birds

Article

Innovative Foraging Behavior of Urban Birds: Use of Insect Food Provided by Cars

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Simple Summary: Simple Summary: Although protein-rich insect food is important for the development of birds, high-quality insect food is often limited in cities. However, plenty of insects are smashed on cars, and cars in parking areas might provide additional food resources for the urban birds. Using our own data as well as data provided by community science networks and Internet sources, we managed to retrieve 308 observations of birds collecting insects on car panels. Most observations considered the House Sparrow, followed by the White Wagtail and several species of corvids. The phenomenon was globally widespread. European bird species able to use the novel insect source were characterized by a larger residual brain size. There was also some indication that bird species using insects on cars had a larger number of feeding innovations, greater diet generalism, and longer times living in urbanized areas than birds not observed using insects on cars. Often these species are also resident and able to use food offered in feeding sites. We anticipate that more bird species will adopt this innovative foraging behavior in the future, as urban insect populations continue to decline, and cars increasingly become richer sources of insect food for the birds.

Abstract: Despite high-quality insect food being often restricted in cities, insects are important for the development of birds. Nonetheless, plenty of insects are smashed on cars, and they are available for those species that are able to use them. We used both our own data and community science and Internet sources for surveying global, national, and local data about birds using insects on cars. Our results contained a total of 308 observations of birds collecting insects on car panels, which indicated that 39 species used this food resource since 1928 in 33 countries. Most observations considered the House Sparrow, followed by the White Wagtail and several species of corvids. European urban bird species observed to use insects on cars had a larger residual brain size. There was also some indication that bird species using insects on cars had a larger number of innovations (i.e., production of novel behaviors), greater diet generalism, and longer times living in urbanized areas than birds not observed using insects on cars. Often these species are also resident and able to use food offered in feeding sites. We assume that more bird species will use insects on cars in the future, as urban insect populations continue to decline, and thereby insects on cars will increasingly become more important sources of food for urban birds.

Keywords: urbanization; novel behavior; traits; insect loss; food availability; insectivores; parking sites

Citation: Jokimäki, J.; Ramos-Chernenko, A. Innovative Foraging Behavior of Urban Birds: Use of Insect Food Provided by Cars. *Birds* **2024**, *5*, 469–486. https://doi.org/10.3390/birds5030032

Academic Editor: Yanping Wang

Received: 26 June 2024
Revised: 5 August 2024
Accepted: 8 August 2024
Published: 10 August 2024

1. Introduction

Urbanization changes habitat structure and species composition via different kinds of disturbances (increased temperature, buffered seasonal variation, increased abundance of urban exploiters, decreased abundance of native species, etc.) [1,2]. Wildlife, including birds, tries to adapt to these novel urban conditions, e.g., by behavioral adjustments [3–5]. Food availability is one of the main drivers influencing species success in cities [2,6]. The availability of anthropogenic food is likely to have substantial effects on avian demography in urban landscapes [2,6]. For example, feeder users [7,8] and some other opportunistic species, like crows [9–13], have benefitted from both incidentally and non-incidentally provided food by people in cities. Moreover, anthropogenic food resources and feeding can facilitate life in urbanized areas [14], changes in migratory habits to a resident way of life in cities [15], and species' ability to adapt to city life [16–18]. According to Väisänen [19], some new species, like the Long-tailed Tit (*Aegithalos caudatus*), Eurasian Treecreeper (*Certhia familiaris*), and Eurasian Blackcap (*Sylvia atricapilla*), have learned and adapted rapidly to utilize the new, industrialized, small-fractioned wild bird seed mixes (including, e.g., millet, hemp, chopped peanuts, and sunflower hearths) offered nowadays at Finnish winter bird feeding sites [19]. Also, several species that were formerly characteristic of wilderness areas, such as the Raven (*Corvus corax*), Black Woodpecker (*Dryocopus martius*), and Pine Grosbeak (*Pinicola enucleator*), have been observed to use winter-feeding sites located in cities in Finland [20].

Bird feeding is common practice in some places, especially during the winter, and provides easily available energy-rich resources [21–24]. Additional food sources, such as refuse, are also likely to provide important resources for some species (e.g., [25]). However, the low quality of widely available junk food may have an adverse impact on urban birds [6,10,26]. For instance, Shochat [27] suggested that urban food resources might be inadequate and lead to poor body condition in urban wildlife, ultimately resulting in a decrease in the average body mass of individuals. Chamberlain et al. [2] indicated in their review that urban birds have a lower nestling weight and lower productivity per nesting attempt than their rural conspecifics, probably due to the lack of natural food sources in cities. It is not clear if anthropogenic food quality is sufficient to support the reproductive success of birds because birds seldom use anthropogenic food to feed their nestlings [28–30]. And even when regular anthropogenic urban food resources may have been used to some extent by omnivore birds, other anthropogenic phenomena such as air pollution, use of insecticides, and loss and fragmentation of natural habitats, as well as intensive management of green, blue, and brown habitats, have decreased the number of arthropods, and thereby also the food supplies for insectivore birds [9,31–33].

Studies about declines in abundance and biomass of insects from around the world (e.g., [34–38]) have raised concerns about food limitations that could have serious impacts on insectivore bird species [39,40]. One reason for the insect decline is urbanization [41]. According to Svenningsen et al. [42], urban cover has a strong negative impact on insect communities, indicating that urbanization could contribute to insect declines. Moreover, they indicated that it is especially insect biomass that decreases with urbanization, causing serious ecosystem-level consequences. Another study, the global meta-analysis of Vaz et al. [43], stated that insects are negatively affected by urban stressors across most moderators evaluated, such as insects' activity periods, climatic zones, development stages, ecosystem, functional roles, mobility, orders, and life history, among others. They highlighted that urbanization resulted in over 40% declines, both in insect richness and abundance. However, there can be also variation in the responses of arthropods to urbanization, and the responses of invertebrates to urbanization can be complex and variable [44]. But, in general, the invertebrate community is less favored by urban habitats than by natural habitats [1,2,45]. This reduced availability of the most important and preferred nestling season diet, i.e., insects within cities [46–48], is responsible for lower avian reproductive success in cities [28,49–52].

Urban environments impose novel challenges on animals and, as a result, the behaviors of urban wildlife are changing. Animals, including birds, can respond to urban-induced environmental changes, like lack of insect food, by changing their behavior [53]. Lowry et al. [17] have suggested that individuals able to adjust their behaviors to city life can have greater success in urban environments. Correspondingly, urban wildlife often exhibits changed behaviors, e.g., in food preferences. Shochat [27] supposed that generally high food availability and low mortality characterizing urban environments might explain the changes observed in the foraging behavior of birds. Therefore, it is important for urban birds to find high-quality food, at least during their breeding season (e.g., [6]). Obviously, successful urban birds will need behavioral adaptation to cope somehow with the lack of insect-based resources [1,54].

A great number of insects are killed by cars [38], and cars might incidentally transport significant amounts of insect remains into cities. Despite the first observation of House Sparrows using insects smashed on cars having been reported as early as the late 1920s, only one more detailed and nationwide study has been conducted since then [55], and as such, the phenomenon is not yet very well-known. Therefore, the main aims of the current study were to analyze (1) which species are able to use insects smashed on cars worldwide, (2) how widespread this phenomenon is, and (3) what characterizes the species that are able to use this city-based resource. One measurement of the ability to cope with novel conditions is the rate of feeding innovations (i.e., rate of cultural transmission of behavioral innovations related to feeding in animal populations), which has been shown to successfully predict a number of different ecological phenomena in both birds and primates [56–58].

We hypothesized that the number of innovations, residual brain size, boldness (flying initiation distance [FID]), number of habitats where species live, dietary generalism, and urbanization year of the species will influence the species' capacity to use the insects smashed on cars as a food source. As some bird species are more innovative than others [59,60], we predicted that innovative species would use this food resource more often than less innovative species. Foraging innovation occurs when animals exploit novel food sources (such as insects smashed on cars) or invent new foraging techniques (picking insects from the front panel of the cars). An earlier study reported that there might be a positive relationship between innovation rate and habitat generalism, but not necessarily between the innovation rate and diet breadth of birds [59]. Because brain size is related to the innovativeness of species [59,61], we predicted that large-brained species would use insects smashed on cars more often than small-brained species. In addition, because the occurrence of cars is linked to people and disturbance, we predicted that bolder species would be able to use insects on cars more often than shyer species with longer escape distances. Likewise, because species occurring in a wide range of habitats and with a generalist diet will probably more often face novel conditions, we predicted that species with wide habitat utilization habits and dietary generalism would be able to use insects on cars more often than species with strict habitat needs or a specialist diet. Lastly, because early-urbanized species have lived longer in novel habitats than recently urbanized species, we predicted that these species would be able to use insects on cars more often than more recently urbanized species. Since ecological phenomenon can be scale-dependent [62,63], we studied the use of car-provided insect food by birds worldwide via a regional (national) to local (single city) scale. Worldwide scale size is greater than the species average dispersal distance, while local scale size corresponds broadly to species territory size as suggested by Jackson and Fahring [63].

2. Materials and Methods

2.1. Worldwide Scale

Firstly, we extracted data about species using insects smashed on cars by using Lefebvre's [60] publication and its supplementary database about innovative foraging methods of birds. If we found a suitable observation from the database, we then searched the original reference related to the specific observation, and extracted the following information: species, date or year, country, city name, and if the observation was conducted either urban or non-urban site.

Secondly, we conducted a separate literature search by using Google Scholar at the end of the year 2023. The following search words were used: bird, car, radiator, grill, insect, and bug. The language was restricted to English, and only to peer-reviewed articles. The first 200 hits with the abstract were checked. Later, we conducted additional analyses using Scopus, but no new relevant results were found.

Thirdly, we send short queries for the known urban ornithologists (about 30) and the following email lists: URBICON (Urban Birds Consortium; 110 subscribers around the world), and WGUS (Working Group Urban Sparrows; 103 subscribers around the world). Despite that the WGUS is specialized in sparrows, participants of this group have a wide knowledge of urban bird species and their behaviors. We requested the following information from the receivers: if they have or not seen such behavior, which species, in which country and city, which year (and date if available), and if the observation was made either in urban or in rural areas. We also encouraged participants to report if they have not made any observations of the interested behavior in their home cities. These queries were sent in the mid of September 2023. Also, a corresponding announcement about this query was put on the European Ornithologists' Union webpages, their Twitter (2149 followers), and Facebook (363 followers) on 18 September 2023.

Finally, as the Internet offers nowadays also new possibilities for bird behavioral studies [64,65] and as non-usual observations interest people, we conducted a YouTube and Google photo and video search on 23 September 2023 by using the following search words or strings: ”birds using insects smashed on cars”; “bird eating insects smashed on a car”; “birds, insects, bugs, cars, radiator, grill”; “bird eats bugs from a car”; “sparrow eating insects from a cars”; and corresponding searches were conducted for all other bird species that were earlier observed to take insects from car. In addition to English searches, we conducted corresponding searches by using our own native languages, i.e., in Finnish and Spanish. The global data are given in Table S1.

2.2. National Scale

Firstly, national data from Finland were extracted from the publication of Jokimäki and Kaisanlahti-Jokimäki [55], and the corresponding unpublished database. In the current study, we used basically the same questionnaire study method that was used by Jokimäki and Kaisanlahti-Jokimäki [55] in their study. A questionnaire was sent to the Finnish birders via the BirdLife Finland Birdnet emailing list with about 1000 receivers on 3 July 2023, and repeated on 4 August, 28 August, and 24 September 2023. The questionnaire contained the following questions: What species you have observed to take insects from the front panels of cars, sex and age, date, time, municipality/city; habitat (urban vs. non-urban); and a more detailed description of the site (parking site of the hyper/supermarket; parking site of gasoline station; roadside parking site; other type [give a description]). Secondly, we also conducted a data search on 29 September 2023 by using the tiira.fi bird observation information service database of the BirdLife Finland, in which birders save their observations in Finland (see more details in [55]). The national data are given in Table S2.

2.3. Local Scale (City of Rovaniemi, Finland)

A more detailed study was conducted in the city of Rovaniemi, Finland (66° N; 25° E; 64,022 inhabitants) [66,67], which is located in the Köppen-Geiger Dfc (cold, without dry season, and cold summer) climate type [68] and middle boreal vegetation zone [69] in northern Finland.

At the local level, we used both the data collected earlier by Jokimäki and Kaisanlahti-Jokimäki [55], and additional data collected during the field work between 3 July and 10 October 2023. Because the earlier data indicated that most observations about birds using insects on cars were conducted in large parking areas, we restricted our field work to parking sites of hyper/supermarkets, gasoline stations, tourist attractions, road sites within the core city area, universities, and other sites with a considerable (30–250) number of cars.

A total of 31 parking sites were included in the study. Most sites were visited at least three times. Each individual visit lasted at least 15 min, and they were conducted only during weekdays, and non-rainy and windless weather conditions. During the visit, all bird species observed in the parking site were counted. When we detected a bird(s) near the cars, we followed it to see if it would take insects from the cars.

About 160 bird species are breeding surely or probably in the Rovaniemi municipality area (8016 km^2) [70]. About 50 out of the pool of 160 regional species are breeding in the urban area, i.e., in the area where most inhabitants live, and where this local study was conducted. The number of breeding species in the core city area (81 ha) is about 20. The local-level data are provided in Table S2.

2.4. Data Handling and Statistical Methods

The database and sources of each observation are provided in the Tables S1 and S2. A number of innovations (combined numbers of technical and food type innovations) as well as relative brain size, diet generalism, and number of habitats were extracted from the Lefebvre database [60]. To avoid data duplication, we removed examples of the use of smashed insects on cars from the number of innovations per species before running the analysis. Some analyses were conducted by using European data only. For these analyses, FID from urban birds was extracted from Díaz et al. [71]. When comparing the traits of urban species using insects on cars to urban species not observed to use insects on cars, we used Morelli et al. [72]'s supplementary data to determine the most common and abundant urban species that were not observed to use insects on cars. These species were *Sturnus vulgaris*, *Turdus merula*, *Streptopelia decaocto*, *Carduelis carduelis*, *Sylvia atricapilla*, *Fringilla coelebs*, *Serinus serinus*, *Phoenicurus phoenicurus*, *Turdus pilaris*, *Phasianus colchicus*, *Phylloscopus collybita*, *Garrulus glandarius*, *Ficedula hypoleuca*, *Sylvia curruca*, *Luscinia megarhynchos*, *Muscicapa striata*, *Troglodytes troglodytes*, *Corvus frugilegus*, *Carduelis cannabina*, *Prunella modularis*, *Phylloscopus trochilus*, *Myiopsitta monachus*, and *Larus ridibundus*.

We used the Mann–Whitney U-test to compare the characteristics between the users and non-users. When conducting multiple tests, test results can be significant only by chance. We used the Holm–Bonferroni sequential correction procedure to avoid these Type I errors (false positives); the p-value for the significance level was set on <0.05 [73]. The false discovery rate was set to 25% in this procedure. Spearman's (rho) non-parametric test was used in correlative analyses.

3. Results

3.1. Data Structure

The data contain 308 observations from 39 species or subspecies (Tables S1 and S2). A total of 51 observations were extracted from the literature, 142 were received via questionnaires, 14 were YouTube videos, 6 were Google images/news, and 27 were extracted from the Finnish bird observation tiira-database. Our own field data contain a total of 68 observations.

3.2. Distribution of the Observations and Species Reported

From 308 observations, only 46 (15%) were reported from non-urban areas, like parking areas of the national parks or small-sized villages (Tables S1 and S2). Half of the reported observations considered the House Sparrow (*Passer domesticus*) (Figure 1A), followed by the White Wagtail (*Motacilla alba*) (9%) (Figure 1B), the Eurasian Jackdaw (*Corvus monedula*) (7%) (Figure 1C), and the Carrion Crow (*Corvus corone*) and Hooded Crow (*Corvus cornix*) (6%) (Figure 1D) (Tables S1 and S2). Observations were reported from 33 countries. The greatest number of observations was reported from Finland (174), the USA (20), Russia (15), the U.K. (9), and Algeria (7; Tables S1 and S2). On the other hand, a total of 27 (25%) out of 106 observers reported that they had never detected such behavior in their home city areas (31 cities located in 9 countries). Based on the whole data, no observations were detected in eight countries (Figure 1E).

At the Finnish national level, a total of 174 observations from 8 species were reported (Table S2). Most of them considered the House Sparrow (62%), the White Wagtail (13%), the Eurasian Jackdaw (8%), and the Hooded Crow (6%).

At the local city level, Rovaniemi (Finland), a total of 65 observations from 6 species were detected (Table S2). Most of the observations considered the House Sparrows (72%), the White Wagtails (11%), and the Eurasian Magpie (9%; Table S2).

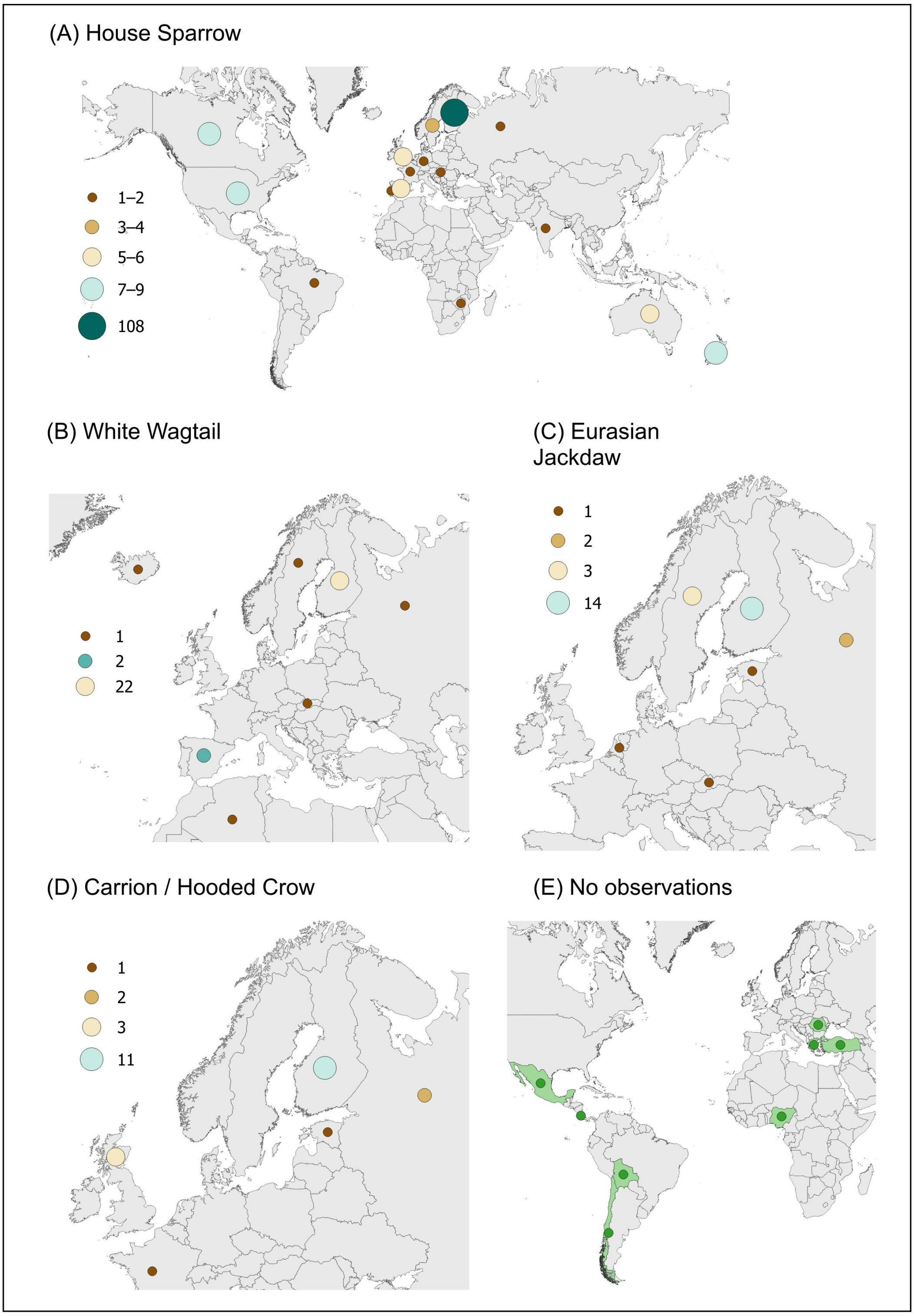

Figure 1. Country-based distribution and numbers of the observations of (**A**) House Sparrows (*Passer domesticus*), (**B**) White Wagtails (*Motacilla alba*), (**C**) Eurasian Jackdaws (*Corvus monedula*), (**D**) Carrion/Hooded Crows (*Corvus corone* and *Corvus cornix*, respectively) picking insects from cars, and (**E**) countries (marked in green with a green dot) were the responders reported that they have not observed such behavior.

3.3. Who Started First?

The first bird species observed to take insects from the cars was the House Sparrow (year 1928, Table 1). Two species were added to the list during the 1970s, the White Wagtail (1975) and the Boat-tailed Grackle (1977). During the 1980s, only one additional species was added to the list (the European Greenfinch, 1987). During the 1990s, seven new species were added to the list. Later, an additional 26 species, most of them (20) were added to the list during the 2010–2020s (Table 1). In addition, there is an observation from one species without the observation year details.

Table 1. Total number of observations (in parentheses after the species name) and the first-year observations were made of the bird species taking insects from the cars worldwide, in Finland, and in the city of Rovaniemi, Finland. Years given in parentheses are not accurate.

Species	Worldwide (Country)	Finland	Rovaniemi
House Sparrow (*Passer domesticus*) (154)	1928 (UK)	1971	1996
White Wagtail (*Motacilla alba*) (28)	1975 (Finland)	1975	2022
Boat-tailed Grackle (*Quiscalus major*) (8)	1977 (USA)		
European Greenfinch (*Carduelis chloris*) (1)	1987 (New Zealand)		
Black-billed Magpie (*Pica hudsonia*) (3)	1990 (Canada)		
Eurasian Jackdaw (*Corvus monedula*) (22)	1995 (Sweden)	2006	2023
Hooded Crow (*Corvus cornix*) (12)	1997 (Finland)	1997	2023
Eurasian Blackbird (*Turdus merula*) (2)	1998 (UK)		
Common Starling (*Sturnus vulgaris*) (2)	1995 (UK)		
Red-legged Partridge (*Alectoris rufa*) (1)	1998 (UK)		
Herring Gull (*Larus argentatus*) (2)	1999 (UK)		
Carib Grackle (*Quiscalus lugubris*) (1)	2002 (Barbados)		
Cactus Wren (*Campylorhynchus brunneicapillus*) (1)	before 2005 (USA)		
Great-tailed Grackle (*Quiscalus mexicanus*) (1)	2009 (USA)		
Brown Shrike (*Lanius cristatus*) (1)	2010 (Philippines)		
Eurasian Magpie (*Pica pica*) (9)	2010 (Russia)	2019	2019
Great Tit (*Parus major*) (9)	2010 (Russia)	2022	2023
Eurasian Tree Sparrow (*Passer montanus*) (14)	2011 (Finland)	2011	
Black Redstart (*Phoenicurus ochruros*) (4)	2012 (Slovakia)		
African Blue Tit (*Cyanistes teneriffae*) (1)	2014–2018 (Algeria)		
European Robin (*Erithacus rubecula*) (1)	2014–2018 (Algeria)		
Red-winged Starling (*Onychognathus morio*) (2)	(2014) (South Africa)		
Cape Wagtail (*Motacilla capensis*) (1)	(2015) (Botswana)		
Rock Dove (*Columba livia*) (1)	2014–2018 (Algeria)		
Wood Pigeon (*Columba palumbus*) (1)	2014–2018 (Algeria)		
Blue Tit (*Cyanistes caeruleus*) (2)	2016 (Russia)		
Common Raven (*Corvus corax*) (2)	2017 (USA)		
Greater Antillean Grackle (*Quiscalus niger*) (1)	2018 (Puerto Rico)		
Italian Sparrow (*Passer italiae*) (1)	(2018) (Italy)		
Carrion Crow (*Corvus corone*) (5)	2019 (Scotland)		
Coal Tit (*Periparus ater ledouci*) (1)	2019 (Algeria)		
Common Myna (*Acridotheres tristis*) (3)	2020 (India)		
House Crow (*Corvus splendens*) (1)	2020 (India)		
Snow Bunting (*Plectrophenax nivalis*) (1)	2022 (Iceland)		
Large-billed Crow (*Corvus macrorhynchos*) (1)	2023 (Japan)		
Oriental Magpie-Robin (*Copsychus saularis*) (1)	2023 (China)		
Red-whiskered Bulbul (*Pycnonotus jocosus*) (1)	2023 (China)		
Light-vented Bulbul (*Pycnonotus sinensis*) (1)	2023 (China)		
Patagonian Mockingbird (*Mimus patagonicus*) (1)	2023 (Argentina)		

3.4. Birds Using Insects in Parking Areas of Rovaniemi City

A total of 6 species out of the total 20 bird species observed were detected to use insects on cars (Table 2; Figure 2). There was a positive correlation between the observed species abundance in parking areas and the observed species abundance of species using insects on cars (Spearman's rho = 0.760, $p < 0.001$, $n = 20$). The House Sparrow and the White Wagtail were both the most abundant species in parking sites and the species most often observed to use insects on cars. Some abundant parking site bird species, like the Black-headed Gull, the Barn Swallow, and the Blue Tit, were not observed to use insects on cars. Of the six species observed to use insects on cars, all except the White Wagtail were residents, omnivores, and able to use winter feeding sites. The proportion (%) of House Sparrow of the total number of foraging observations ($n = 61$; blue bars) was greater than the proportion of the House Sparrow observations of the total numbers of birds observed ($n = 477$; green bars) in the parking sites (Figure 2). Because of the high dominance of the House Sparrow in the data, no statistical testing was performed.

Table 2. Number of bird species present, and number of bird species using insects on cars in parking areas in Rovaniemi. Traits indicated by abbreviations after species names: R = Resident species; M = Migratory; F = Feeding site species (species using commonly offered food at bird feeding sites [feeders]); O = omnivore; I = Insectivore (during breeding season).

Species (Traits)	Latin Name	Number of Individuals Present in Parking Sites	Number of Individuals Using Insects on Cars in Parking Sites
House Sparrow (R, F, O)	*Passer domesticus*	131	46
White Wagtail (M, I)	*Motacilla alba*	100	6
Eurasian Jackdaw (R, F, O)	*Corvus monedula*	51	1
Great Tit (R, F, O)	*Parus major*	39	4
Black-headed Gull (M, O)	*Larus ridibundus*	32	0
Eurasian Magpie (R, F, O)	*Pica pica*	23	3
Barn Swallow (M, I)	*Hirundo rustica*	22	0
Hooded Crow (R, F, O)	*Corvus cornix*	19	1
Blue Tit (R, F)	*Cyanistes caeruleus*	18	0
Common Swift (M, I)	*Apus apus*	9	0
Mew Gull (M, O)	*Larus canus*	8	0
Eurasian Tree Sparrow (R, F, O)	*Passer montanus*	7	0
Redwing (M)	*Turdus iliacus*	7	0
Common Chaffinch (M)	*Fringilla coelebs*	2	0
European Greenfinch (R, F)	*Chloris chloris*	2	0
Fieldfare (M)	*Turus pilaris*	2	0
Northern House Martin (M, I)	*Delichon urbicum*	2	0
Common Raven (R, O)	*Corvus corax*	1	0
Rock Dove (R, F, O)	*Columba livia*	1	0
Yellow Wagtail (M, I)	*Motacilla flava*	1	0

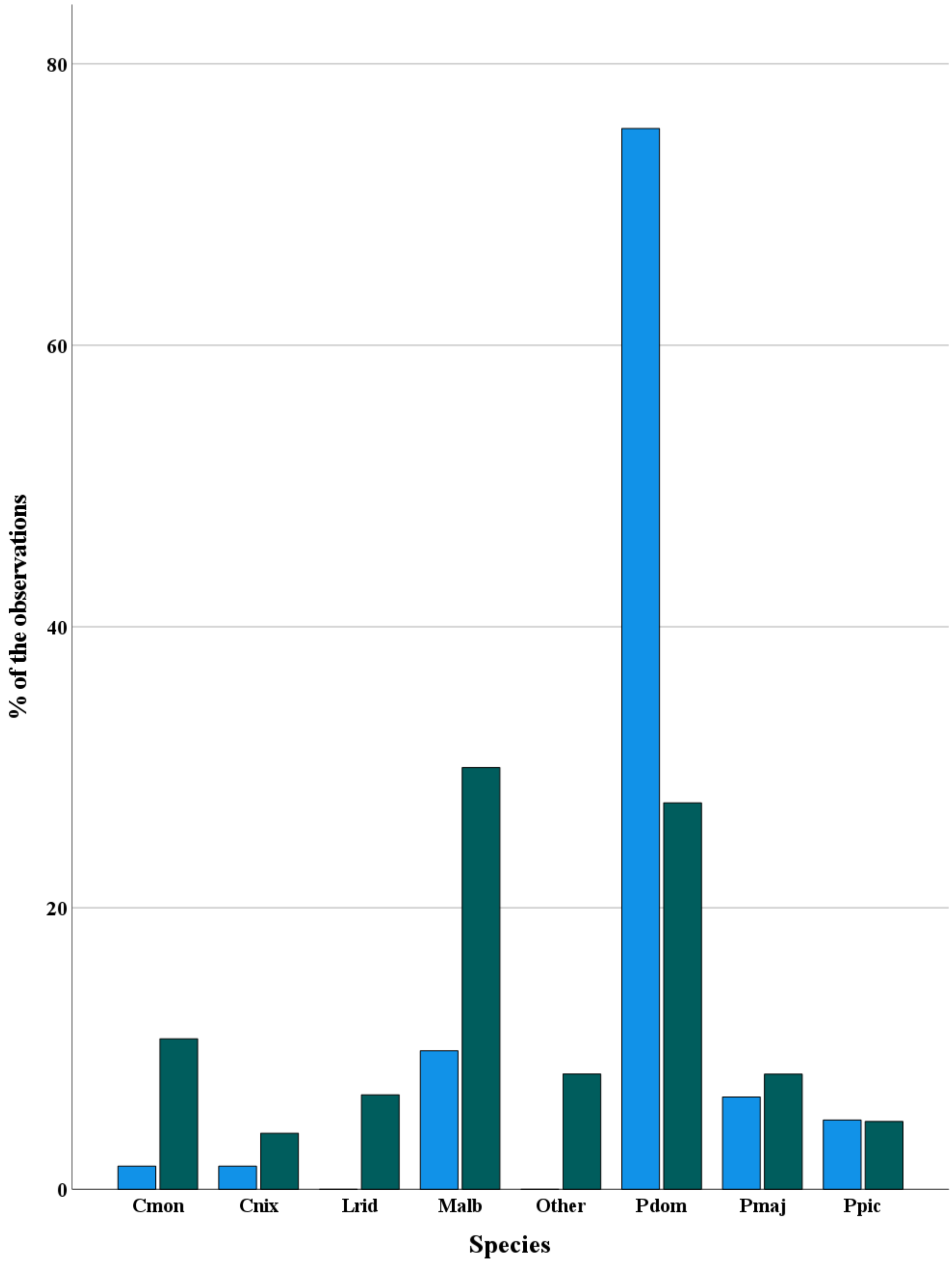

Figure 2. Proportion (%) of species of the total number of foraging observations (n = 61; blue bars) and of the total numbers of birds observed (n = 477; green bars) in the urban parking areas in Rovaniemi, Finland. Cmon = *Corvus monedula*, Cnix = *Corvus cornix*, Lrid = *Larus ridibundus*, Malb = *Motacilla alba*, Pdom = *Passer domesticus*, Pmaj = *Parus major*, Ppic = *Pica pica*, and other = sum of the following other species (*Apus apus*, *Carduelis chloris*, *Cyanistes caeruleus*, *Columba livia*, *Corvus corax*, *Delichon urbica*, *Fringilla coelebs*, *Hirundo rustica*, *Larus canus*, *Motacilla flava*, *Passer montanus*, *Turdus iliacus*, and *Turdus pilaris*).

3.5. Factors Affecting the Existence of Behavior

European urban bird species observed to use insects on cars had larger residual brain size, larger number of total innovations, greater diet generalism, and longer time since their urbanization than urban birds not observed to take food from the cars (Table 3). However, after the Holm–Bonferroni sequential correction for the p-values, only the result related to the residual brain size was significant.

Table 3. Comparisons of the flight initiation distances (FIDs), residual brain sizes, number of habitat types used, diet generalism, and time since urbanization between urban bird species observed and not observed using insects on cars in Europe. European urban species were extracted from Morelli et al. 2021 [72]. Mann–Whitney U-test was used in statistical comparisons. Significant results after applying the Holm–Bonferroni sequential correction are indicated in bold.

Variable	**Species Using Insects on Cars in Cities (*)** **Mean (±SD)**	***n***	**Species Not Using Insects on Cars in Cities (**)** **Mean (±SD)**	***n***	**U**	***p***
Flying initiation distance (1)	8.83 (3.66)	16	7.99 (3.13)	20	134.0	0.408
Residual brain size (2)	**0.05 (1.01)**	**19**	**−0.39 (0.78)**	**19**	**94.0**	**0.012**
Number of innovations (2)	16.45 (14.46)	20	7.85 (8.04)	20	127.5	0.049
Number of habitat types used (2)	4.17 (1.25)	18	3.63 (0.96)	19	130.5	0.201
Diet generalism (2)	3.00 (0.97)	18	2.37 (0.66)	19	111.0	0.049
Urbanization year of species (3)	1942 (40.09)	16	1974 (22.93)	15	60.0	0.018

(1) Díaz et al., 2013 [71]; (2) Lefebvre, 2021; [60]; (3) Møller et al. 2012 [74], the mean value of the reported values in different European cities was used. (*) *Alectoris rufa*, *Carduelis chloris*, *Columba livia*, *Columba palumbus*, *Corvus corone*, *Corvus corax*, *Corvus monedula*, *Erithacus rubecula*, *Larus argentatus*, *Motacilla alba*, *Parus caeruleus*, *Parus major*, *Passer domesticus*, *Passer italiae*, *Passer montanus*, *Phoenicurus ochruros*, *Pica pica*, and *Plectrophenax nivalis*. (**) *Sturnus vulgaris*, *Turdus merula*, *Streptopelia decaocto*, *Carduelis carduelis*, *Sylvia atricapilla*, *Fringilla coelebs*, *Serinus serinus*, *Phoenicurus phoenicurus*, *Turdus pilaris*, *Phasianus colchicus*, *Phylloscopus collybita*, *Garrulus glandarius*, *Ficedula hypoleuca*, *Sylvia curruca*, *Luscinia megarhynchos*, *Muscicapa striata*, *Troglodytes troglodytes*, *Corvus frugilegus*, *Carduelis cannabina*, *Prunella modularis*, *Phylloscopus trochilus*, *Myiopsitta monachus*, and *Larus ridibundus*.

4. Discussion

Our results indicated that 39 bird species in 33 countries have been observed to use insects smashed on cars. Most (85%) observations were reported from urban areas and considered the House Sparrow, followed by the White Wagtail and several species of corvids. According to our questionnaire study, about 25% of the responders answered that they had never seen birds picking insects from cars. European urban bird species observed to use insects on cars had larger residual brain size. There was also a tendency for European urban bird species using insects on cars to have a larger number of innovations, greater diet generalism, and longer time since their urbanization than birds not observed to take food from the cars. However, neither the boldness of species nor the number of habitat types used by the species influenced the ability to use insects on cars. Based on the local-level data, species commonly using insects on cars were also resident and able to use food offered in bird feeders.

Despite the fact that the first observation of birds taking insects smashed on cars was made in 1928 (House Sparrow in the city of Sanford, FL, USA; [75]), which was then followed by some anecdotal recordings, prior to the present study, only one more detailed and nation-wide study has been conducted [55]. In general, the species most often reported to use insects on cars are either House Sparrows, White Wagtails, or corvids, irrespective of the spatial scale of the analyses (see [55]). On the premise of the results of the present study, the behavioral phenomenon discussed here may not be very common, as observations were only recorded in 33 countries. Nevertheless, it is quite widespread around the globe; at least in the case of the House Sparrow, observations have been reported on six continents: North America, South America, Europe, Asia, Africa, and Oceania. On the other hand, the White Wagtail's observations were limited to two continents: Europe and Africa, whereas the observations referred to the Eurasian Jackdaw and the Carrion/Hooded Crow were restricted to the European continent. These results were not surprising given the distribution range of those bird species. Observations were registered in urban settings, and rarely was this phenomenon detected in sites where cars are parked for a longer time, like in parking sites of national parks. We found no significant link between the number of habitat categories inhabited by the species and the species' ability to use insects on cars. This result agrees with the findings of Ducatez et al. [76] who stated that habitat generalism is not related to brain size and innovation rate. It is noteworthy that, along with the House Sparrow and the White Wagtail, many of the reported observations identified bird species belonging to the corvidae family. They represent about one-twentieth of the listed bird species. One possible explanation could rely on the innovativeness of corvids, as well as sparrows, caused by their relatively large brain sizes [60] compared to other common urban bird species like the Rock Dove, Blackbird, Greenfinch, or Blue Tit. Likewise, other studies have also linked the rate of foraging innovations in birds to their relative brain size [77,78]. The House Sparrow also has other characteristics that help the species exploit novel food resources: the species is an urban exploiter, omnivore, and sedentary [79]. However, the overrepresentation of omnivores or diet generalists in species using insects on cars as compared to real insectivore bird species can be partly related to the differences in ability to catch flying insects. Obviously, true insectivores are much better at catching flying insects and do not, therefore, need to rely on the death of insects on cars.

Our results give support to the earlier studies [60,77,78], which stated that bird species having larger residual brain sizes were more likely to display novel foraging behavior in parking areas in cities. One might argue that some bird species reported as displaying this singular behavior could be because they are simply more abundant and, thus, more likely to be encountered. Surprisingly, the boldness of the bird species (measured by the FIDs) was not a guarantee for the species to be using insects on cars, although the House Sparrow was an exception.

Some researchers have stated that omnivore (generalist) species have larger rates of food types and technical innovations than diet specialist species, as well as larger brains, suggesting that cognitive skills benefit generalist species to expand their diet for new resources, such as insects on front panels of cars [76]. Our national and local-level studies indicated that most species using insects on cars were also species able to use foods offered in feeding sites. Thus, foraging innovations both during winter and breeding seasons could be behind their success in cities. We suppose that species that visit the feeding sites more often will also more frequently use insects on cars in the near future in cities.

We are confident that the present study not only shed light on the geographical scope of the behavioral phenomena of birds feeding on insects smashed on cars, and on the explanatory avian features that could be behind this behavior, but also has helped to elucidate the processes leading the adaptation of bird species to urbanization. For instance, our results indicated that most of the observations of birds taking insects from cars took place in urban environments. Indeed, the traits that determine whether bird species are able to tolerate urban environments remain poorly understood. A plausible explanation for why some species are more successful in exploiting urban environments than others might rely on the cognitive buffer hypothesis [80,81]. This hypothesis states that a larger brain should enhance adaptation to novel environments by facilitating the production of behaviors directed to cope with the new challenges those environments present. In the case of birds, the positive association between brain size and adaptation to urbanization has been already highlighted in earlier studies [82,83]. Our study gives additional support for the cognitive buffer hypothesis because the bird species using insects on cars, a behavior that might help bird species adapt to urbanization, had larger brain sizes and were more innovative [78].

Another important matter of discussion is the relationship between brain size and innovation (i.e., production of novel behaviors), with two main explanatory hypotheses on the topic. One is the technical intelligence hypothesis, which suggests that the evolution of an increased brain size was led by the cognitive demands linked to technical skills (such as the use of a tool) [84–86]. The other is the opportunistic-generalist hypothesis, which suggests that the evolution of a larger brain size was enhanced by a generalist feeding lifestyle that favored learning capacity [87–89]. Overington et al. [59] indicated that the diversity of technical innovations displayed by bird families was a much better predictor of residual brain size than was the number of food-type innovations, providing support for the technical intelligence hypothesis. The present study could also give at least partial support for the technical intelligence hypothesis in birds, as residual brain size was significantly larger in those bird spaces performing the behavior of picking insects from cars. However, more research is needed in order to elucidate the complex evolutionary basis of behavioral innovation in birds. For instance, Ducatez et al. [76] state that larger brains are linked not only to higher technical innovation rates but also to higher food-type innovation rates as well as to dietary generalism.

Besides the role of cognition, other noncognitive mechanisms have been proposed to facilitate the occurrence of technical innovations, such as motor diversity [78], which is the capacity to produce a diverse range of motor actions to accomplish a given act [90]. In fact, motor diversity and cognition could be linked. Indeed, the technical intelligence hypothesis states that high sensorimotor coordination (motor skills) has evolved in parallel with high intelligence (cognition) to support the identification of the required techniques while foraging [84,91–93]. In favor of the link between motor diversity and cognition, it has been shown that motor diversity is related to increased brain size in mammals [94]. As for birds, it has been proven that motor diversity is linked to foraging innovation [95,96], but questions are still open about the role of cognition in respect to that matter. The present investigation might advance the elucidation of the link between motor diversity and cognition in birds; in our study, greater brain size was associated with innovativeness (feeding on insects stuck to the cars), and since motor diversity has been demonstrated to be related to foraging innovation [95,96], we assume that an increased brain size and motor diversity are intertwined in birds too. For instance, during our field work, we observed that the bird species that exhibited more diverse motor skills while foraging on the insects smashed on cars were, in particular, those with greater brain sizes like corvids and the House Sparrow. Corvids were certainly acknowledged by Diquelou et al. [96] to have great motor diversity. As for House Sparrows, we witnessed them using several different techniques, like jumping repeatedly from the ground to the front plate of the car, sitting on the front plate or on the extra car light, and going inside the car radiator, among others. Such a diverse collection of methods obviously needs good motor skills. That motor flexibility was not observed in other passerine bird species like the White Wagtail though. Therefore, this may imply that there is a correlation between the bird species' innovation propensity and motor diversity: the House Sparrow was observed more often to feed on insects smashed on cars than the White Wagtail, and likewise, showed greater motor flexibility. Additional studies are required to analyze the impacts of motor skills and diversity on the foraging behavior of urban birds.

Callaghan et al. [97] have suggested that avian trait specialization is negatively associated with urban tolerance. One would expect urban species with a shorter FID would more often use insect food on cars than shyer species, which might avoid sites with a lot of cars, and thereby people. However, we failed to find any significant relationships between the FID of the bird species, taken as a proxy of boldness (reaction to a risky situation; [98]), and the species' ability to use insects smashed on cars. Correspondingly, Ducatez et al. [99] found no significant link between FID and innovativeness in urban areas.

Limitations of the Study

Part of the methodology of our research on birds taking insects smashed on cars conducted at a global scale, relied on the use of questionnaires sent to several bird organizations (URBICON, WGUS, and European Ornithologists' Union). Although those organizations are largely integrated by professional ornithologists, even those professionals could fail to notice possible observations or report negative cases. Indeed, some responders said that they had not paid any attention to this behavior, and probably, therefore, they have not observed it (see also [55]). Related to the reporting of the first year of the observation of the behavior, some participants indicated that they have observed this observation "years ago", but they do not remember the exact year or even the species. In addition, there exists the possibility of negative observations not being sufficiently reported, even if we also asked people to report negative observations. Thus, both an underestimation as well as an overestimation of the behavioral phenomena studied here might have occurred. Furthermore, at the regional scale in the city of Rovaniemi, we performed field studies that allowed us to acquire more comparable and quantitative data, and, in consequence, added more robustness to our research outcomes. All in all, we are confident that the methodological design of the present study has been consistent enough to derive reliable scientific conclusions.

Apart from technical limitations, other research questions arise. For instance, most of the observations of birds taking insects from cars were recorded in urban environments. The answer to what extent this is an indication of the adaptation of a bird species to urbanization, and not because of other confounding variables (greater number of cars in the urban environments, number of dead insects on cars, the species of dead insects available, etc.), remains to be elucidated by future studies. It might be also interesting to study, how this additional food source impacts birds' reproductive success, if there are sex- or age-specific differences in the use of this food resource, and how a car's characteristics influence the use of the car by the birds.

5. Conclusions

We conclude that the phenomenon was globally widespread, although it so far has been restricted only to 33 countries and quite a few bird species. European bird species able to use the novel insect source were characterized by a larger residual brain size. There was also some indication that bird species using insects on cars had a larger number of innovations, greater diet generalism, and longer time since their urbanization than birds not observed using insects on cars, but those parameters failed to be significant. Often these species are also residents, generalists, and able to use food offered at the feeding sites. We expect more species will engage in this innovative foraging behavior in the future, as the decline of insects within cities continues. The use of a citizen-science approach seems to be a good method to collect data about novel behaviors of birds. The novel methodology consisted of conducting research using tools provided by the Internet, the use of which has been encouraged by other researchers [64,65]. Therefore, this allowed us to record observations that might have been overlooked by the scientific community. Nevertheless, caution is always advised when dealing with those observations as they have not been fully controlled and checked by scientists.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/birds5030032/s1, Table S1: Supplementary global data; Table S2: Supplementary Finnish data [100–157].

Author Contributions: Conceptualization, J.J.; methodology, J.J.; formal analysis, J.J.; investigation, J.J. and A.R.-C.; writing—original draft preparation, J.J.; writing—review and editing, J.J. and A.R.-C.; visualization, J.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Ethical review and approval were waived for this study due to its observational nature.

Data Availability Statement: Data will be made available after publication, under reasonable request to the authors.

Acknowledgments: A.R.-C. acknowledges the financial support from the University of Granada, Spain, within its International Mobility Program for Doctorate Students ("Programa Movilidad Internacional Estudiantes de Doctorado") (decision on 15 September 2023), which provided the opportunity for her to visit the University of Lapland, Finland, and to take part of this research project. We want to thank URBICON (Urban Birds Consortium), WGUS (Working Group Urban Sparrows; 103 subscribers around the world), European Ornithologists' Union, and BirdLife Finland managers for supporting our questionnaire type of research. We thank the regional ornithological bird societies (Lapin LTY; Kanta-Hämeen LTY; Pohjois-Pohjanmaan LTY; Päijät-Hämeen LTY and Suomenselän LTY) in Finland for allowing us to use their observations saved in the tiira.fi bird observation data base. System analyst Arto Vitikka from the Arctic Centre is acknowledged for producing the map. Lastly, we want to thank all ornithologists for sending us their observations.

Conflicts of Interest: The authors declare no conflicts of interest.

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