cowie & Hinsley 1988, Plummer *et al.* 2019). Therefore, while there has been a prevailing notion that in Europe bird feeding is far more prevalent in North-western European cities (Reynolds *et al*. 2017), research from Central and Eastern European countries is rare. From this region, to our knowledge, research published on human residents' bird feeding habits is only available from Poland where the authors found no significant difference in the number of bird feeders between urban and rural settings, although urban residents tended to fill a higher proportion of bird feeders with food (Tryjanowski *et al.* 2015).

The aim of the present study was to provide an accurate picture of the prevalence of winter bird feeding in Hungary, Central Europe, in areas that considerably differ in their degree of urbanization. Our study objectives were as follows. First, to survey the density and characteristics of winter bird feeders (placed by citizens) in Veszprém (a middle-sized city) and Budapest (the capital of Hungary) and also in nearby peri-urban forested areas with low housing densities. Second, to document the bird species and number of individuals attracted by the different types of feeders.

Material and Methods

Study areas

We conducted our study in two Hungarian cities: Veszprém, a middle-sized city with ~57,100 residents, and Budapest, the capital city with 1,707,000 residents (Hungarian Central Statistical Office, 2021.01.01; https://www.ksh.hu/stadat_files/fol/hu/fol0014.html). For the winter bird feeder surveys, we selected five study sites in each city, comprising four urbanized areas (within the city) and one peri-urban wooded area in the proximity of the city *(Figure 1)*.

A) City centre I (Veszprém): Located in one of Veszprém's central districts, this site surrounds the city's main bus station. It is a bustling area with several high-traffic roads, shops, offices, an urban park, and some residential buildings (47°05'46.3"N 17°54'45.6"E, area: ~0.12 km^2).

B) Office area I (Veszprém): This site is located in the middle of the city near the main campus of the University of Pannonia. It features university buildings, parking lots, a nearby cemetery with mature trees, an urban park, office buildings, and high-traffic roads (47°05'19.1"N 17°54'34.3"E, area: ~0.333 km^2).

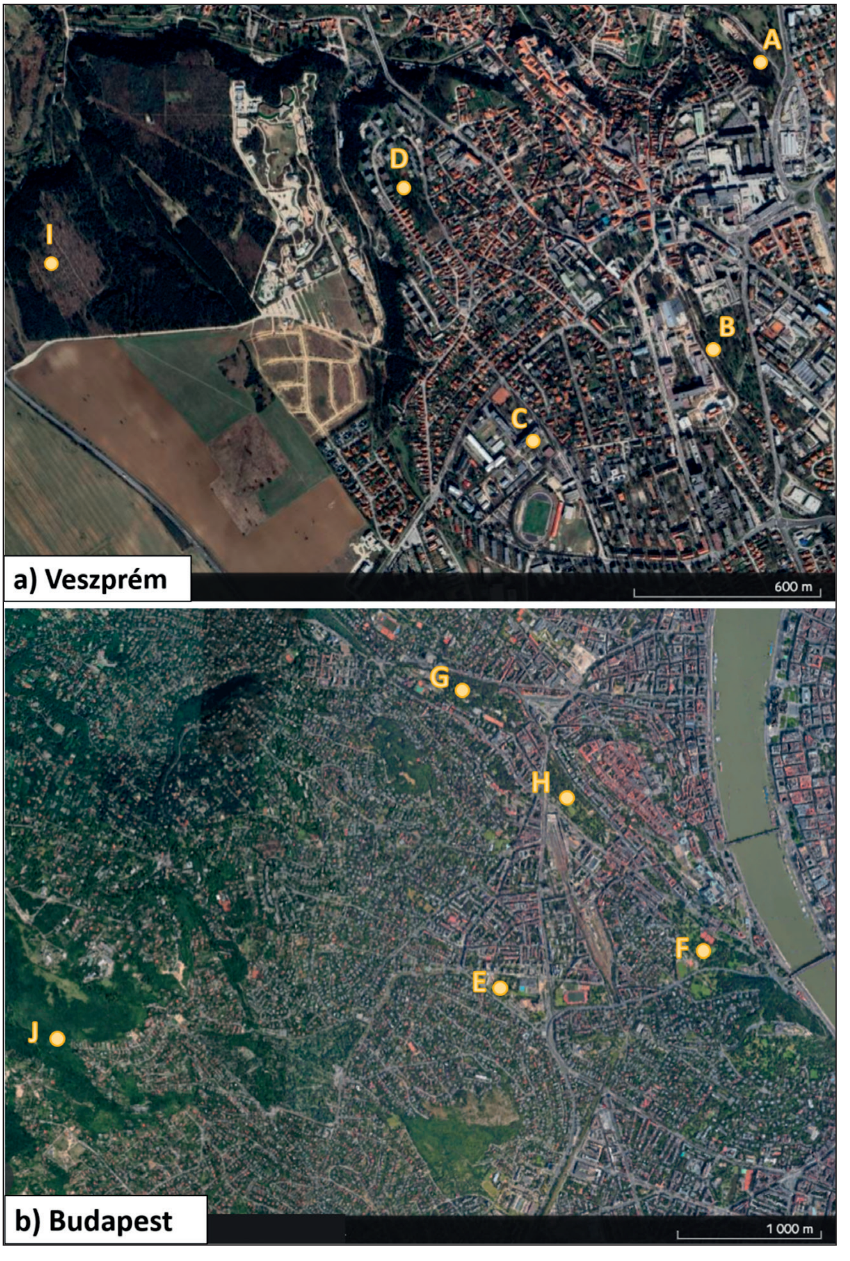

Figure 1. The map of the winter bird feeder survey sites in Veszprém (panel a) and Budapest (panel b) during the winter of 2021–2022. A) City centre I; B) Office area I; C) Residential area I; D) Residential area II; E) Office area II; F) Urban park; G) Residential area III; H) City centre II; I) Peri-urban woodland I; J) Peri-urban woodland II.

1. ábra A téli madáretető felmérés területeinek a térképe Veszprémben (a panel) és Budapesten (b panel), 2021–2022 telén. A) Városközpont I; B) Üzleti negyed I; C) Lakóövezet I; D) Lakóövezet II; E) Üzleti negyed II; F) Városi park; G) Lakóövezet III; H) Városközpont II; I) Városszéli erdős terület I; J) Városszéli erdős terület II.

C) Residential area I (Veszprém): The Egyetemváros neighbourhood is characterized by a mix of green spaces, recreational facilities, and residential buildings, including multi-storey block housing flats and houses with gardens. Another university campus with a large park is also located here (47°05'09.1"N 17°54'11.5"E, area: ~0.209 km^2).

D) Residential area II (Veszprém): The Jeruzsálemhegy neighbourhood is primarily a housing estate with multi-story block housing flats, public green spaces, and an old and relatively undisturbed cemetery with mature broadleaved trees (47°05'36.8"N 17°53'51.2"E, area ~0.131 km^2).

E) Office area II (Budapest): The Gesztenyés-kert park consists of green spaces, a shopping centre, and extensive office and sports facilities (47°29'22.8"N 19°01'14.1"E, area ~0.15 km^2).

F) Urban park (Budapest): The Tabán urban park near the Danube River and adjacent to Gellért Hill's green area, is covered with large grassy fields, dotted with trees and bushes. It is a popular site for recreational activities among locals and it is surrounded by residential flats (47°29'33.9"N 19°02'16.7"E, area ~0.258 km^2).

G) Residential area III (Budapest): Characterized mostly by residential multi-story blocks of flats and an urban park with green spaces and several recreational facilities (47°30'27.7"N 19°01'06.0"E, area ~0.299 km^2).

H) City centre II (Budapest): This area features one of the main train stations of Budapest, and parking lots, office and residential buildings. A large urban park with green spaces and walking paths is also located here (47°30'03.7"N 19°01'37.1"E, area ~0.265 km^2).

I) Peri-urban woodland I (Veszprém): The Gulya-domb is a semi-natural forest on the outskirts of Veszprém, adjacent to the zoo. This area is very popular for recreational activities with campfire spots and numerous hiking trails. The most common tree species are the native flowering ash *(Fraxinus ornus)*, downy oak *(Quercus pubescens)* and Turkey oak *(Quercus cerris)*, and the non-native black pine *(Pinus nigra)* (47°05'28.2"N 17°52'59.4"E, area ~0.292 km^2).

J) Peri-urban woodland II (Budapest): The Ördög-orom within the borders of Budapest, is a semi-natural forest with weekend houses and hiking trails. This site is mainly characterized by the native common hornbeam *(Carpinus betulus)* mixed with sessile oak *(Quercus petrea)*, English oak *(Quercus robur)* and flowering ash (47°29'09.6"N 18°58'42.2"E, area ~0.346 km^2).

Field methods

We conducted bird feeder surveys during the winter season, between November 25, 2021 and March 1, 2022. Each site was surveyed three times with a minimum two-week interval between the consecutive surveys. Surveying took place only during favourable weather conditions (no snowfall or rain, wind force below 20 km/h [Beaufort-scale 3]) between 8:00 and 14:00. During these surveys, one or two observers equipped with binoculars walked through the study site at a slow pace, following a route that enabled to visually cover all accessible areas as much as possible without cross-passing. We meticulously mapped the location of every bird feeder and documented the following details: the type of the bird feeder (see below), the type(s) of food provided, and the abundance and species of birds visiting the feeders (detailed below).

We differentiated five types of feeders (following Tryjanowski *et al.* 2015): (1) typical bird table often with a roof (having a fixed position e.g. on a pole, fence, or window sill; (2) bottle-type hanging feeders providing seeds (often made from plastic water bottles); (3) fat balls; (4) food scattered on the ground (typically sunflower seeds, but sometimes breadcrumbs or kitchen waste); and (5) mixed feeders where more than one feeder types were present together (e.g. bottle feeders with fat balls).

Furthermore, we categorized the type of food provided at the feeders into seven main categories: (1) sunflower seeds; (2) seed mix; (3) fat ball (fat mixed with seeds); (4) animal fat; (5) nuts; (6) fruits; and (7) human food waste (e.g. bread, oat or cooked rice).

We also recorded the presence of birdbaths. Note however, that we started to record baths only during the first field surveys, and that due to the decreased visibility of baths, this type of data was less accurate than the rest of the data collection protocol. Therefore, the data on the presence of birdbaths is likely incomplete to some degree.

During the surveys, we conducted observations at each feeder for 3–5 minutes (depending on the birds' activity on the feeder), to record all bird species appearing at the feeder. First, we recorded the number of species, estimated as the maximum number of bird species in one feeder per survey. Second, for each species present we also recorded the number of birds as the highest observed count of individuals that were present at the feeder and/or in its immediate vicinity during the observation period.

Statistical analysis

We analysed our data in RStudio (R 4.3.2.). For fitting generalized linear mixed models, we used Template Model Builder automatic differentiation engine (package 'glmmTMB'; Brooks *et al*. 2017). We built generalized linear mixed models with Poisson distribution separately for the number of birds and the number of species (response variables). The models included feeder ID as a random factor. The models contained the following environmental predictor variables potentially affecting the number of birds and the number of species: feeder type (5 levels), the daily minimum temperature (on the day of the survey), the city (Budapest or Veszprém), the date (numeric variable; 1 = 25th of November, the date of the first survey), and the presence of a birdbath on the feeder (present/absent). Snow coverage (present/absent) was not included in the analysis, because snow cover was rare during the surveys and its presence was unbalanced between the study sites: snow coverage during survey days was present only in the two peri-urban sites and the urban sites in Veszprém, but never in the urban sites at Budapest. Removing step-wise the non-significant predictors from the models did not change the results qualitatively, so we present the results of the full models. We tested the fit of the models using the 'DHARMa' R package (Hartig 2019); the fit of all models was acceptable. Finally, we compared the effect of the feeder type on the number of birds and number of species with Tukey's post-hoc tests (using R package ”glht”).

Results

Density of the surveyed feeders

We completed 30 surveys in total, three at each of the 10 study sites. During these, we mapped the locations of a total of 202 bird feeders that contained food on at least one occasion. The density of the active feeders (i.e. the feeders that contained food on a given field survey) varied highly across study sites and even from one survey to the next within the same site, and was notably lower in the two peri-urban woodland sites compared to the other 8 urban locations *(Table 1)*.

In the urban study sites in Veszprém, the number of active feeders varied between 11–33, translating to a density ranging from 60.1 to 206.1 bird feeders/km^2. The feeder density was usually two times higher in Veszprém than in Budapest where, the number of active feeders ranged between 4–22, extrapolating to a density of 23.3–80.0 bird feeders/km^2. At Veszprém, we found the highest feeder densities in the two residential areas (C and D), during all three surveys. But in Budapest, we found the highest feeder densities in the city centre area (H; *Table 1*). In comparison to the urban sites, bird feeders were much scarcer in the peri-urban forest sites in both cities. The number of active bird feeders ranged between 1–4 with their density spanning between 3.4–13.7 bird feeders/km^2, in the peri-urban woodland at Veszprém (I). Similarly, in the peri-urban woodland at Budapest (J), the number of active feeders was 4–5, resulting in a density of 13.5–14.5 bird feeders/km^2.

Table 1. Density and number of active bird feeders at each site, surveyed in the cities of Veszprém and Budapest, in the winter of 2021–2022

1. táblázat A Veszprémben és Budapesten felmért aktív madáretetők denzitása 2021–2022 telén

	Site	Area of site (km^2)	Number of active feeders			Density of active feeders (\km^2)			
			Survey No.1	Survey No.2	Survey No.3	Survey No.1	Survey No.2	Survey No.3	Mean
Veszprém	A) City centre I	0.12	13	15	11	108.3	125.0	91.7	108.3
	B) Office area I	0.333	20	22	26	60.1	66.1	78.1	68.1
	C) Residential area I	0.209	27	33	28	129.2	157.9	134.0	140.4
	D) Residential area II	0.131	23	24	27	175.6	183.2	206.1	188.3
	I) Peri-urban woodland I	0.292	4	3	1	13.7	10.3	3.4	9.1
Budapest	E) Office area II	0.15	6	4	7	40.0	26.7	46.7	37.8
	F) Urban park	0.258	8	6	6	31.0	23.3	23.3	25.8
	G) Residential area III	0.299	9	12	11	30.1	40.1	36.8	35.7
	H) City centre II	0.265	14	22	18	52.8	83.0	67.9	67.9
	J) Peri-urban woodland II	0.346	4	5	5	11.6	14.5	14.5	13.5

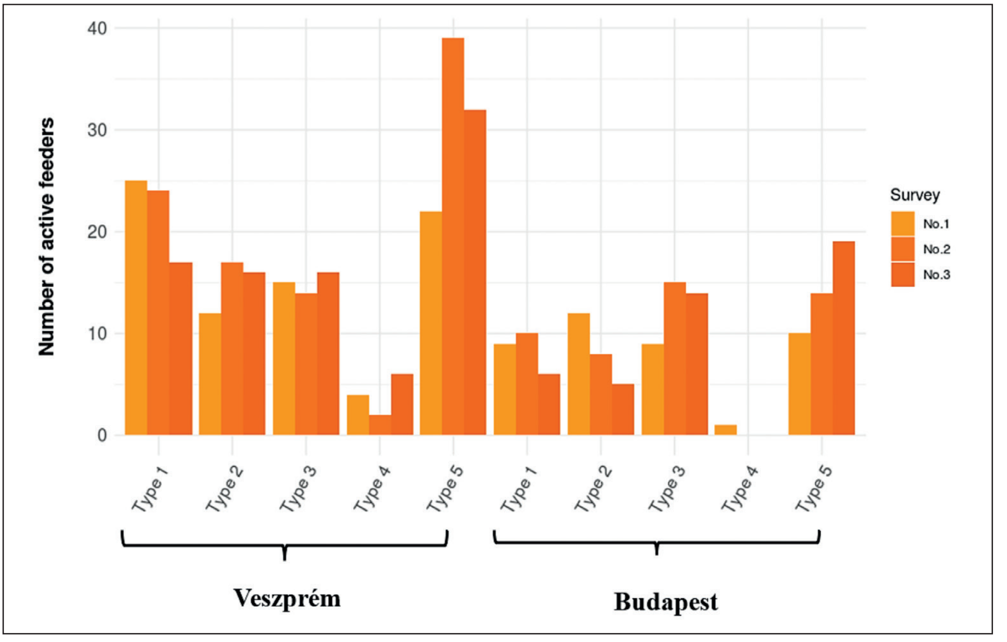

Figure 2. The distribution of the number and type of active bird feeders in Veszprém and Budapest. The feeder types were: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

2. ábra Az aktív madáretetők száma madáretető típusonként lebontva Veszprémben és Budapesten. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle etető típus is jelen van egyszerre

Feeder and food types

The most frequent type of currently active feeders was type 5 (mixed feeders) and the least frequent was type 4 (food scattered on the ground) both in Veszprém and Budapest *(Figure 2)*. Fat balls, seed mixes, and sunflower seeds were by far the most popular types of food that people provided to birds both in Veszprém and Budapest. However, in Veszprém those feeder types were present in a higher ratio than in Budapest, which were associated with the other four food types (animal fat; nuts; fruits; and human food waste; *Figure 2*). In Veszprém, we registered only eight feeders associated with birdbaths (seven in the Residential area II (D) and one in the City centre I (A), while birdbaths were present at only three feeders in Budapest, all of them in the City centre II site (H).

Number of birds

We recorded a total number of 516 individuals belonging to 24 species visiting the bird feeders (Veszprém: 20 species, Budapest: 14 species; *Table 2*, *Appendix 1*). There was no significant difference in the number of birds present on the feeders per survey between the

Table 2. The number of birds and bird species surveyed in different feeder types in the cities of Veszprém and Budapest, during the winter of 2021–2022. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

2. táblázat A Veszprémben és Budapesten felmért aktív madáretetőkön megfigyelt madarak egyedszáma és fajszáma 2021–2022 telén. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle etető típus is jelen van egyszerre

	Feeder type	**Number of birds**				**Number of species**			
		Survey No.1	Survey No.2	Survey No.3	Total	Survey No.1	Survey No.2	Survey No.3	Total
Veszprém	**Type 1**	25	36	30	91	2	6	8	8
	Type 2	4	19	13	36	1	7	5	10
	Type 3	8	3	3	14	2	1	2	2
	Type 4	0	2	5	7	0	2	2	3
	Type 5	52	101	51	204	9	13	10	17
Budapest	**Type 1**	9	8	1	18	3	3	1	4
	Type 2	24	7	11	42	6	4	4	7
	Type 3	0	6	5	11	0	4	3	5
	Type 4	4	0	0	4	2	0	0	2
	Type 5	34	32	23	89	6	7	5	10

two cities *(Table 3)*. However, we found significant differences in the number of birds visiting the different feeder types *(Table 3, 4)*: feeder type 3 (fat balls) had the lowest (compared to type 1, 2, or 5 feeders) while the highest number of individuals was observed at feeder type 5 (mixed feeders), but this difference was statistically significant only compared to feeder type 3 *(Table 2 and 4)*. Furthermore, both daily minimum temperature and the date had significantly negative impact on the number of birds, while the presence of a birdbath had a significantly positive effect on the number of birds *(Table 3)*.

Number of species

The number of species per survey significantly differed between feeder types

Table 3. The effect of feeder type, daily minimum temperature, date, the city (Veszprém or Budapest), and the presence of a birdbath on the number of birds observed on winter feeders

3. táblázat A madáretető típusának, a napi minimum hőmérsékletnek, a dátumnak, a városnak (Veszprém vagy Budapest) és a madáritató jelenlétének hatása a madáretetőkön megfigyelt madarak egyedszámára

Predictors	**Chisq**	**df**	**p-value**
Intercept	6.217	1	0.012
Feeder type	42.338	4	**<0.001**
Daily min. temperature	19.995	1	**<0.001**
Date	7.639	1	**0.005**
City	0.355	1	0.551
Birdbath	9.25	1	**0.002**

The type 3 ANOVA (analysis of variance) results are from a generalized linear mixed-effects model using Template Model Builder, with Poisson distribution and feeder ID as a random factor. Statistically significant ($P<0.05$) differences are highlighted in bold. N=516 individuals in 412 active feeders.

Table 4. Pairwise comparisons of the differences in the number of birds surveyed in different feeder types during the winter of 2021–2022 in Veszprém and Budapest. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

4. táblázat Az eltérő típusú madáretetőkön megfigyelt madarak egyedszámainak páros összehasonlítása. A megfigyeléseket Veszprémben és Budapesten végeztük 2021–2022 telén. Öt féle madáretető típust különböztettünk meg, ezek a következők: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle típusú etető is jelen van egyszerre

Contrast	Contrast ± SE	z ratio	p-value
type 2 – type 1	0.045 ± 0.317	0.143	0.998
type 3 – type 1	-1.346 ± 0.358	-3.757	**0.001**
type 4 – type 1	-0.017 ± 0.557	-0.032	1.000
type 5 – type 1	0.573 ± 0.263	2.176	0.171
type 3 – type 2	-1.392 ± 0.349	-3.982	**<0.001**
type 4 – type 2	-0.063 ± 0.555	-0.114	0.999
type 5 – type 2	0.528 ± 0.223	2.359	0.114
type 4 – type 3	1.329 ± 0.588	2.259	0.143
type 5 – type 3	1.92 ± 0.306	6.267	**< 0.001**
type 5 – type 4	0.591 ± 0.513	1.152	0.759

The table shows the results of linear Tukey contrasts that were calculated from the final model presented in Table 3. Statistically significant (P<0.05) differences are highlighted in bold. N=516 individuals in 412 active feeders.

(Table 5, Appendix 1): there were significantly fewer species in type 3 than in type 1, 2, or 5 feeders *(Table 6)*. There was no significant difference between cities in the number of feeder-visiting bird species. The presence of a birdbath at the feeder had significantly positive effect on the number of feeder-visiting bird species while the date and the daily minimum temperatures had no significant effect on it *(Table 5)*.

Table 5. The effect of feeder type, daily minimum temperature, date, the city (Veszprém or Budapest), and the presence of a birdbath on the number of bird species observed on winter feeders

5. táblázat A madáretető típusának, a napi minimum hőmérsékletnek, a dátumnak, a városnak (Veszprém vagy Budapest) és a madáritató jelenlétének hatása a madáretetőkön megfigyelt madarak fajszámára

Predictors	Chisq	df	p-value
Intercept	3.713	1	0.053
Feeder type	22.87	4	**<0.001**
Daily min. temperature	0.795	1	0.372
Date	0.652	1	0.419
City	2.843	1	*0.091*
Birdbath	15.105	1	**<0.001**

The table shows type 3 ANOVA (analysis of variance) results from the generalized linear mixed-effects model using Template Model Builder, with Poisson distribution and feeder ID as a random factor. Statistically significant (P<0.05) differences are highlighted in bold and marginally nonsignificant (0.05<P<0.1) differences are highlighted in italics. N=516 individuals (24 species) in 412 active feeders.

Discussion

In this study, we conducted field surveys in two Hungarian cities to assess the prevalence of residents' winter bird-feeding practices. We focused on quantifying the density and

Table 6. Pairwise comparisons of the differences in the number of bird species surveyed on the different feeder types during the winter of 2021–2022 in Veszprém and Budapest. Feeder types are the following: (1) typical bird table often with a roof; (2) bottle-type hanging feeders providing seeds; (3) fat balls; (4) food scattered on the ground; (5) mixed feeders where more than one feeder types were present together

6. táblázat Az eltérő típusú madáretetőkön megfigyelt madarak egyedszámainak páros összehasonlítása. A megfigyeléseket Veszprémben és Budapesten végeztük 2021–2022 telén. Öt féle madáretető típust különböztettünk meg: (1) hagyományos, tetős, telepített etető; (2) felfüggesztett, palack típusú etető; (3) cinkegolyó; (4) földre kiszórt mag vagy élelmiszer-hulladék; (5) vegyes etető, ahol többféle típusú etető is jelen van egyszerre

Contrast	Contrast ± SE	z value	p-value
type 2 – type 1	0.085 ± 0.292	0.292	0.998
type 3 – type 1	-1.244 ± 0.372	-3.340	**0.006**
type 4 – type 1	0.017 ± 0.56	0.032	1.000
type 5 – type 1	0.374 ± 0.254	1.472	0.558
type 3 – type 2	-1.329 ± 0.373	-3.565	**0.002**
type 4 – type 2	-0.067 ± 0.565	-0.12	0.999
type 5 – type 2	0.288 ± 0.241	1.194	0.737
type 4 – type 3	1.261 ± 0.612	2.06	0.219
type 5 – type 3	1.618 ± 0.339	4.766	**<0.001**
type 5 – type 4	0.356 ± 0.541	0.658	0.961

The table shows the results of linear Tukey contrasts that were calculated from the final model presented in Table 5. Statistically significant ($P<0.05$) differences are highlighted in bold. N=516 individuals (24 species) in 412 active feeders.

characteristics of winter bird feeders and also recorded the bird species and number of individuals visiting various feeder types.

The mixed feeder emerged as the most common feeder type in both cities, indicating a widespread attempt of the residents to offer a diverse array of bird food, likely to attract a larger number of birds to the bird tables. During the field surveys, we observed the highest number and diversity of birds in the mixed feeders, which supports the effectiveness of this practice. However, it is important to note, that this result could be attributed to the overall larger size and the higher variety of food available in mixed feeders, making them more accessible to a broader range of birds compared e.g. to fat balls, which are generally smaller and offer mostly fat and to a smaller degree, seeds. In addition, our observations revealed that feeders combined with birdbaths, irrespective of the feeder type, attracted the highest number of individuals and species. This finding underlines the importance of water sources, alongside food, for birds during the winter, emphasizing the value of birdbaths in supporting bird populations in urban environments.

The most frequent food types offered at feeders were fat balls and seed mixes, likely due to their easy commercial availability on supermarket shelves. This observation aligns with the findings by Orros and Fellowes (2015), who reported that among the UK citizens who provide food for wild birds, various seed mixes (including millet, barley, and sunflower seeds) are the most common. This food type is accepted and favoured as winter food by several bird species, especially granivores, due to its high energy content (Horn *et al.* 2014, Tryjanowski *et al.* 2018). However, several species that are relatively common in urban environments (like robins, blackbirds, or woodpeckers) do not prefer or cannot utilize seed mixes as food source, therefore making these feeders less suitable for supporting a diverse winter bird community (Horn & Johansen 2013, Galbraith *et al.* 2015, Støstad *et al.* 2017).

Our study revealed a significantly higher density of feeders in the urban sites of Veszprém (a medium-sized town) compared to Budapest (a metropolis, and the capital city of Hungary). We also found that feeder densities were notably the highest in the residential areas of Veszprém (range: 129.2–206.1 bird feeders/km^2). This variation highlights the influence of the urban landscape structure on birds' winter food availability (Ciach & Fröhlich 2017). In Veszprém, these study sites were situated in block housing areas and detached houses with private gardens with interconnected green spaces, whereas, in Budapest, the study sites were in densely built-up areas with green spaces resembling more like small, "isolated islands" within the urban landscape. In addition to the cities' architectural structure, other factors could also play a role in shaping bird feeder densities, such as differences in the mentality of the residents between the cities or city districts, or local regulations that sometimes prohibit bird feeding near apartments due to the attraction of unwanted guests on bird feeders, like city-dwelling pigeons. These type of regulations are present in both Veszprém and Budapest. However, Budapest is a bigger and more densely populated city, also with more pigeons *(Appendix 1)*, thus these types of regulations are probably more frequent and prevalent there, which could also negatively affect the number of bird feeders there. Our results revealed a remarkable and fine-scale (i.e. within-city) variation in the availability of winter bird feeders – and consequently food supply – that probably influence various aspects of birds' biology, including physical condition, physiological stress, behaviour (Broggi *et al.* 2005, Roth & Vetter 2008, Lawson *et al.* 2018), and most importantly, birds' chances of survival during the winter months. Therefore, we suggest that future studies focusing on the survival patterns of urban birds should consider this factor rather than treating distinct parts of the city with different landscape structures as the same.

In contrast to the urban sites, we found no considerable difference in the density of feeders between the two peri-urban woodlands, where feeder density was markedly lower than in the city, similarly to the findings of Tryjanowski *et al.* (2015). Even though, the vegetation of these two sites is quite different, both are characterized by the low rate of built-in areas (mostly weekend houses) and low human population density, which could explain the similarly low bird feeder densities at both sites.

Finally, it is important to acknowledge the limitations of our study. Our chances of detecting bird feeders might have varied between or even within cities, due to the different architectural layout of buildings, green spaces, and private properties. During the surveys, we were looking for bird feeders visually, making it challenging to spot feeders located high above the ground (e.g. on a fourth-floor balcony or windowsill) or completely hidden within private gardens. This difficulty may have had a greater impact on our results regarding food type and the presence of birdbaths, as a good view of the feeding station is important to reliably collect such data. Moreover, the differences we found in the distribution of birdbaths across cities and study sites might partially result from the initial inconsistency among surveyors in recording the presence of birdbaths. Nonetheless, we believe that our feeder density results were less affected by these difficulties, as the presence of an active feeder could be often inferred from birds' activity and vocal cues even if we did not have a clear view of the feeder's exact location.

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Appendix 1. List of surveyed bird species and number of individuals (516 individuals of 24 species in total), in winter feeders in Veszprém and Budapest, in the winter of 2021–2022. Those species that only appeared in one city are highlighted in bold

1. függelék A Veszprémben és Budapesten 2021–2022 telén felmért madáretetőkön megfigyelt madarak egyedszámának és fajainak listája (összesen 24 faj 516 példánya). Azokat a fajokat, amelyeket csak az egyik városban figyelünk meg, félkövér betűtípussal jelöltük

Species	Number of individuals				
	Survey No.1	Survey No.2	Survey No.3	Total	
Columba livia f. domestica	1	0	0	1	**Veszprém (total number of species = 20)**
Columba palumbus	**0**	**10**	**2**	**12**	
Streptopelia decaocto	3	0	3	6	
Erithacus rubecula	**1**	**3**	**1**	**5**	
Turdus merula	4	21	9	34	
Regulus ignicapilla	**0**	**0**	**1**	**1**	
Cyanistes caeruleus	6	6	11	23	
Parus major	70	79	48	197	
Periparus ater	**1**	**6**	**4**	**11**	
Poecile palustris	**0**	**1**	**2**	**3**	
Aegithalos caudatus	0	0	2	2	
Sitta europaea	1	4	1	6	
Passer domesticus	0	1	21	22	
Passer montanus	0	0	1	1	
Fringilla coelebs	**1**	**12**	**0**	**13**	
Fringilla montifringilla	**0**	**1**	**0**	**1**	
Carduelis carduelis	0	11	22	33	
Chloris chloris	**0**	**3**	**1**	**4**	
Spinus spinus	**0**	**1**	**3**	**4**	
Coccothraustes coccothraustes	**0**	**2**	**1**	**3**	
Columba livia f. domestica	6	25	12	44	**Budapest (total number of species = 14)**
Streptopelia decaocto	2	0	0	2	
Dendrocopos major	**1**	**0**	**0**	**1**	
Dendrocopos syriacus	**1**	**0**	**0**	**1**	
Turdus merula	0	3	1	4	
Cyanistes caeruleus	0	2	3	5	
Parus major	30	28	15	73	
Sitta europaea	4	1	1	6	
Aegithalos caudatus	0	2	0	2	
Garrulus glandarius	**0**	**1**	**0**	**1**	
Corvus cornix	**1**	**0**	**0**	**1**	
Passer domesticus	21	25	0	46	
Passer montanus	3	5	8	16	
Carduelis carduelis	2	1	0	3	

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