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**Artificially Created Feeding Stations for Native Urban Birds in
Viennese parks: Environmental Determinants and Feeder Traits
Shaping Exploration Time and Station Use**

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Wien, den 01.02.2026

Sophie Hatzl

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1. Abstract

Urban environments can pose challenges for birds in winter, as natural food sources are often limited by vegetation structure and human land use. For this reason, supplementary feeding has become increasingly important in cities. However, birds do not use all feeders equally, and the factors influencing feeder use in urban habitats are still not fully understood, particularly in Austrian urban parks.

In this study, I investigated how feeder location, habitat structure, habitat diversity, and feeder height influence bird feeder use in Vienna. Feeding experiments were carried out at four urban locations: the Augarten, the Danube Island, the Danube Canal towards the city center, and the Danube Canal towards Klosterneuburg. In total, 40 standardized bird feeders were installed in paired sets at two different heights and monitored over an eight-day period. Food consumption was measured repeatedly, and thirteen habitat attributes were recorded within a 10 m radius around each feeder. Habitat diversity was quantified using the Shannon–Wiener index.

Feeder use differed strongly between locations, while feeder height had no significant effect on food consumption. Analyses showed that habitat context explained most of the variation in feeder use. Feeders placed in structurally diverse habitats were used more intensively than those in more uniform surroundings. Multivariate analyses further indicated that birds preferred mixed, intermediate habitat types rather than highly specialized environments. Overall, feeder use was best explained by combinations of habitat features and human infrastructure, rather than by any single habitat attribute.

These results suggest that habitat diversity and local habitat context are key drivers of feeder use by urban birds in winter. Creating and maintaining structurally diverse urban habitats may therefore support bird populations during this critical period.

2. Introduction

Urban ecosystems pose various challenges for wildlife, and for birds one of the most pressing issues is finding enough food during the winter months. In Austria, many native bird species increasingly depend on supplementary feeding by humans, as natural food sources such as seeds, berries, and overwintering insects become scarce once temperatures fall. The ongoing decline in insect populations documented across Central Europe in recent decades further intensifies this seasonal limitation (Hallmann et al., 2017). Many resident and migratory species rely on insects as a crucial food source, as they provide essential protein for winter survival and early spring breeding. When insect numbers decrease, the entire food web is affected, reducing both the quantity and quality of available prey at critical times of the year.

Alongside these seasonal shortages, climate change adds further stress. Changes in temperature and precipitation alter the timing of flowering and fruiting in plants, as well as the life cycles of invertebrates, creating mismatches between birds' energetic needs and food availability. Warmer winters can disrupt these natural rhythms, while extreme weather events make foraging more unpredictable. At the same time, urban expansion, intensive agriculture, and the removal of mature trees and hedgerows cause habitat loss and fragmentation, which further limit nesting and feeding opportunities. In many urban areas, diverse vegetation has been replaced with sealed surfaces, reducing structural complexity, and eliminating microhabitats that once offered food and shelter (Shochat et al., 2010). Urban environments may provide more predictable anthropogenic food sources, but they often offer fewer high-quality natural resources, especially for insectivorous species (Seress et al., 2020). In response to these environmental pressures, artificial feeding stations have become increasingly common as a form of public engagement and small-scale conservation. Several studies have shown that winter bird feeding can strongly influence bird abundance, community structure, and spatial distribution (Robb et al., 2008; Galbraith et al., 2015). Such feeders can provide crucial energy sources during harsh winters and may help stabilize bird populations facing declines in natural food

availability. Nevertheless,, their ecological impact remains only partly understood. Important questions persist: To what extent do native birds actually depend on these feeders? Are they used opportunistically, or have some species come to rely on them as part of their regular winter strategy? Moreover, might regular feeding alter natural foraging behavior or competition among species? Understanding these dynamics is essential for evaluating both the benefits and potential drawbacks of human-provided food.

Previous studies have identified several factors influencing how birds use feeders - including feeder design and color (Goławski & Sytykiewicz, 2021), height and placement, surrounding vegetation, and proximity to human activity. Previous research indicates that various factors, such as feeder design, placement, surrounding vegetation, and proximity to human activity, influence feeder use. Urban birds are often less fearful of humans and novel objects, a behavioral trait linked to reduced neophobia and increased risk-taking (Møller, 2010; Tryjanowski et al., 2015). However, there is still a lack of specific research on native bird population in Austrian urban areas. In particular, few studies have examined behavioral aspects such as neophobia, the reluctance to approach unfamiliar objects, or explored how birds adapt to microhabitat conditions in urban and semi-natural settings. These gaps make it difficult to fully understand how birds in cities respond to supplemental feeding within a changing environment.

This study aims to help close these gaps by examining how native bird species in and around Vienna respond to standardized feeding stations placed along an urban-to-semi-natural gradient. The project focuses on behavioral indicators such as neophobia and adaptability, as well as preferences for feeder characteristics including height, shelter, and proximity to human or animal disturbance. By analyzing patterns of feeder use in relation to habitat features, this research seeks to assess how strongly native birds utilize and potentially depend on artificial feeding opportunities. Ultimately, the findings will contribute to a clearer understanding of how winter feeding affects urban bird communities and may provide guidance for supporting native bird populations in Austrian cities more effectively.

To better understand the ecological and behavioral mechanisms underlying feeder use in urban environments, the following literature review synthesizes relevant findings on supplementary feeding, habitat structure, and bird behavior.

2.1 Urban environment and winter feeding

2.1.1 Food for thought: supplementary feeding as driver of ecological change in avian populations

Robb et al. (2008) discuss in their paper how bird feeding by humans has become a widespread practice and how it can influence natural ecological processes. The authors contend that supplementary feeding not only assists birds during periods of food scarcity but may also result in enduring ecological consequences. By providing additional energy sources, humans may unintentionally alter bird behaviour, reproduction, migration, and even community structure. In some regions, almost half of all households are involved in bird feeding, which highlights the scale of this human influence.

The study points out both advantages and disadvantages of artificial feeding. On the one hand, it can increase survival rates and improve breeding success, especially during harsh winter months. On the other hand, it may also promote disease transmission, change species interactions, and benefit more dominant or aggressive species. The authors therefore stress the need for more controlled and long-term experiments to understand these dynamics better.

For the purpose of this thesis, Robb et al. (2008) provide important background to understand how supplementary feeding can shape local bird populations. Their work supports the idea that the surrounding habitat and the availability of human-provided food sources jointly influence feeding behaviour and species composition in urban parks such as those in Vienna.

2.1.2 Garden bird feeding predicts the structure of urban avian assemblages

Fuller and colleagues (2008) investigated how bird-feeding practices in domestic gardens relate to the composition and structure of urban bird communities. Their research, entitled “*Garden bird feeding predicts the structure of urban avian assemblages*”, examined survey data from various residential areas and determined that the provision of supplementary food significantly influenced alterations in avian assemblages within urban environments. Specifically, they showed that gardens where feeders were frequently used tended to support higher densities of certain bird species, altering community structure relative to non-feeding sites.

One key finding was that the provisioning of bird food may augment the carrying capacity of urban habitats for particular species, thereby increasing their relative abundance. Fuller et al. also highlight that such anthropogenic food sources can facilitate the dominance of generalist or adaptable species, potentially reducing community diversity and favouring species tolerant of human-modified environments. Furthermore, the authors argue that supplementary feeding should be considered a strong driver of ecological change in urban bird assemblages, modifying not just abundance but also species composition and community structure.

For the present study on urban feeding stations in Vienna, Fuller et al.’s work offers an important conceptual foundation. Their results support the hypothesis that not only the presence of feeders but also the environmental context (such as habitat structure and human activity) affects how bird communities respond. This underpins our examination of how habitat attributes around feeders correlate with food consumption and bird activity within urban parks. It also highlights the need to consider how feeding interventions might influence broader community dynamics beyond individual feeding events.

2.2 Neophobia and adaptive behaviour

2.2.1 Individual repeatability, species differences, and the influence of socio-ecological factors on neophobia in 10 corvid species

Miller et al. (2021) conducted one of the most comprehensive comparative investigations to date into neophobia - the reluctance to approach novel objects or foods - within corvid birds. Their multi-lab study tested 241 individuals from ten corvid species across ten laboratories worldwide. Birds were presented with familiar food alone (baseline) and then with either a novel object or novel food alongside that familiar food. The authors found significant species-level variation in latency to approach food when novelty was present, indicating that neophobic responses differ meaningfully between corvid species.

Beyond species differences, the study identified several socio-ecological drivers of object-based neophobia: use of an urban habitat (versus rural), social system (territorial pair vs family group), maximum flock size, and caching behaviour. Interestingly, for food neophobia (novel food rather than novel object) only maximum flock size emerged as a significant predictor.

A key finding was the high individual repeatability of neophobic responses over time and context - most individuals exhibited consistent behaviour across repeated tests, suggesting that neophobia behaves as a relatively stable behavioural trait within these species.

This study offers critical conceptual insight for my investigation of feeder use and habitat attributes in Vienna's urban parks. It emphasises that individual bird behaviour (habituation to novelty) and wider socio-ecological context (urbanization, sociality) both shape interaction with novel feeding opportunities. In other words, the success of a feeder may depend not only on habitat structure but also on how accustomed local bird populations are to novelty and human-provided food sources.

2.2.2 Urbanization affects neophilia and risk-taking at bird-feeders

In this study, Tryjanowski et al. (2016) explored how urbanization influences birds' responses to novelty and risk at feeding stations by comparing urban and rural habitats in Poland. Their experimental design involved placing feeders with and without an unfamiliar, brightly-coloured object in 14 cities and matched rural areas during the winter months. Across 1,845 birds and 19 species observed, the authors found that urban sites attracted more birds overall and exhibited a higher likelihood of birds visiting feeders even when the novel object was present. In rural areas, birds were more hesitant: the presence of the novel object reduced feeder visits significantly, whereas in urban sites the effect was smaller or reversed. This suggests that urban birds are likely more neophilic (willing to approach new stimuli) and more willing to take risks than rural conspecifics, possibly due to habituation to human-provided resources and frequent exposure to anthropogenic novelty. The authors also controlled for potential confounders such as temperature, local bird density, and the presence of cats, dogs and pedestrians, strengthening the validity of their conclusions.

For the present investigation into feeder use in Vienna's urban parks, this work provides a key conceptual foundation. It emphasizes the importance of behavioural traits - specifically neophobia/neophilia and risk-taking - in shaping how birds exploit supplemental food resources. The study supports the idea that local bird populations' previous experiences with human feeding and novel stimuli may critically influence their response to artificial feeders. This reinforces our focus not only on feeder placement and habitat attributes, but also on the adaptive behaviour of urban birds and their readiness to use novel food platforms.

2.3 Influence of feeding station-design and location

2.3.1 *How urban and rural birds respond to the colour of bird feeders?*

In their study, Goławski and Sytykiewicz (2021) investigated how urban and rural birds respond to feeder colour, focusing on behavioural differences related to neophobia - the avoidance of novel stimuli. They compared visitation rates to paired feeders painted in green and yellow across several sites in both urban and rural environments in east-central Poland. While the overall interaction between habitat type and feeder colour was small, two consistent trends emerged: green feeders were generally preferred over yellow ones, and urban birds showed higher visitation rates than rural birds. The authors interpreted these findings as evidence that urban birds, being more habituated to human presence and artificial objects, exhibit reduced neophobia, whereas the avoidance of yellow feeders may relate to yellow's association with warning colours in nature.

These results are particularly relevant for my experiment in Vienna's urban parks. The feeders used in my study featured a green perch and feeding opening area - similar in colour to the more frequently visited feeders in Goławski and Sytykiewicz's research. This design choice may have contributed to the local birds' higher acceptance of the feeders. The study therefore highlights how even subtle design elements, such as colour, can influence feeding behaviour, particularly in urban populations already familiar with human-made structures.

2.3.2 *Bird community responses along urban-rural gradients: Does the size of the urbanized area matter?*

Garaffa, Filloy, and Bellocq (2009) investigated how bird communities respond along urban-rural gradients and whether the size of urbanized areas influences these patterns. Conducted in the Argentine Pampas region, their study analyzed species richness, composition, and abundance across settlements of different sizes. The authors discovered that in larger towns (over 7,000 residents), the proportion of built-

up land negatively affected bird species richness, while in cities exceeding 13,000 inhabitants, the abundance of native species decreased from the outskirts toward the urban center. In contrast, both small towns (below 2,000 inhabitants) and large cities (over 60,000 inhabitants) showed little variation in community composition along the gradient. These results suggest the existence of a threshold effect, where urbanization begins to significantly alter avian assemblages only beyond a certain scale.

This finding is particularly relevant for my study in Vienna, as it highlights that not only the presence but also the extent and intensity of urbanization shape bird behavior and diversity. In the context of my feeding station experiment, the result implies that local habitat features, such as vegetation structure or cover, cannot be interpreted in isolation; rather, the broader urban context (including human activity, surrounding infrastructure, and landscape heterogeneity) likely plays a key role in influencing feeding behavior and habitat preferences among native bird species.

3. Materials and methods

3.1 Study Design and Objectives

This study investigated the behavioral responses of native bird species in the Vienna region of Austria to standardized artificial feeding stations installed in urban and semi-urban habitats. Observations were conducted from November 2024 to March 2025, a period typically marked by limited natural food availability and the importance of supplemental feeding.

The primary goal was to examine feeding behavior in relation to neophobia, adaptive responses, and preferences for feeder characteristics such as height, degree of shelter, and proximity to human activity.

3.2 Study Sites

Four locations representing different urban contexts were selected:

1. Danube canal (city-center section)
2. Augarten
3. Danube island
4. Danube canal towards Klosterneuburg

Within these locations, five observation sites were established. Each site contained ten feeding stations, arranged as five paired sets with two feeders per tree or shrub.

3.3 Feeder Configuration

Each feeder pair was suspended using a two-meter wire, allowing one feeder to hang approximately one meter lower than its partner to facilitate analysis of vertical preferences. Feeders were filled with 500 g of bird seed (initial column height: 17 cm)

and designed to permit access for small native bird species while limiting larger species (e.g., *Corvus* spp., *Columba livia*).

3.4 Environmental Data Collection

A standardized protocol documented eight environmental parameters within a 10 m radius of each feeder pair:

- Feeder height
- Proximity to trees and shrubs
- Surrounding surface composition (e.g., lawn, bike path, sidewalk)
- Presence of anthropogenic features (e.g., streets, benches, pedestrian or animal activity)

For each 10 m section, ground-cover categories were measured in meters and then converted to percentages:

$$Percent = \frac{x \text{ meters}}{80} \times 100$$

Example Location 1: 61 m lawn, 4 m bike path, 6 m shrubs, 1 m bench, 8 m sidewalk
→ 76.25 % lawn, 5 % bike path, 7.5 % shrubs, 1.25 % bench, 10 % sidewalk.

3.5 Monitoring Procedure

Feeding stations were monitored for eight consecutive days. Observations occurred on days 0, 2, 4, 6, and 8. At each visit, the remaining seed column was measured (cm) and bird activity was recorded, allowing estimation of seed consumption and species-specific feeding behavior. The eight-day interval was chosen based on pilot observations that indicated substantial bird activity within the first few days.

3.6 Data Analysis

Environmental measurements were entered into Microsoft Excel to calculate percent ground cover and canopy cover, and to derive a habitat diversity index (Shannon-Wiener-Index). Relationships between habitat features and observed feeding behavior were then analyzed to identify potential site preferences and patterns of behavioral adaptation.

$$H = - \sum (p_i \times \ln(p_i))$$

H: habitat diversity index

pi: proportion of individual habitat diversity

ln: natural logarithm

Number of feeding station	Habitat diversity index
1.1	0,835844481
1.2	0,835844481
2.1	0,680666833
2.2	0,680666833
3.1	0,685979616
3.2	0,685979616
4.1	1,33140327
4.2	1,33140327
5.1	1,34202271
5.2	1,34202271
6.1	1,167224764
6.2	1,167224764
7.1	0,250501282
7.2	0,250501282
8.1	0,183785237
8.2	0,183785237
9.1	0
9.2	0

10.1	0,733984585
10.2	0,733984585
11.1	0,815239669
11.2	0,815239669
12.1	1,688792943
12.2	1,688792943
13.1	1,004801683
13.2	1,004801683
14.1	0,387104725
14.2	0,387104725
15.1	0,544094083
15.2	0,544094083
16.1	1,28238347
16.2	1,28238347
17.1	1,226203902
17.2	1,226203902
18.1	1,483740228
18.2	1,483740228
19.1	1,273936183
19.2	1,273936183
20.1	1,329723518
20.2	1,329723518

Table 1 “Habitats diversity index”: This table shows the results of the formula for the habitats diversity index for every feeding station.

3.7 Study Site Description and Environmental Characteristics

To provide a clearer visual representation of the different study areas, one representative site per location was selected for graphical illustration. For each of the four locations, the site with the highest habitat diversity index was chosen (as shown in Figure 5, page 10).

3.7.1 Danube canal towards city center, Site 5

Danube canal November–December 24, Site: 5

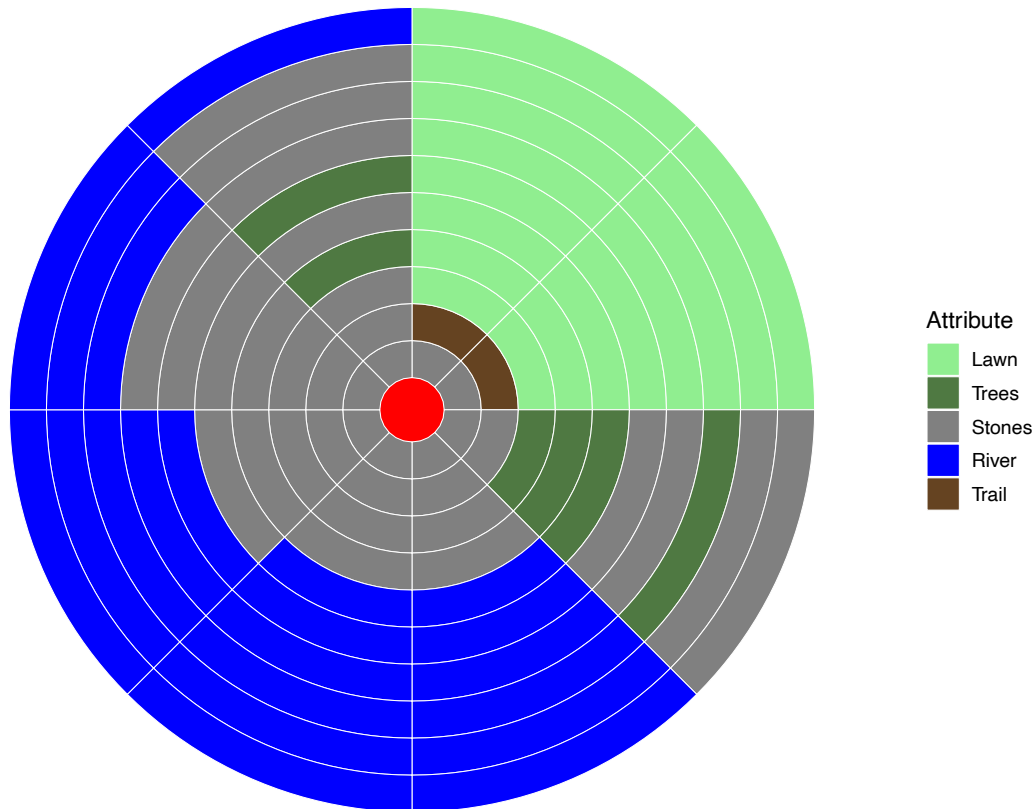


Figure 1 „Danube canal (city center section), Site 5:” This figure illustrates the study area located along the Danube Canal near Vienna’s city center. The legend on the right provides an overview of the five environmental attributes recorded at this site. The red dot at the center indicates the position of the paired feeding stations installed for this location.

The figure illustrates the spatial layout of the study site located along the Danube Canal near Vienna’s city center (Site 5). The legend on the right-hand side indicates the various habitat components and environmental features recorded within the 10-meter observation radius.

Site 5 was selected because it includes five distinct environmental attributes: lawn, trees, stones, the Danube River, and a trail. As shown in the figure, approximately one quarter of the area consists of lawn, while another quarter is covered by the Danube. The stony riverbank leading to the water accounts for over 40% of the surface, interspersed with several individual trees. The pedestrian trail running alongside the lawn represents only a minor proportion of the total site area.

Attribute	Percentage
Lawn	20%
Trees	8,75%
Stones	42,5%
River	26,25%
Sidewalk	2,5%

Table 2 “Danube canal Site 5”: The table provides an overview of the different environmental attributes identified at each site and their respective percentage composition within the sampled

3.7.2 Augarten, Site 6

Augarten January 25, Site: 6

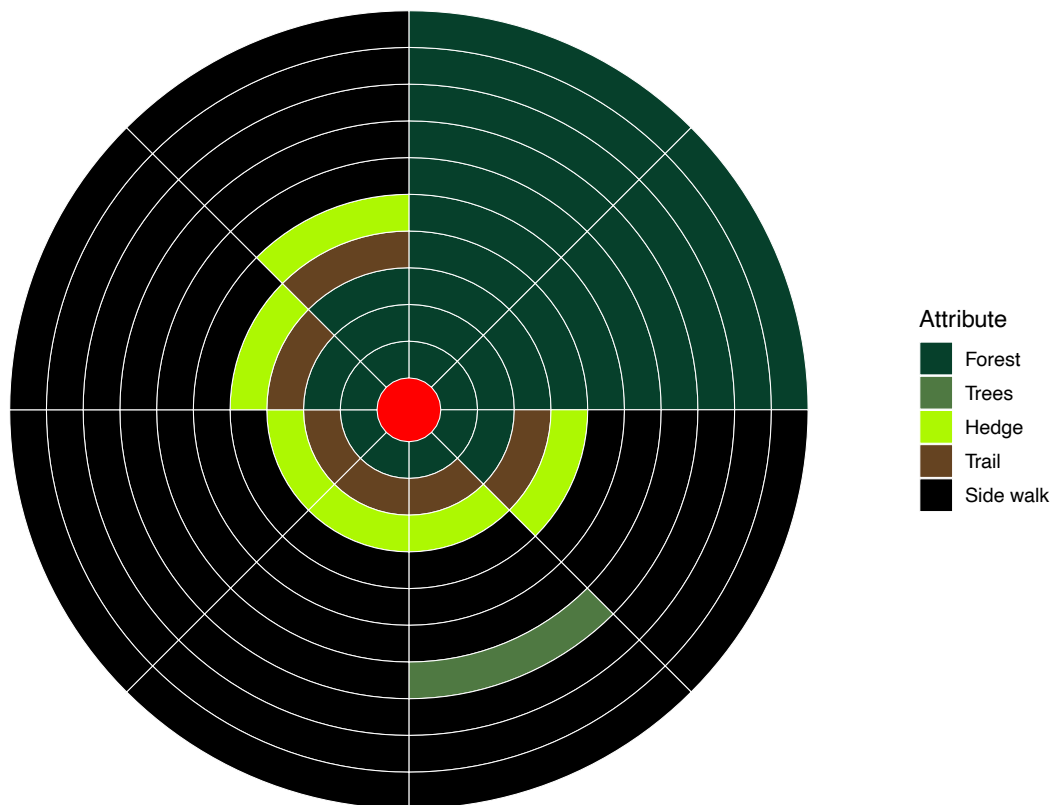


Figure 2 „Augarten, Site 6“: This figure illustrates the study area located at the Augarten. The legend on the right provides an overview of the five different environmental attributes recorded at this site. The red dot at the center indicates the position of the paired feeding stations installed for this location.

The figure depicts the spatial configuration of the study site located within the Augarten (Site 6). The legend on the right-hand side identifies the main habitat components and structural features within the 10-meter observation radius. Site 6 was selected because it represents a diverse urban green space characterized by a combination of natural and anthropogenic elements. The area includes a wide sidewalk, a section of forest with individual mature trees, and a dense hedge

separating the walkway from the wooded area. In addition, a narrow trail runs through the forest, providing a heterogeneous structure that may influence both habitat diversity and bird activity within this location.

Attribute	Percentage
Forest	37,25%
Trees	1,25%
Hedge	7,5%
Trail	7,5%
Sidewalk	46,5%

Table 3 “Augarten Site 6”: The table provides an overview of the different environmental attributes identified at each site and their respective percentage composition within the sampled area.

3.7.3 Danube island, Site 12

Danube island January 25, Site: 12

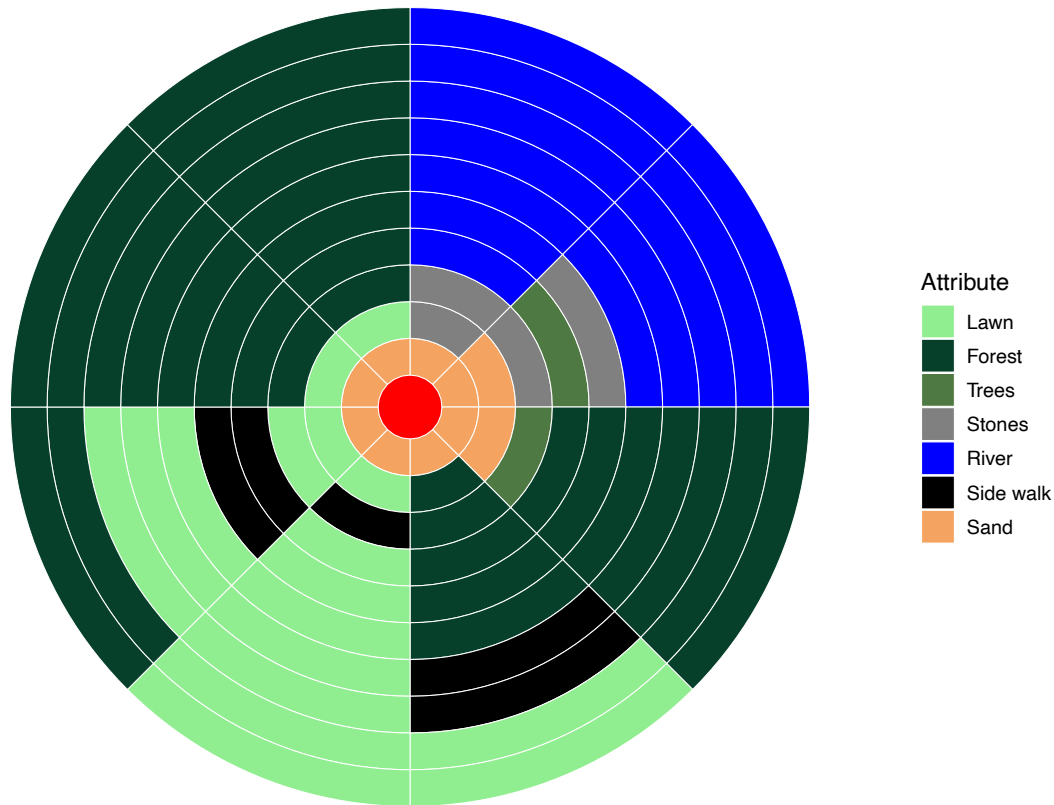


Figure 3 „Danube Island, Site 12“: This figure illustrates the study area located at the Danube Island. The legend on the right provides an overview of the 7 different environmental attributes recorded at this site. The red dot at the center indicates the position of the paired feeding stations installed for this location.

The figure illustrates the spatial composition of the study site located on the Danube Island (Site 12), which exhibited the highest habitat diversity index among all sampled locations. The legend on the right-hand side identifies the seven distinct habitat attributes recorded within the 10-meter observation radius.

Approximately one-third of the site is covered by forested areas, while about one-quarter consists of the Danube River itself. Additional environmental components

include individual trees, sandy ground beneath the feeding station, and a section of stones leading directly to the riverbank. Furthermore, pedestrian sidewalks and lawn areas occupy a considerable portion of the remaining surface. This diverse combination of natural and anthropogenic structures contributes to the site's particularly high habitat diversity and likely plays a role in shaping local bird activity patterns.

Attribute	Percentage
Lawn	23,75%
Forest	33,75%
Trees	2,5%
Stones	5%
River	15%
Sidewalk	7,5%
Sand	12,5%

Table 4 "Danube Island, Site 12": The table provides an overview of the different environmental attributes identified at each site and their respective percentage composition within the sampled

3.7.4 Danube canal towards Klosterneuburg, Site 18

Danube canal Klosterneuburg 25, Site: 18

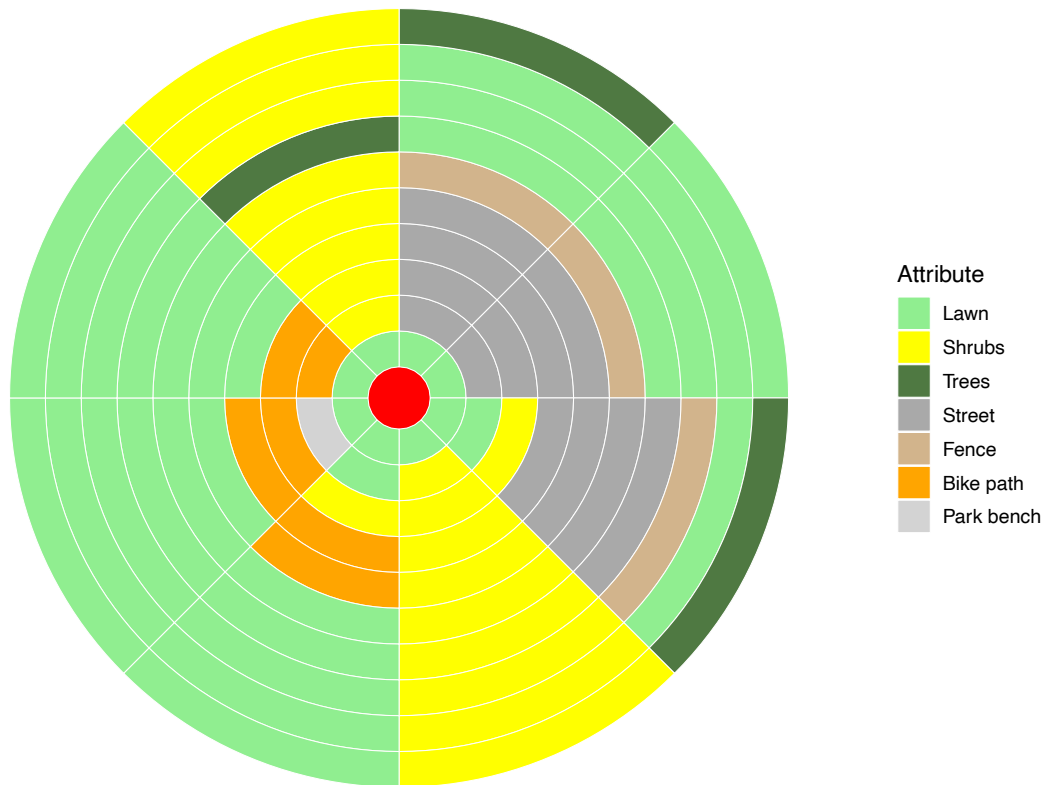


Figure 4 „Danube canal towards Klosterneuburg, Site 18“: This figure illustrates the study area located at the Danube island. The legend on the right provides an overview of the 7 different environmental attributes recorded at this site. The red dot at the center indicates the position of the paired feeding stations installed for this location.

The final study site, located along the Danube Canal towards Klosterneuburg, corresponds to Site 18. This site comprises seven distinct environmental attributes. Nearly half of the area (approximately 45%) consists of lawn, interspersed with shrubs and individual trees. Adjacent to the site runs a major street, separated by a fence, while a bicycle path crosses the lawn. A single park bench is also situated

within this area, indicating a relatively high level of human activity and anthropogenic influence at this location.

Attribute	Percentage
Lawn	44,5%
Shrubs	24,25%
Trees	3,75%
Street	7,5%
Fence	3,75%
Bike path	7,5%
Park bench	1,25%

Table 5 “Danube canal towards Klosterneuburg, Site 18”: The table provides an overview of the different environmental attributes identified at each site and their respective percentage composition within the sampled area.

4. Results

4.1 Habitat Composition Analysis Based on Radar Plots

To enable a clear visual comparison between the different study sites, radar plots were created for all four locations. Within each plot, the five observation points per site are visually represented to illustrate variations in environmental attributes and habitat composition.

Each of the five radar plots represents one of the five observation sites within each study location. The data for these plots were derived using the formula to convert distances in meters into percentages (see formula on page 7). To enhance clarity and interpretability, the percentage values were grouped into four categories: *not present* (0%), *mildly present* (> 0 – 33%), *moderately present* (> 33 – 66%), and *strongly present* (> 66 – 100%). The axes of the radar plots correspond to different habitat attributes such as lawn, fence, sand, street, and other environmental features. These visualizations provide a concise and comparative overview of the habitat composition across the individual sites within each study area.

4.1.1 Danube canal towards City center November-December 24

Site: Danube canal November-December 24 — Radar (Classification)

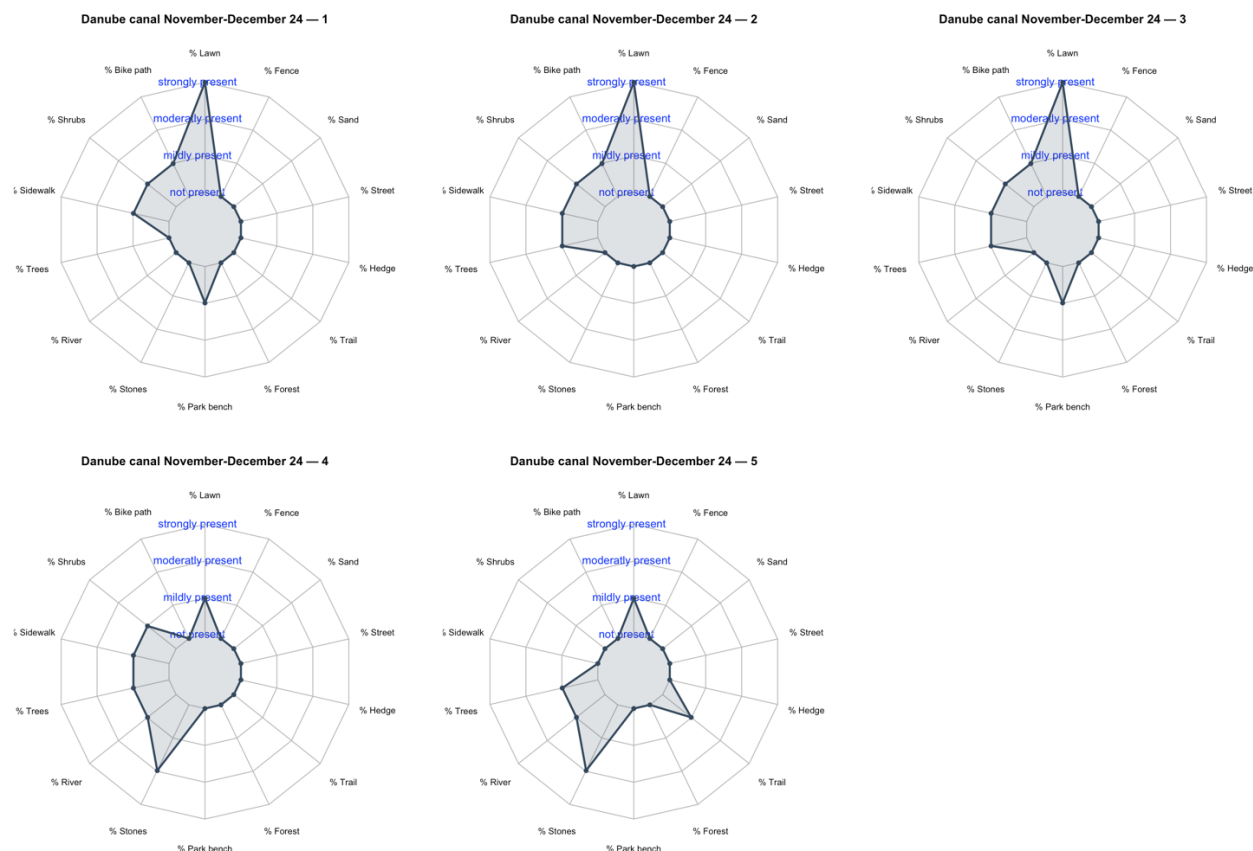


Figure 5 „Site: Danube canal November – December 24“: Radar plots showing the relative presence of habitat attributes across the five observation sites per study location. Each axis represents a specific environmental attribute, while the color intensity indicates the degree of its presence, ranging from not present to strongly present.

In the example of the Danube Canal toward the city center, three of the five observation sites show a strong presence of lawns, while the remaining two sites are located closer to the river and therefore exhibit a higher proportion of stones. Trees are moderately represented across all five sites, indicating a consistent but limited vegetative cover. Evidence of human activity is present at each site, as reflected by the appearance of park benches, sidewalks, and walking trails.

4.1.2 Augarten January 25

Site: Augarten January 25 — Radar (Classification)

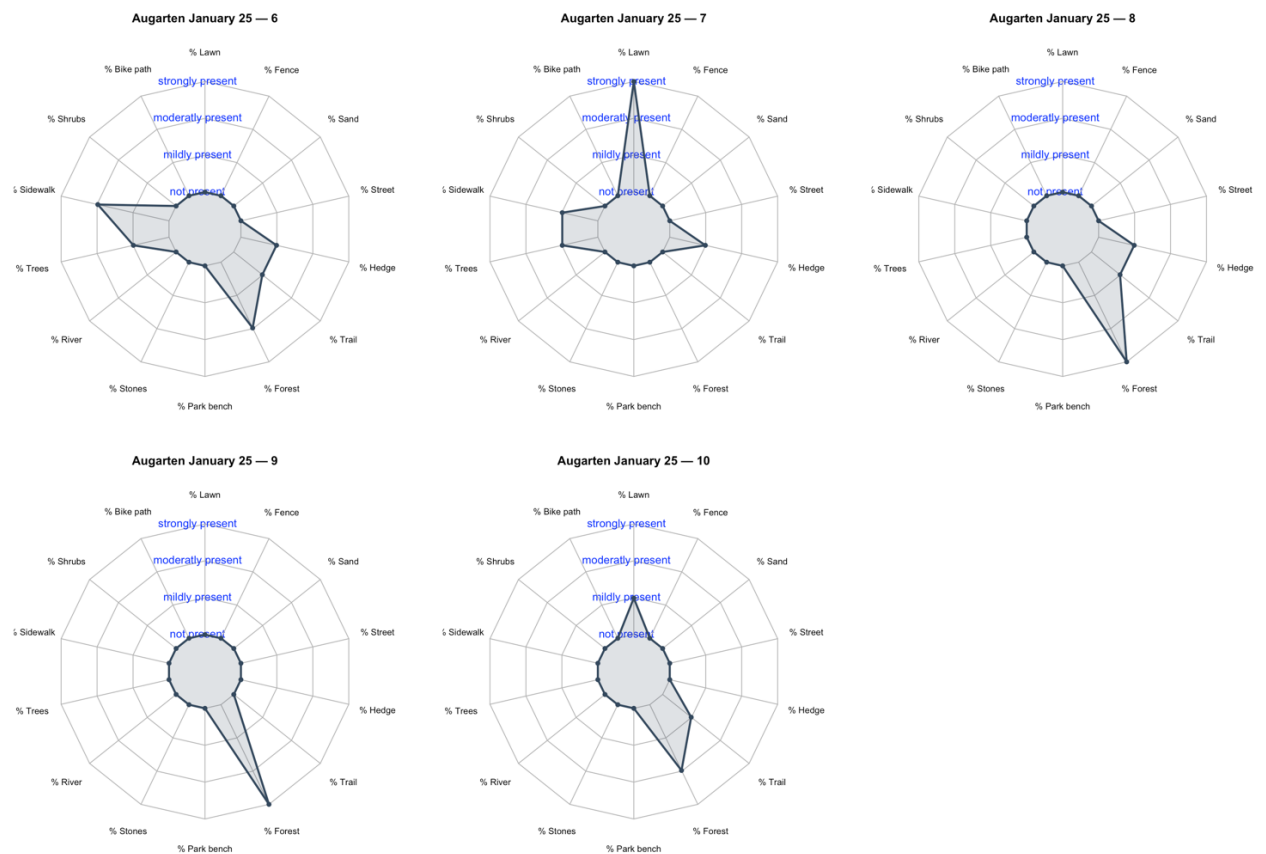


Figure 6 “Site: Augarten January 25”: Radar plots showing the relative presence of habitat attributes across the five observation sites per study location. Each axis represents a specific environmental attribute, while the color intensity indicates the degree of its presence, ranging from not present to strongly present.

At the Augarten site, four out of five observation areas show a moderate to strong presence of forested habitat. Two sites are located near pedestrian sidewalks, indicating regular human activity. Overall, the Augarten sites exhibit a largely natural character, as reflected by the dominance of forested areas, individual trees, and hedges. Signs of human presence are nonetheless evident through the occurrence of pedestrian paths, small trails, and open lawn areas.

4.1.3 Danube island January 25

Site: Danube island January 25 — Radar (Classification)

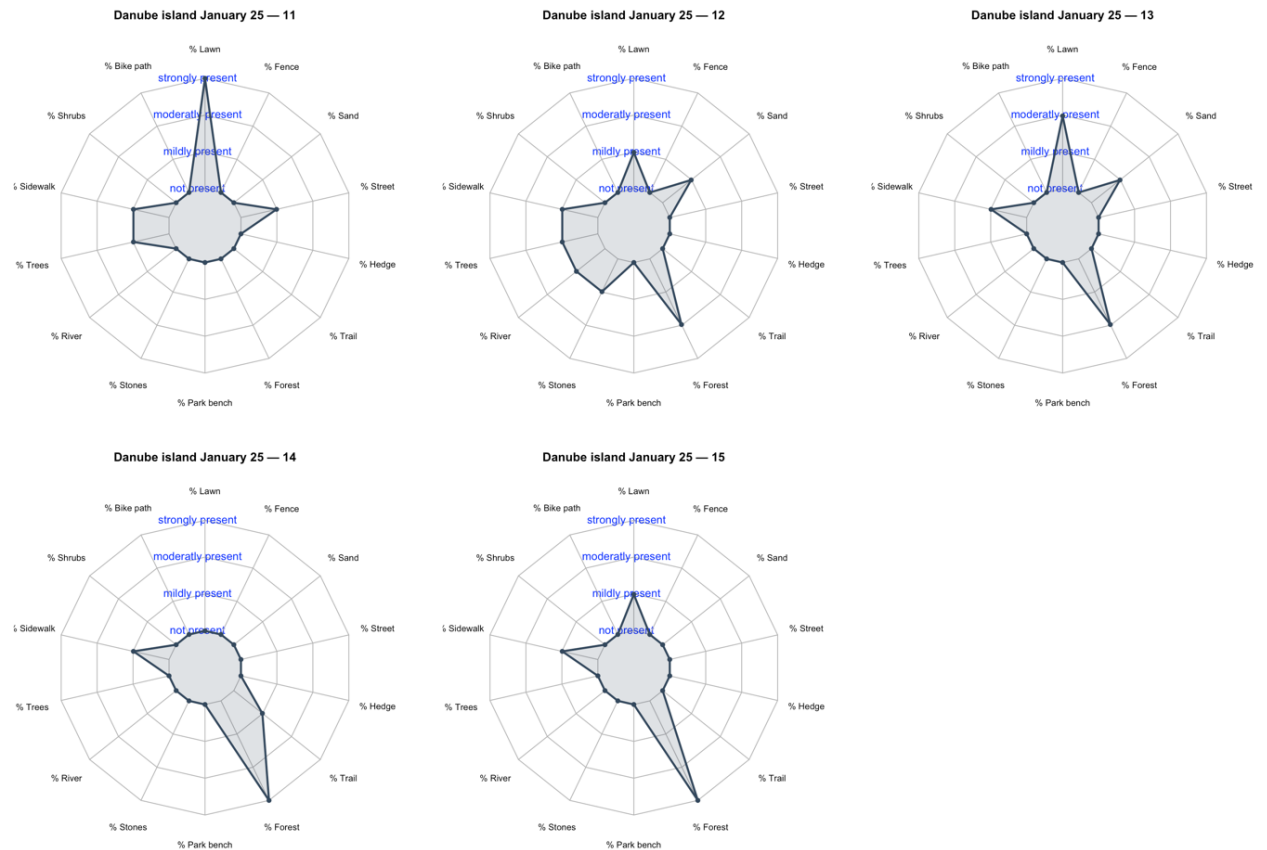


Figure 7 „Site: Danube island January 25”: Radar plots showing the relative presence of habitat attributes across the five observation sites per study location. Each axis represents a specific environmental attribute, while the color intensity indicates the degree of its presence, ranging from not present to strongly present.

The observation sites at the Danube Island display a high degree of environmental diversity, characterized by a broad range of natural habitat features. The sites prominently represent forest areas, sandy ground, individual trees, and stone-covered riverbanks. Despite this strong natural composition, there are also clear indicators of human presence, including sidewalks present at all five sites, small walking trails, and even a nearby road adjacent to the first observation site.

4.1.4 Danube canal towards Klosterneuburg March 25

Site: Danube canal Klosterneuburg March 25 — Radar (Classification)

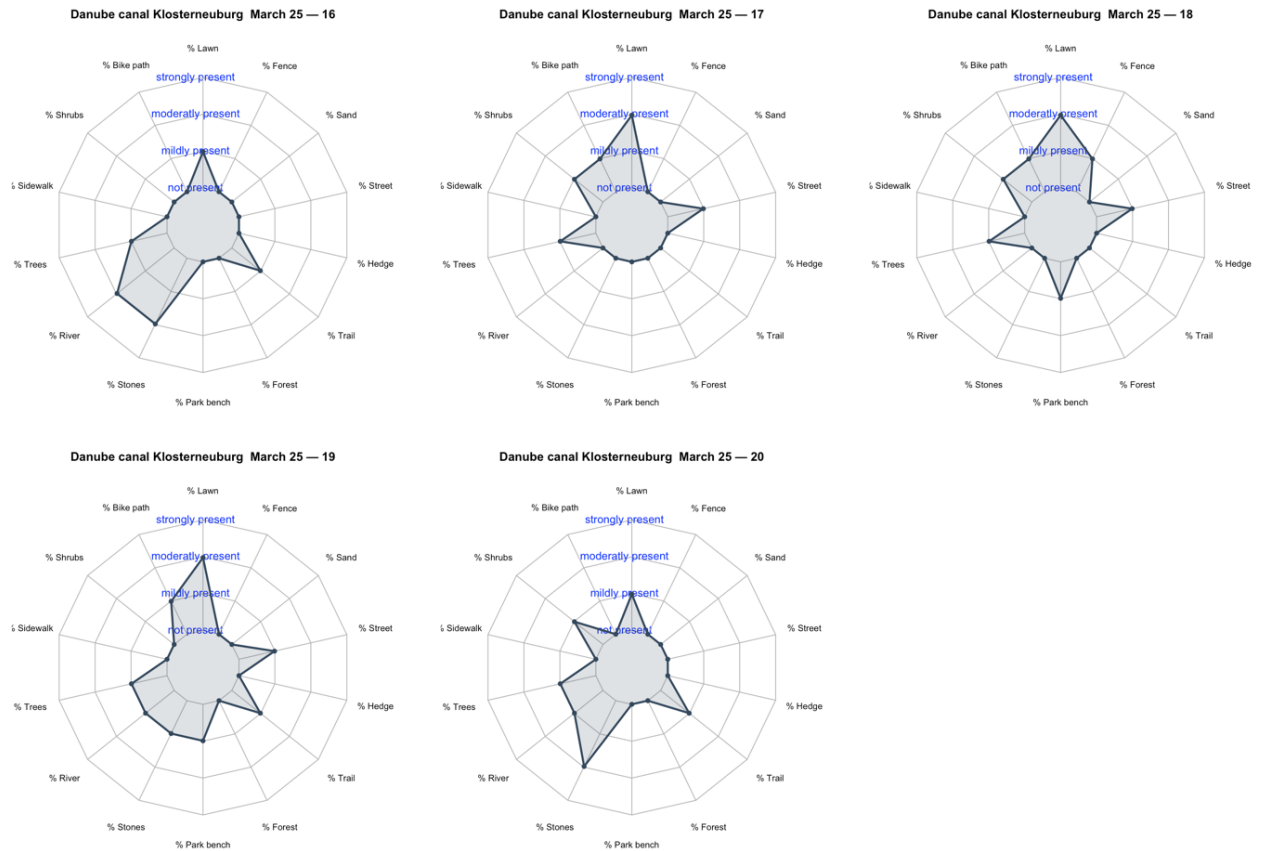


Figure 8 „Site Danube canal Klosterneuburg March 25”: Radar plots showing the relative presence of habitat attributes across the five observation sites per study location. Each axis represents a specific environmental attribute, while the color intensity indicates the degree of its presence, ranging from not present to strongly present.

At the final study location, the Danube Canal towards Klosterneuburg, *lawn* is a dominant feature appearing across all five radar plots. Similarly, *trees* are consistently present at each site, while *shrubs* occur in three out of five locations. In three of these sites, proximity to the Danube River is evident through the presence of stone-covered riverbanks leading directly to the water. Overall, this area exhibits a

balanced combination of natural elements and clear indicators of human activity, including bike paths, walking trails, park benches, and managed lawn areas.

4.1.5 Summary of Habitat Composition Across All Study Sites

Across all study locations, the radar plots reveal notable differences in habitat composition and the degree of human influence. Sites such as the Augarten and the Danube Island display a higher proportion of natural attributes, including forested areas, shrubs, and riverbank vegetation, indicating a greater level of habitat diversity. In contrast, locations along the Danube Canal - particularly towards Klosterneuburg - show a stronger presence of anthropogenic elements such as bike paths, sidewalks, and managed lawns. These visual comparisons highlight the gradient between natural and urbanized environments within Vienna's urban landscape and provide an important contextual foundation for interpreting bird feeding behavior in relation to habitat diversity.

4.2 Feeding behaviour across sites

The first research question this study addressed was the amount of food that local birds consumed across the four study sites. This information is illustrated in Figure 9, titled *"Feeding behaviour across sites."*

In this figure, the y-axis represents the amount of bird seed consumed, measured in centimeters, using a scale with five-centimeter intervals. The x-axis represents the observation period, covering eight days with measurements taken every two days (days 0, 2, 4, 6, and 8).

The dashed lines indicate individual feeding stations, with ten per site corresponding to the ten feeders installed in each location. The solid bold line represents the mean food consumption for each site, providing an overview of average feeding activity.

The legend, located on the right side of the graph, identifies each study site by color and alphabetical order: red for *Augarten*, green for the *Danube Canal towards Klosterneuburg*, blue for the *Danube Canal towards the city center*, and purple for the *Danube Island*.

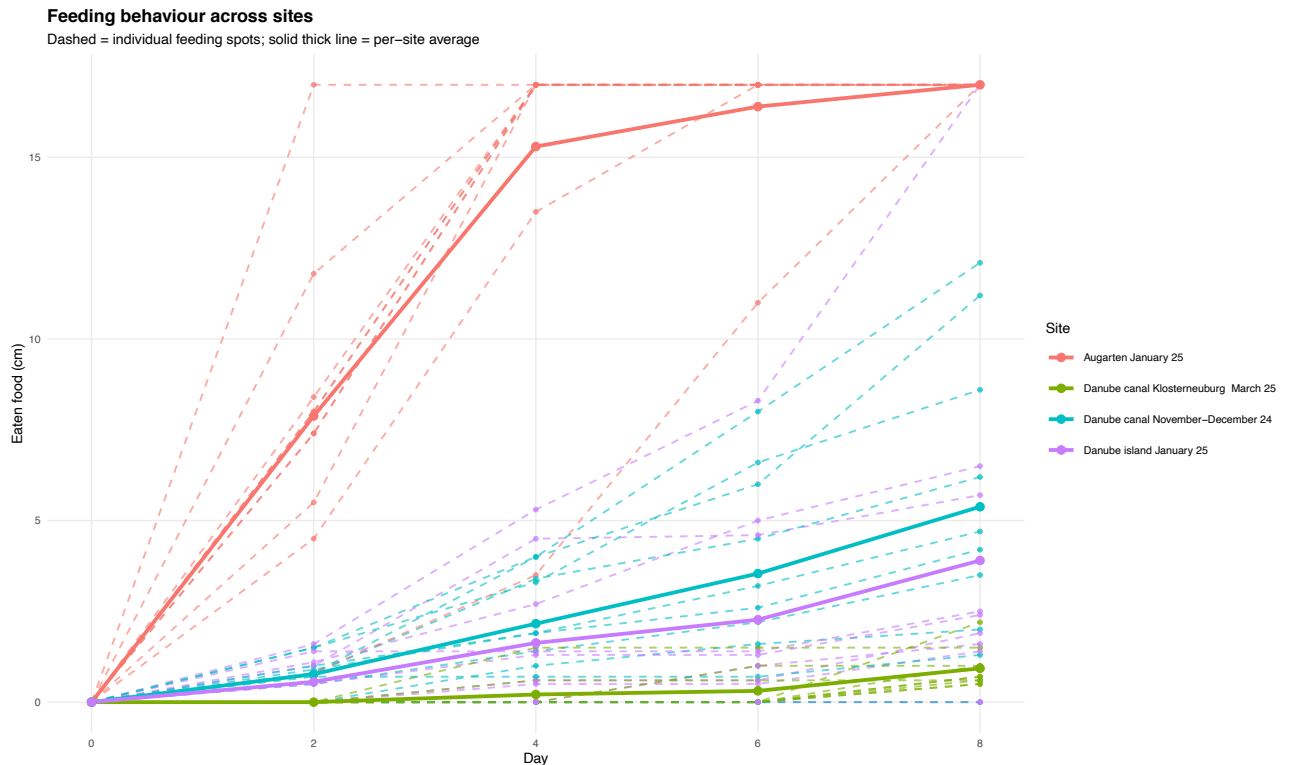


Figure 9: “Feeding behaviour across sites”. The y-axis indicates the amount of food consumed (in centimeters), displayed in 5-centimeter intervals. The x-axis represents the observation period from day 0 to day 8, with measurements taken at two-day intervals. Dashed lines correspond to individual feeding stations, while the solid bold line represents the average food consumption per site. The figure illustrates variation in feeding activity across locations, suggesting site-specific differences in food consumption and feeder use among local bird populations.

4.2.1 Danube Canal towards City center

For the first study site, observations were conducted along the Danube Canal between November and December 2024. At this location, the birds initially required some time to adjust to the newly installed feeding stations, suggesting a short

acclimation period before regular feeder use began. Among all feeding stations, station no. 3.1 showed the highest level of food consumption, with a total of 12 cm of seed consumed during the observation period.

For this site, both the total and the average food consumption per feeder were analyzed to assess overall feeding activity and potential spatial differences between individual feeders. These results provide a basis for later comparisons with other locations and for examining possible environmental influences on feeding behavior in the discussion section.

Number of the feeding station	Average food consumption in centimeters	Total food consumption in centimeters after 8 days
1.1	0,875 cm	3,5 cm
1.2	0,5 cm	2 cm
2.1	0 cm	0 cm
2.2	0,325 cm	1,3 cm
3.1	3,025 cm	12,1 cm
3.2	1,05 cm	4,2 cm
4.1	1,55 cm	6,2 cm
4.2	2,8 cm	11,2 cm
5.1	2,15 cm	8,6 cm
5.2	1,175 cm	4,7 cm

Table 6: this table shows the average food consumptions and the total food consumption in centimeters of the Danube canal towards city center after 8 days from feeding station number 1 to 5.

However, in contrast to expectations, this site did not show the highest Shannon-Wiener diversity index. This indicates that food consumption at this location was not directly related to habitat diversity (as shown in Table 1 *Habitats diversity index*)

One possible explanation for this result could be that factors other than structural habitat diversity influenced the birds' feeding activity. For example, proximity to

human activity, the degree of shelter, or the visibility of the feeders may have played a more significant role than overall habitat heterogeneity. Furthermore, it is possible that specific species present at this location were more dominant or better adapted to urban environments, leading to higher food consumption despite lower environmental diversity.

4.2.2 Augarten

For the second study site, observations were conducted at Augarten in January 2025.

At this location, the results were particularly striking, as every feeding station was completely emptied by the end of the observation period. Each feeder had a maximum fill height of 17 cm, and as shown in the graph, all dashed lines reach this upper limit, indicating full food consumption across all stations.

Given this uniform pattern, special attention was directed toward the average feeding activity, represented by the solid bold line, to better illustrate overall consumption trends at the site.

In the Augarten dataset, feeding stations were labeled from 6 to 10, with each position including two feeders: one suspended lower (*n.1*) and one positioned higher (*n.2*), allowing for direct comparison of feeding preferences relative to feeder height.

Number of the feeding station	Average food consumption in centimeters	Total food consumption in centimeters after 8 days
6.1	8,5 cm	17 cm
6.2	17 cm	17 cm
7.1	4,25 cm	17 cm
7.2	8,5 cm	17 cm
8.1	8,5 cm	17 cm
8.2	8,5 cm	17 cm
9.1	5,66 cm	17 cm
9.2	8,5 cm	17 cm
10.1	8,5 cm	17 cm
10.2	8,5 cm	17 cm

Table 7: this table shows the average food consumption in centimeters of the Augarten site with number 6 to 10 of the feeding stations and the total food consumption in centimeters after 8 days.

When comparing the average food consumption data with the habitat diversity index (as shown in Table 1, page 17), it becomes evident that the highest Shannon-Wiener Index value was recorded at feeding station no. 6 in Augarten. Correspondingly, this location also exhibited the highest average food consumption among all observed stations. This alignment between habitat diversity and feeding activity suggests a positive correlation, indicating that areas with greater structural and environmental diversity may provide more favorable conditions for native birds and thus promote higher feeder usage.

4.2.3 Danube island

The third study site, located on the Danube Island, was observed in January 2025. Similar to the Danube Canal site, birds required some time to adjust to the feeding stations. Feeding station 13.2 showed the highest activity, with 17 cm of seed consumed, indicating it was completely emptied.

Both total and average food consumption per feeder were analyzed to assess overall feeding activity and spatial differences between stations. Comparison with the Shannon-Wiener Index (*Table 1*) shows that, although 13.2 was the most visited feeder, it did not have the highest habitat diversity index (1.0048), ranking second after feeder 12 (1.6888), suggesting that habitat diversity alone did not fully determine feeder use.

Feeding station 12 at the Danube Island exhibited the highest Shannon-Wiener Index of all feeders across the entire study, indicating the greatest habitat diversity at this location. This demonstrates that, within the project, station 12 provided the most structurally and environmentally diverse conditions for visiting birds.

Number of the feeding station	Average food consumption in centimeters	Total food consumption in centimeters after 8 days
11.1	0,475 cm	1,9 cm
11.2	0,35 cm	1,4 cm
12.1	0,625 cm	2,5 cm
12.2	0,4 cm	1,6 cm
13.1	1,625 cm	6,5 cm
13.2	4,25 cm	17 cm
14.1	0 cm	0 cm
14.2	0,6 cm	2,4 cm
15.1	0 cm	0 cm
15.2	0 cm	0 cm

Table 8: this table shows the average food consumption in centimeters of the Danube island site with number 11 to 15 of the feeding stations and the total food consumption in centimeters after 8 days.

4.2.4 Danube canal towards Klosterneuburg

For the final study site, observations were conducted along the Danube Canal towards Klosterneuburg in March 2025. This site showed the lowest total and average food consumption among all locations. Several factors may have contributed to this pattern, including proximity to a major road, high levels of human activity, and the relatively warmer temperatures in March compared to the winter months.

Number of the feeding station	Average food consumption in centimeters	Total food consumption in centimeters after 8 days
16.1	0,375 cm	1,5 cm
16.2	0,25 cm	1 cm
17.1	0,125 cm	0,5 cm
17.2	0,175 cm	0,7 cm
18.1	0,15 cm	0,6 cm
18.2	0,55 cm	2,2 cm
19.1	0,175 cm	0,7 cm
19.2	0,25 cm	1 cm
20.1	0,125 cm	0,5 cm
20.2	0,15 cm	0,6 cm

Table 9: this table shows the average food consumption in centimeters of the Danube canal towards Klosterneuburg site with number 16 to 20 of the feeding stations and the total food consumption in centimeters after 8 days.

When comparing food consumption with the Shannon-Wiener Index, feeding station 18 exhibited the highest habitat diversity index (1.484) at this site. The average and total food consumption at feeder 18.2 corresponded with this high index value, suggesting a positive relationship between habitat diversity and feeding activity at this location.

4.3 Correlation

4.3.1 Consumed food by interval and site (Low vs High) (box plots)

In this experiment, two feeding stations were installed per tree, positioned approximately one meter apart vertically, with one feeder placed higher than the other. The aim was to investigate whether feeder height influences bird feeding activity, under the assumption that the higher-positioned feeder is more protected and less exposed than the lower one.

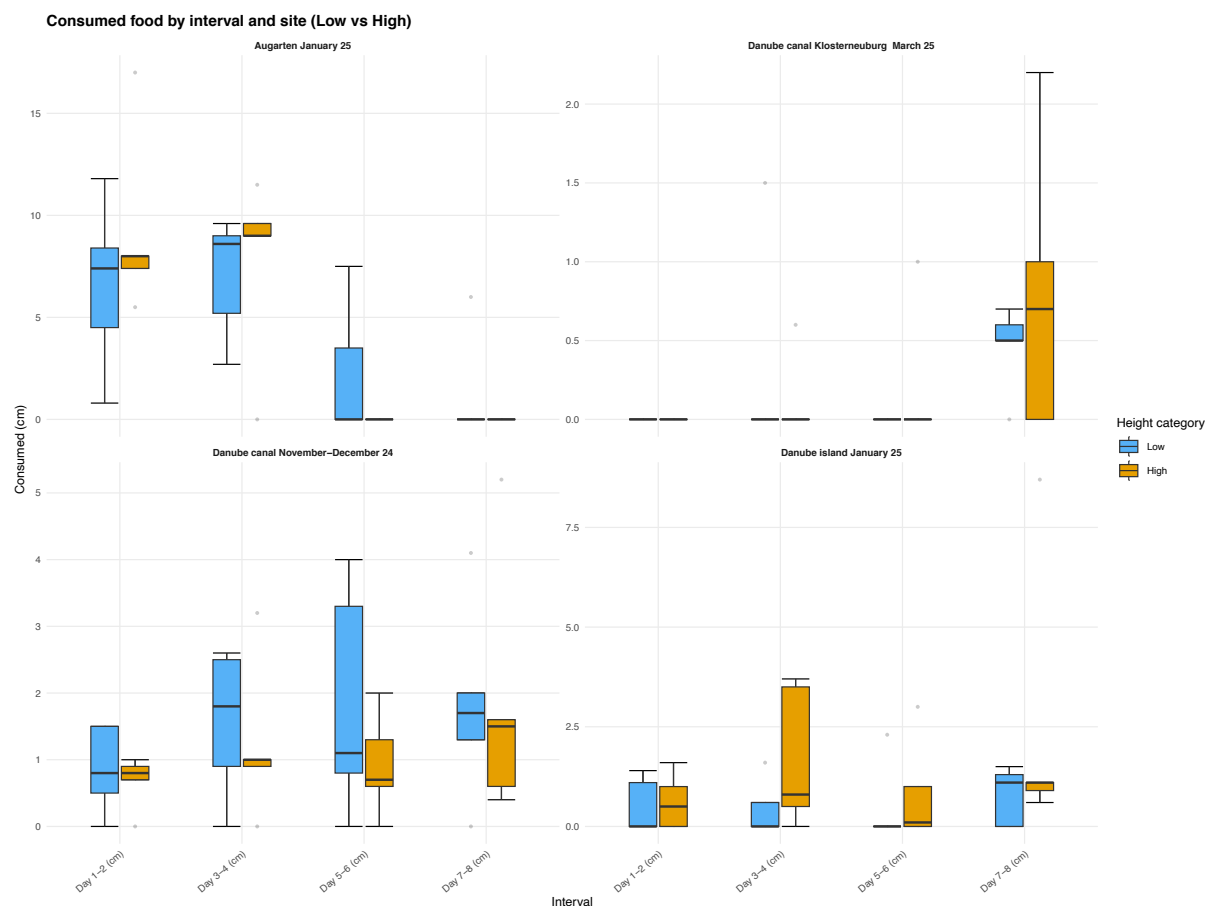


Figure 10 „Consumed food by interval and site (Low vs High): In this boxplot lower-positioned feeders are shown in blue and higher-positioned feeders are shown in yellow. The y-axis represents the amount of bird seed consumed in cm and the x-axis indicates the observation period in two-day intervals, up to eight days. The dark black line shows the median food consumption across all feeders at each site. The lower whisker of the boxplot represents the minimum bird seed consumption, while the upper whisker indicates the maximum value. The blue or yellow box illustrates the interquartile range (IQR), which encompasses the lower quartile (Q1), the median, and the upper quartile (Q3).

This graphical representation allows for an effortless comparison of variation and general trends in feeding activity between the lower and higher feeders across different study sites.

The results suggest that the vertical positioning of the feeders did not substantially influence feeding activity. As indicated by the median food consumption values, birds showed no consistent preference for either the lower or the higher feeders, implying that feeder height was not a determining factor in their feeding behavior.

4.3.2 Consumed food vs feeding height (scatter plots)

For this analysis, the Danube Canal and Danube Island were selected, as they provide the clearest and most visually representative patterns. The y-axis shows the amount of bird seed consumed (in centimeters, 1 cm increments), and the x-axis shows the feeding station height (in meters, 0.25 m increments). Each point represents an individual feeder. The correlation coefficient (r) indicates the strength and direction of the relationship (for example +1 would be a perfect positive correlation, -1 a perfect negative correlation and 0 no linear correlation), while the p-value (p) indicates statistical significance, with $p < 0.05$ suggesting a non-random correlation. The shaded blue area represents the 95% confidence interval, and the central line depicts the linear regression trend between feeder height and food consumption.

4.3.2.1 Danube canal towards City center

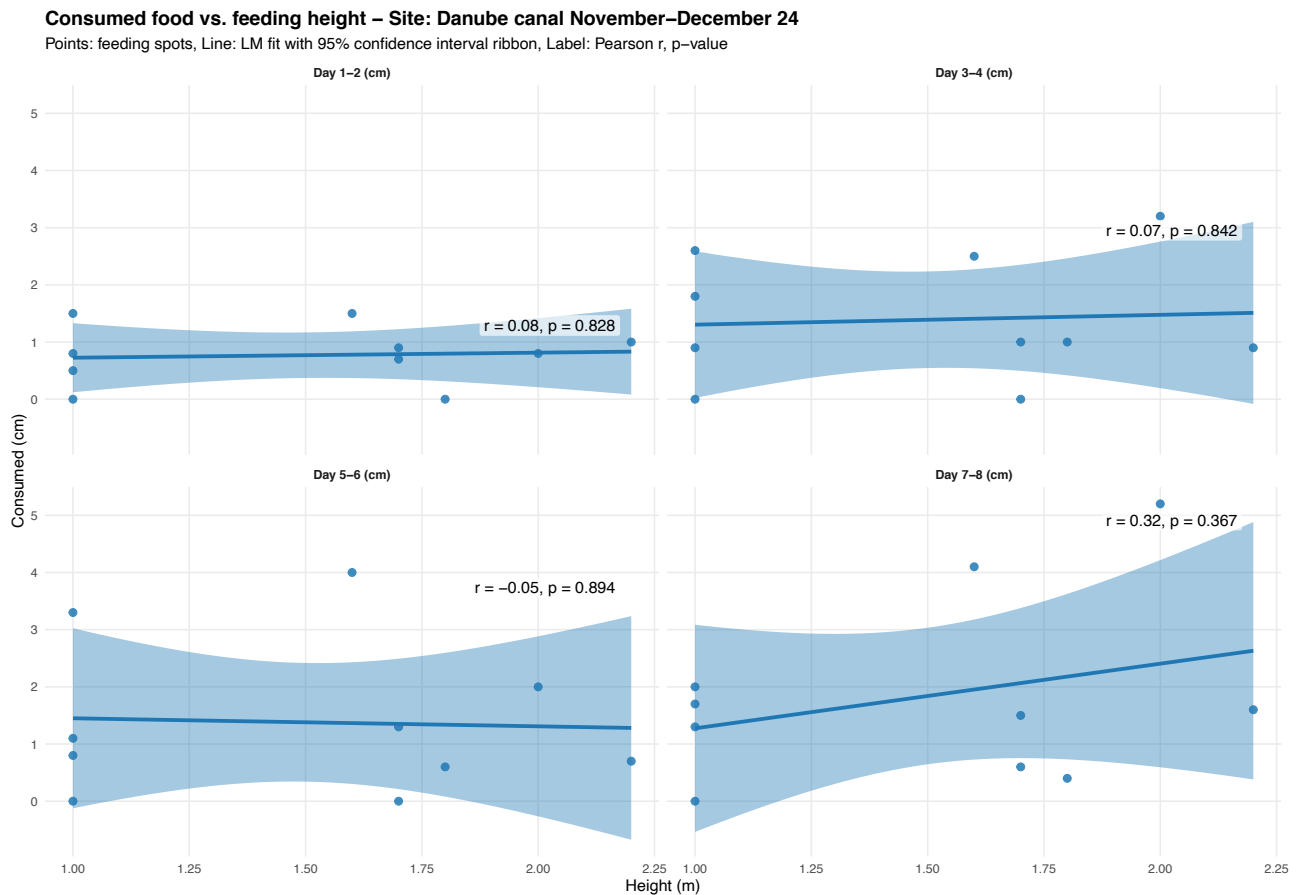


Figure 11 „Consumed food vs. Feeding height - Site: Danube canal November – December 24: The y-axis shows the amount of bird seed consumed (cm), and the x-axis the feeder height (m, 0.25 m increments). Each dot represents a feeding station. The correlation coefficient (r) indicates the strength and direction of the relationship, and the p-value (p) shows its significance. The blue shaded area shows the 95% confidence interval, and the central line depicts the linear regression trend.

In this scatter plot from the Danube Canal towards the city center, a linear trend in food consumption can be observed. A p-value (p) below 0.05 would indicate a statistically significant, non-random correlation. However, in this case, the p-value exceeds 0.05, suggesting that the relationship between feeder height and food consumption is not statistically significant and may be due to random variation. The correlation coefficient (r) is positive, indicating a positive, albeit non-significant, trend.

4.3.2.2 Danube island

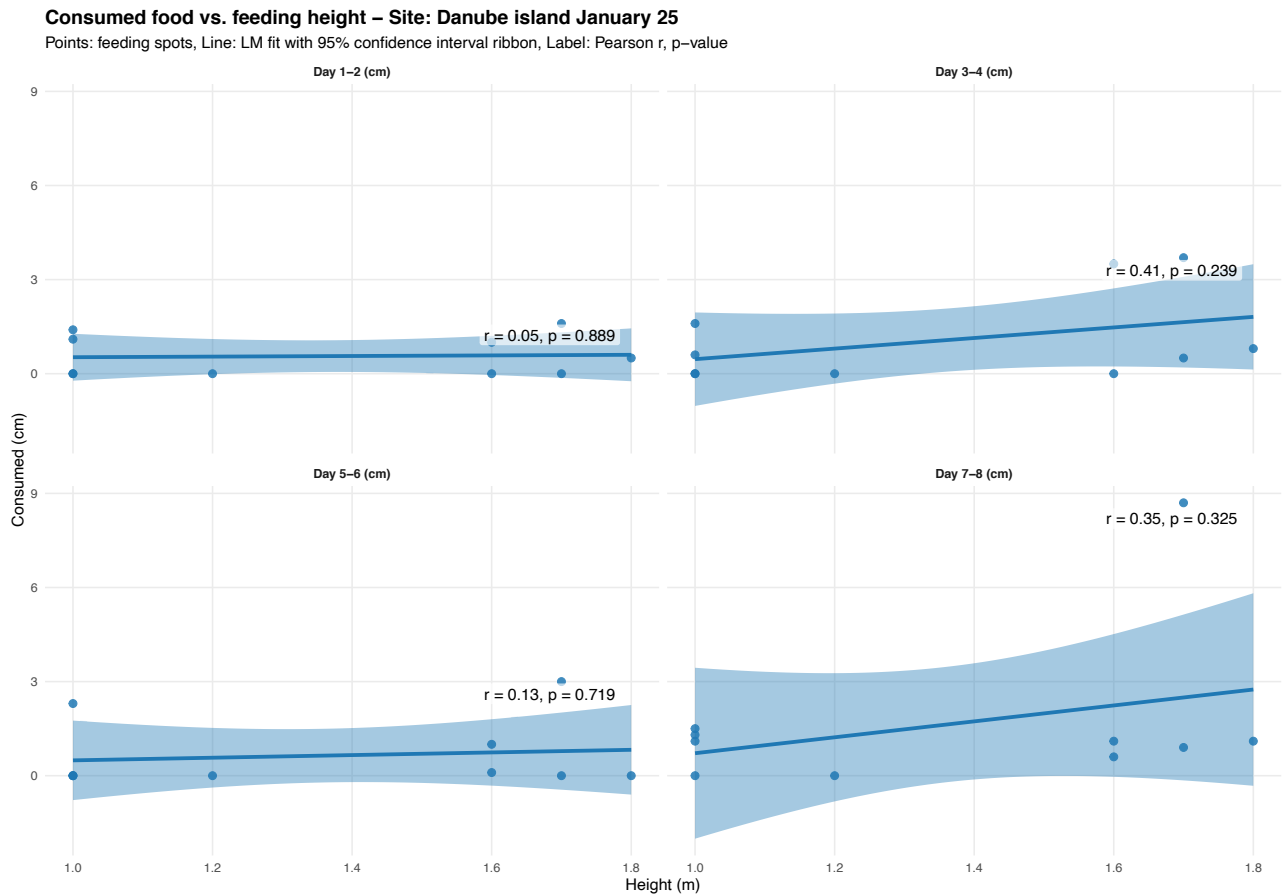


Figure 12 „Consumed food vs. Feeding height - Site: Danube island January 25”: The y-axis shows the amount of bird seed consumed (cm), and the x-axis the feeder height (m, 0.25 m increments). Each dot represents a feeding station. The correlation coefficient (r) indicates the strength and direction of the relationship, and the p -value (p) shows its significance. The blue shaded area shows the 95% confidence interval, and the central line depicts the linear regression trend.

Similar to the Danube Canal example, a slight linear trend in food consumption is observed at the Danube Island. The p -value is above 0.05, indicating that the relationship between feeder height and food consumption is not statistically significant and may be due to random variation. The correlation coefficient (r) remains positive across all eight days of the experiment, reflecting a positive, albeit non-significant, trend.

4.3.2.3 Summary of Feeder Height Effects

Across both the Danube Canal and Danube Island sites, feeder height showed a slight positive association with food consumption. However, in both cases, the correlation was not statistically significant, indicating that feeder height did not have a clear or consistent effect on the amount of food consumed.

4.3.3 Consumed food vs location attributes (scatter plots)

Next, food consumption was analyzed in relation to habitat attributes using scatter plots. The y-axis shows the average food consumed per location (cm), and the x-axis shows the habitat attribute (%) for each feeder pair. The correlation coefficient (r), p-value (p), shaded blue area (95% confidence interval), and central line (linear regression) are interpreted as described for the previous plots.

4.3.3.1 attribute relations – Site: Danube canal November-December 24

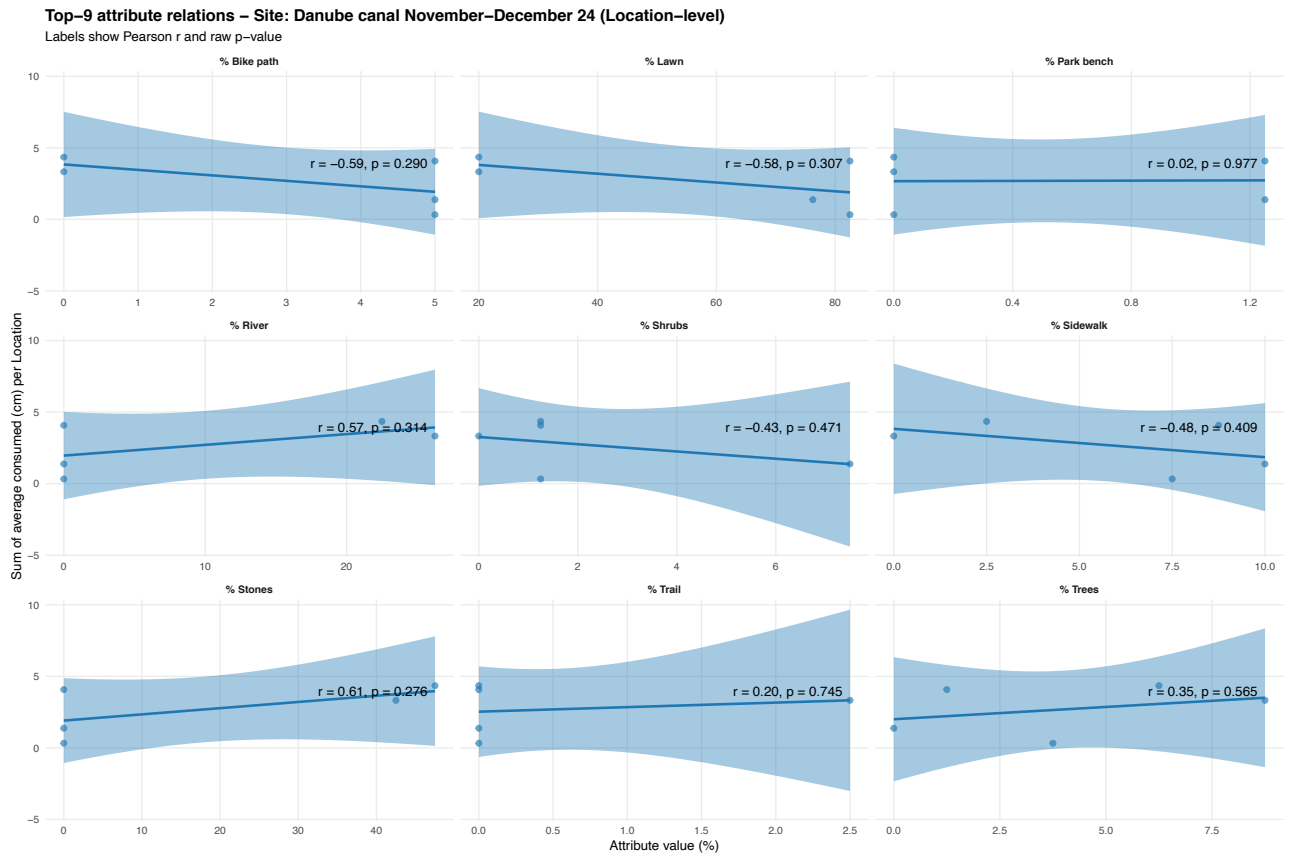


Figure 13 “9 attribute relations - Site: Danube Canal November-December 24”: This scatter plot shows the relationship between habitat attributes and average food consumption per feeder pair. The y-axis represents consumed food (cm), and the x-axis shows the percentage of each habitat attribute. The correlation coefficient (r), p -value (p), shaded blue area (95% confidence interval), and central regression line are interpreted as described for previous scatter plots.

In this example from the Danube Canal site towards the city center, nine habitat attributes were considered: bike paths, lawn, park bench, river, shrubs, sidewalk, stones, trail and trees. The scatter plot shows a positive correlation between food consumption and the presence of rivers, stones, trails and trees, suggesting that feeders located in areas with these natural features experience less human disturbance. Conversely, attributes such as bike paths, lawn, and sidewalk display a negative correlation with food consumption, indicating that higher levels of human activity may interfere with the feeding behavior of local birds.

4.3.3.2 attribute relations - Site: Augarten

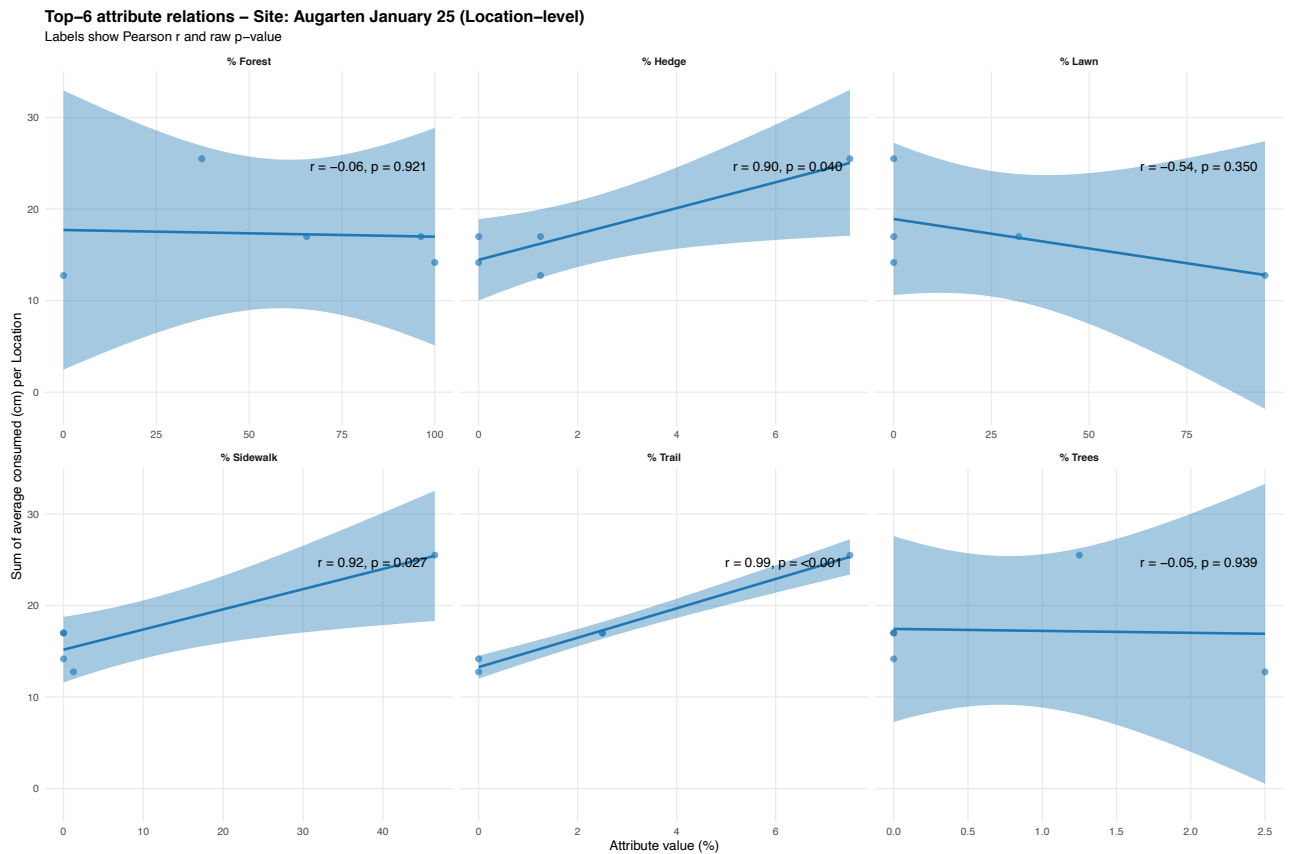


Figure 14 “6 attribute relations – Site: Augarten January 25”: This scatter plot shows the relationship between habitat attributes and average food consumption per feeder pair. The y-axis represents consumed food (cm), and the x-axis shows the percentage of each habitat attribute. The correlation coefficient (r), p -value (p), shaded blue area (95% confidence interval), and central regression line are interpreted as described for previous scatter plots.

At the Augarten site, the results differ from other locations. As shown in Figure 14, not only natural habitat features such as hedges are positively associated with feeding behavior, but certain human-made features, including sidewalks and trails, also show a positive correlation. These findings suggest that local birds in the Augarten exhibit lower neophobia compared to birds at other sites. Observations during the experiment indicate that the birds here are well accustomed to human presence and show curiosity toward it. Additionally, several other feeding stations

maintained by people were observed in the area, which may contribute to this reduced fear and increased feeding activity. Therefore, the results at the Augarten site likely reflect the birds' habituation to human activity.

4.3.3.3 attribute relations – Site: Danube island

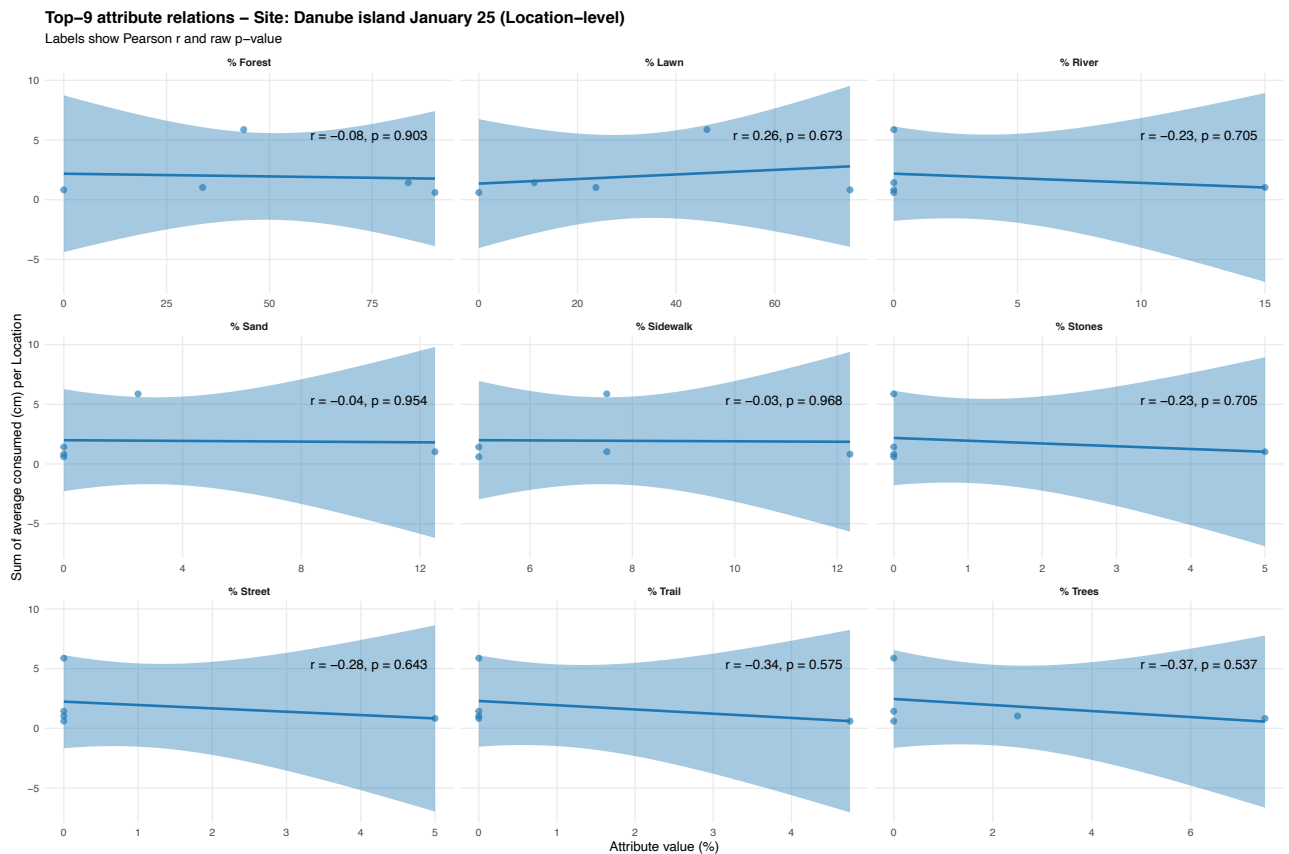


Figure 15 “9 attribute relations – Site: Danube island January 25”: This scatter plot shows the relationship between habitat attributes and average food consumption per feeder pair. The y-axis represents consumed food (cm), and the x-axis shows the percentage of each habitat attribute. The correlation coefficient (r), p -value (p), shaded blue area (95% confidence interval), and central regression line are interpreted as described for previous scatter plots.

The Danube Island site shows no clear or direct correlation between the various habitat attributes present at the sites and the amount of bird food consumed. While some natural features such as forested areas and river proximity appear to slightly favor feeding activity, the overall pattern is inconsistent, suggesting that multiple

factors - including both natural and human-related elements - may interact to influence bird feeding behavior at this location.

4.3.3.4 attribute relations – Site: Danube canal Klosterneuburg

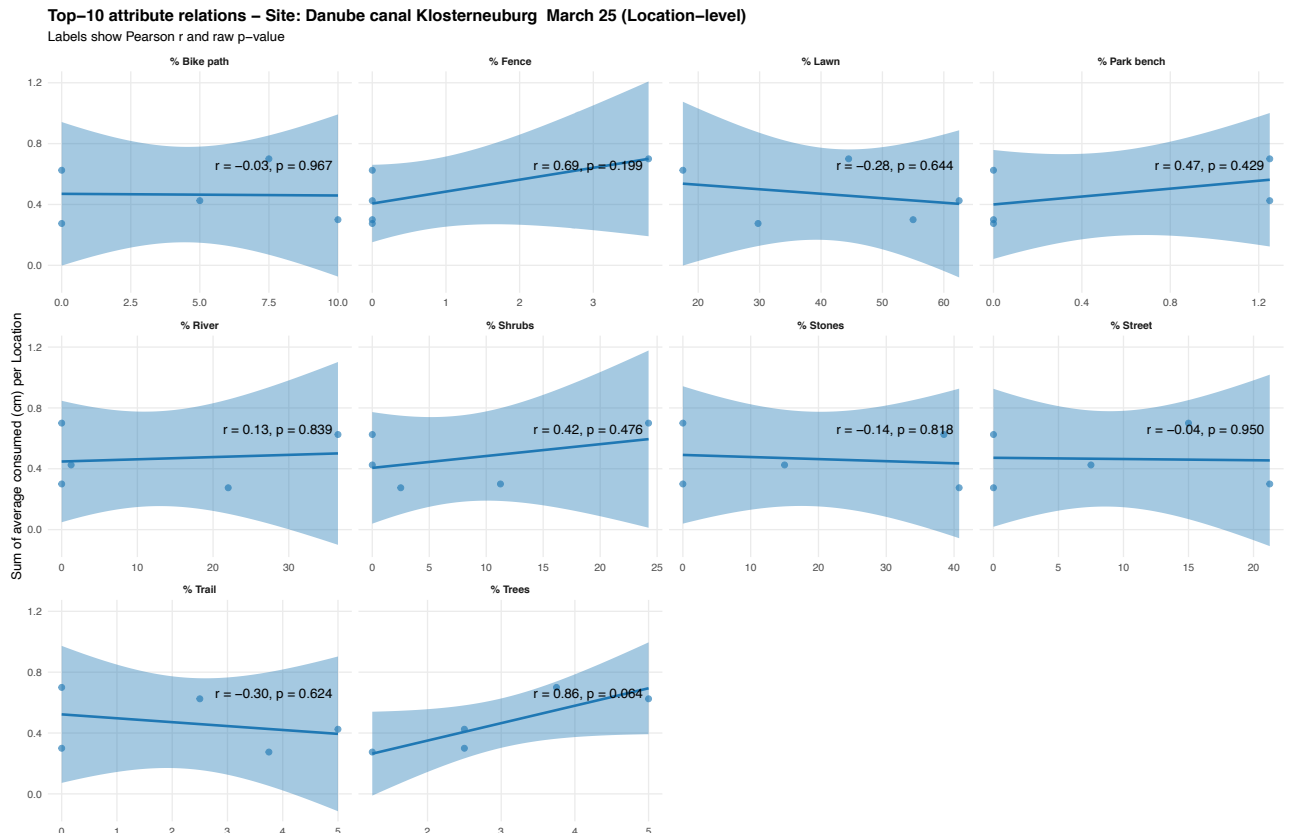


Figure 16 “10 attribute relations – Site: Danube canal Klosterneuburg March 25”: This scatter plot shows the relationship between habitat attributes and average food consumption per feeder pair. The y-axis represents consumed food (cm), and the x-axis shows the percentage of each habitat attribute. The correlation coefficient (r), p-value (p), shaded blue area (95% confidence interval), and central regression line are interpreted as described for previous scatter plots.

At the final location, the Danube Canal towards Klosterneuburg, clear patterns emerge in the relationship between habitat attributes and bird feeding behavior. Natural features such as shrubs and trees show a positive association with food consumption, whereas lawn and park benches exhibit a negative correlation, reflecting the influence of human activity. An interesting case is the presence of a

fence, which appears to mitigate the impact of the nearby street by providing a protective barrier and offering shelter to the birds from both traffic and pedestrians.

4.3.4 Correlation of average food consumption with attributes across locations

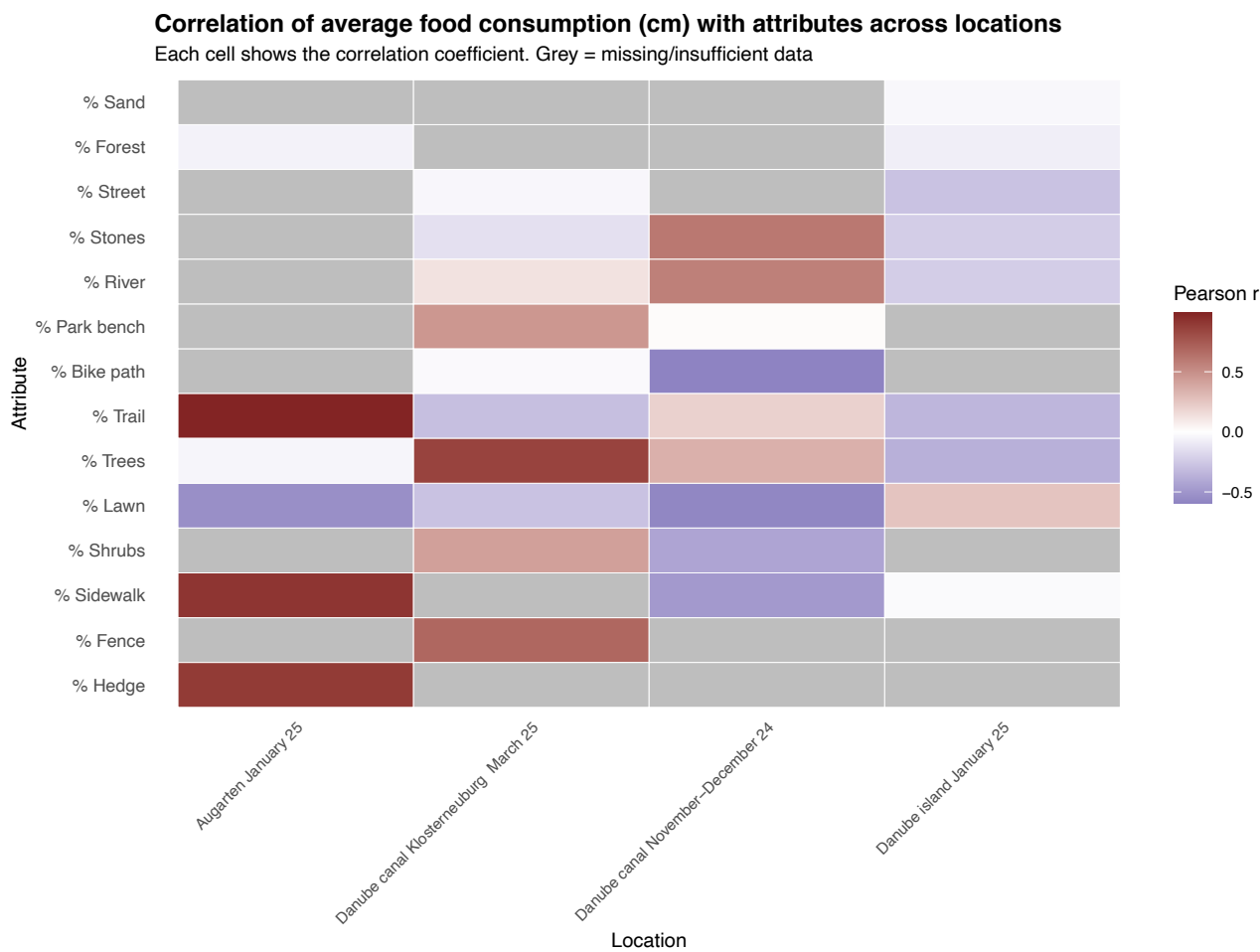


Figure 17 „Correlation of average food consumption (cm) with attributes across locations“: The heatmap illustrates correlations between habitat attributes and feeding behavior across all study sites. The y-axis lists habitat attributes, and the x-axis shows the five locations in alphabetical order. Colors represent the correlation coefficient (r), from strong positive (red) to weak or negative (purple), with grey indicating missing data.

To provide a clearer visual comparison of habitat attributes across all study sites, a heatmap was created to display the relationships between habitat characteristics and feeding behavior.

Trails, sidewalks, and hedges show the strongest positive correlations in the Augarten, while lawns show the weakest relationship.

At the Danube Canal towards Klosterneuburg, trees, fences, park benches, and proximity to the river show the highest correlations, whereas trails and lawns display lower or negative ones.

For the Danube Canal near the city center, stones and the river show the strongest positive correlations, followed by trees and trails, while bike paths, lawns, shrubs, and sidewalks show negative trends.

Finally, at the Danube Island, no clear or consistent correlation between habitat attributes and feeding activity could be identified.

4.3.5 Sum of average consumption vs. attribute presence – ALL SITES

In this final scatter plot, all recorded habitat attributes are compared with the average food consumption across study sites. The plot provides an overall overview of which environmental features are associated with increased or decreased feeding activity among local birds. Attributes such as forests, hedges, and trails show a positive correlation with food consumption, suggesting that these natural or semi-natural elements support bird presence and feeding behavior. In contrast, attributes like bike paths, lawns, park benches, the river, shrubs, stones, streets, and trees exhibit negative correlations, indicating that areas with higher human activity or limited shelter tend to reduce feeding activity.

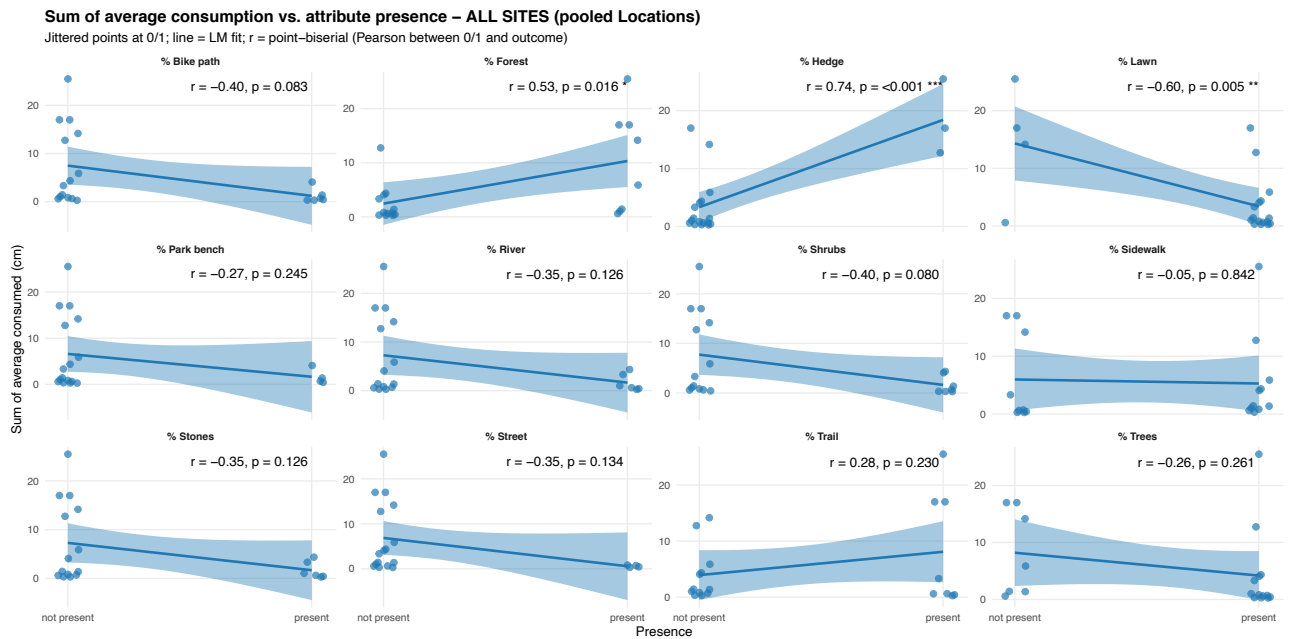


Figure 18 „Sum of average consumption vs. Attribute presence”: Scatter plot showing the relationship between average food consumption and various habitat attributes. The y-axis represents consumed food (cm), and the x-axis shows the percentage of each habitat attribute. The correlation coefficient (r), p-value (p), shaded blue area (95% confidence interval), and central regression line are interpreted as described for previous scatter plots.

4.3.6 Principal components/ factor analysis of habitat composition

4.3.6.1 Total variance

components	Initial eigenvalues			Sums of squared factor loadings for extraction			Rotated sum of the squared charges		
	total	% the variance	Cumulative %	total	% the variance	Cumulative %	total	% the variance	Cumulative %
1	3,860	29,694	29,694	3,860	29,694	29,694	2,801	21,545	21,545
2	2,981	22,932	52,626	2,981	22,932	52,626	2,741	21,081	42,625
3	1,936	14,859	67,521	1,936	14,895	67,521	2,319	17,838	60,463
4	1,277	9,826	77,346	1,277	9,826	77,346	2,088	16,062	76,525
5	1,038	7,986	85,332	1,038	7,986	85,332	1,145	8,807	85,332

Table 10: The table shows the initial eigenvalues, sums of squared factor loadings for extraction, and rotated sums of the squared loadings from a principal components analysis (PCA). Five components were extracted, collectively explaining approximately 85.3% of the total variance in the dataset.

4.3.6.2 rotated component matrix

	components				
	1	2	3	4	5
Lawn	,139	-,101	-,168	,941	-,023
Bike path	,834	-,144	-,094	,385	-,109
Shrubs	,909	-,021	-,096	,066	-,013
Sidewalk	-,120	-,121	,934	,105	,129
Trees	,075	,803	-,031	,283	,131
River	-,184	,903	-,121	-,214	,069
Park bench	-,158	,916	-,123	-,160	-,187
Forest	,466	-,170	-,041	,474	-,294
Trail	-,316	-,599	-,066	-,707	,009
Hedge	-,087	-,007	,673	-,374	-,395
Street	-,066	-,092	,951	-,117	-,027
Sand	,919	-,001	-,069	,044	,017
fence	-,081	-,004	-,026	-,080	,903

Table 11: The table displays the loadings of each variable on the five components after Varimax rotation. These values indicate the strength and nature of the relationship between the observed variables (listed in the rows) and the underlying latent components (listed in the columns).

To reduce the complexity of the habitat dataset and highlight the main environmental gradients around the feeding stations, a principal components analysis (PCA) with was conducted using thirteen ground-cover and structural variables (lawn, shrubs, bike path, sidewalk, trees, river, park bench, forest, trail, hedge, street, sand, fence). The analysis identified five components with eigenvalues greater than one, together accounting for 85.3% of the variation in habitat composition across the 40 sites. The first component (PC1) was associated with high loadings for bike paths, shrubs, and sand, as well as a smaller contribution from forest, while areas with informal trails, riverbank sections, and benches were represented by low loadings. This component reflects a gradient characteristic of shrub- and sand-dominated edge habitats. The second component (PC2) showed strong positive loadings for trees, the river, and benches, and a notable negative loading for trails, capturing a transition from structured riverfront park areas to more informal, trampled sections. The remaining components represented an urban-infrastructure gradient (street, sidewalk, hedge), an open lawn-forest gradient, and the presence of fences. Overall, the results indicate that the surroundings of the feeding stations were structured by a small number of ecologically interpretable gradients rather than by independent variation in individual habitat attributes.

4.3.7 Location vs. feeder height

source	Type III SS	df	Mean square	F	Sig.
Corrected model	1751,085 ^a	20	87,554	13,304	<,001
Constant	76,968	1	76,968	11,695	,003
Hight	4,490	1	4,490	,682	,419
Site	1730,974	19	91,104	13,843	<,001
Error	125,045	19	6,581		
Total	3727,090	40			
Corrected total	1876,130	39			
a. R-squared = ,933 (adjusted R-squared = ,863)					

Table 12: The table presents the results from the Type III sums of squares ANOVA, evaluating the effects of the Hight (height) and Site variables on the dependent variable. The model explains a significant proportion of variance in the dependent measure ($R^2=.933$, adjusted $R^2= .863$), with both factors showing a statistically significant effect ($p < .001$ for Site, $p = .003$ for Constant).

To assess whether feeding rates were influenced more by the vertical placement of the feeders or by their broader location in the landscape, a general linear model was used. Total seed consumption after eight days and average daily consumption served as response variables, while feeder height (low vs. high) and site location were included as fixed factors. In both models, location had a strong and highly significant effect on feeding activity ($F = 13.30 - 13.84$, $p < 0.001$). In contrast, feeder height showed no meaningful influence on either total or average consumption ($F = 0.68$, $p = 0.42$).

Overall, the models explained 93.3% of the variation in feeding rates (adjusted $R^2 = 0.86$), indicating that differences between sites accounted for nearly all variation in seed removal. These results align with the descriptive patterns reported earlier: some locations, such as the Augarten or central sections of the Danube Canal, consistently showed higher feeding activity, while others, including more northern sites along the Danube Canal towards Klosterneuburg, showed much lower use. The analysis also confirms that a vertical separation of roughly one meter between feeders is not sufficient to produce systematic differences in feeding behaviour.

Feeding activity differed strongly between locations but was not influenced by feeder height. The general linear model showed that site identity explained most of the variation in both total and average food consumption, whereas the vertical separation of feeders had no significant effect. Feeding rates were highest at sites such as the Augarten and the Danube Canal near the city centre and lowest towards Klosterneuburg, highlighting the dominant role of location over feeder height.

4.3.8 Habitat diversity and average food consumption

4.3.8.1 Model summary

Model	R	R-Squared	Adjusted R-Squared	Std. Error
1	,354 ^a	,125	,102	1,643059
a. predictors: (Constant), habitat diversity				

Table 13: The table displays the results of the regression analysis, including the multiple correlation coefficient ($R = .354$), the coefficient of determination ($R^2 = .125$), and the adjusted coefficient of determination ($\text{Adj. } R^2 = .102$). The independent variable habitat diversity explains approximately 12.5% of the variance in the dependent variable.

4.3.8.2 ANOVA

Model	Square Sum	df	Mean of the quadrants	F	Sig.
Regression	14,672	1	14,672	5,435	,025 ^b
Residual	102,586	38	2,700		
Total	117,258	39			
a. dependent variable: averageperday					
b. Predictors: (Constant), habitat diversity					

Table 14: The table displays the results of the ANOVA for the dependent variable averageperday, examining the effect of habitat diversity. The regression model is statistically significant ($F(1,38) = 5,435$, $p = .025$). The total sum of the squares is 117.258 with 39 degrees of freedom.

To examine the relationship between structural habitat diversity and feeder use, mean daily seed consumption was related to the Shannon-Wiener habitat diversity index (H), calculated for the 10 m radius surrounding each feeder pair. The linear regression revealed a significant positive association between habitat diversity and feeding rates ($R = 0.354$, $R^2 = 0.125$, $F_{1,38} = 5.44$, $p = 0.025$), indicating that feeders located in more diverse microhabitats were used more intensively. As habitat diversity increased, birds removed more food per day on average, suggesting that

structurally heterogeneous surroundings promote higher feeder acceptance. This pattern is consistent with the descriptive results, where feeding stations in habitat-rich environments, such as Augarten Site 6 and Danube Island Site 12, showed higher visitation rates and faster depletion of food compared to feeders placed in more uniform settings.

When additional microhabitat variables describing vertical structure, including distance to cover, canopy cover above the feeder and vegetation height, were included in a stepwise regression, habitat diversity remained the only variable retained in the final model. This indicates that, within this dataset, overall ground-level habitat diversity is a stronger predictor of feeder use than individual measures of vertical cover.

4.3.9 PCA components as predictors of feeder use

4.3.9.1 Model summary

Model	R	R-Squared	Adjusted R-Squared	Std. Error
1	,386 ^a	,149	,127	1,620467
2	,500 ^b	,250	,210	1,541207
a. Predictors: (Constant), REGR factor score 1 for analysis 1				
b. Predictors: (Constant), REGR factor score 1 for analysis 1, REGR factor score 2 for analysis 1				

Table 15: The table displays the results for two regression models. Model 1 shows that the predictor REGR factor score 1 explains approximately 14.9% of the variance ($R^2 = .149$) Model 2, which adds a second predictor REGR factor score 2 explains an increased cumulative variance of 25% ($R^2 = .250$)

4.3.9.2 ANOVA

Model		Squared sum	df	Mean of the quadrants	F	Sig.
1	Regression	17,473	1	17,473	6,654	,014 ^b
	Residuals	99,785	38	2,626		
	Total	117,258	39			
2	Regression	29,371	2	14,686	6,183	,005 ^c
	Residuals	87,887	37	2,375		
	Total	117,258	39			
a. Dependent Variable: averageperday						
b. Predictors : (Constant), REGR factor score 1 for analysis 1						
c. Predictors: (Constant), REGR factor score 1 for analysis 1, REGR factor score 2 for analysis 1						

Table 16: The table displays the ANOVA results for two sequential regression models predicting averageperday. Model1 is statistically significant ($F(1,38) = 6.654$, $p = .014$). Model 2, which includes an additional predictor, is also significant and accounts for more variance in the dependent measure ($F(2,37) = 6.183$, $p = .005$).

To relate the main habitat gradients identified by the PCA to feeding behaviour, the factor scores of the principal components were used as predictors of mean daily seed consumption in a stepwise regression. The final model retained the first two components and explained 25.0% of the variation in feeding rates ($R = 0.500$, $R^2 = 0.250$, adjusted $R^2 = 0.210$, $F_{2,37} = 6.18$, $p = 0.005$), indicating that broad habitat gradients around the feeders influenced how intensively they were used.

The first component described edge-like habitats dominated by shrubs and sandy ground, often combined with bike paths and some forest cover, while the second component represented formal riverbank park sections characterised by trees and park benches but few informal trails. Both components showed significant negative relationships with food consumption (PC1: $\beta = -0.386$, $p = 0.010$; PC2: $\beta = -0.319$, $p = 0.031$), meaning that feeders located at the extreme ends of these habitat gradients were used less intensively. In contrast, feeding stations in more intermediate or mixed habitats along these gradients tended to show higher average food intake. Together with the positive effect of overall habitat diversity, these results

suggest that birds favour structurally varied microhabitats around feeders, rather than habitats dominated by a single, strongly expressed feature.

4.3.10 Multivariate habitat predictors of feeding rates

4.3.10.1 Modelsummary Multiple regression

Model	R	R-squared	Adjusted R-squared	Std. Error
1	,867 ^a	,751	,626	1,059725
a. Predictors: (Constant), Fence, Trees, Sidewalk, Forest, Sand, Lawn, Habitat diversity, Hedge, River, Shrubs, Bike path, Park bench, Street				

Table 17: The table displays the results for the regression model, including the multiple correlation coefficient ($R = .867$), the coefficient of determination ($R^2 = .751$), and the adjusted coefficient of determination ($\text{Adj.}R^2 = .626$). The model includes various predictors related to the environment, such as fences, trees, sidewalks, and habitat diversity.

4.3.10.2 ANOVA

Model		Squared sum	df	Mean of the quadrants	F	Sig.
1	Regression	88,060	13	6,774	6,032	<,001 ^b
	Non-standardized residues	29,198	26	1,123		
	Total	117,258	39			
a. Dependent Variable: averageperday						
b. Predictors: (Constant), Fence, Trees, Sidewalk, Forest, Sand, Lawn, Habitat diversity, Hedge, River, Shrubs, Bike path, Park bench, Str						

Table 18: The table displays the ANOVA results for the regression model predicting the dependent variable averageperday. The model includes numerous predictors such as fences, trees, and habitat diversity. The regression is statistically significant ($F(13,26) = 6.032$, $p < .001$), explaining a significant portion of the variance.

4.3.10.3 Model summary

Model	R	R-squared	Adjusted R-squared	Std Error
1	,452 ^a	,204	,183	1,567369
2	,603 ^b	,363	,329	1,420644
3	,670 ^c	,448	,402	1,340386
4	,756 ^d	,572	,523	1,197814
5	,811 ^e	,658	,608	1,086041
6	,839 ^f	,704	,650	1,025382
7	,833 ^g	,694	,649	1,027074
a. Dependent variable: (Constant), Street b. Dependent variable (Constant), Street, Trail c. Dependent variable: (Constant), Street, Trail, Hedge d. Dependent variable: (Constant), Street, Trail, Hedge, Sidewalk e. Dependent variable: (Constant), Street, Trail, Hedge, Sidewalk, Sand f. Dependent variable: (Constant), Street, Trail, Hedge, Sidewalk, Sand, River g. Dependent variable: (Constant), Street, Hedge, Sidewalk, Sand, River				

Table 19: The table displays the results for seven regression models that sequentially add new environmental predictors. Each subsequent model accounts for an increasing amount of variance in the dependent variables, as indicated by the increase in the Adjusted R^2 value from Model 1 (.183) to Model 7 (.649). The final model incorporates predictors such as streets, trails, hedges, sidewalks, sand, and rivers.

4.3.10.4 ANOVA

Model		Squared sum	df	Mean of the quadrants	F	Sig.
1	Regression	23,906	1	23,906	9,731	,003 ^b
	Non-standardized residues	93,353	38	2,457		
	Total	117,258	39			
2	Regression	42,584	2	21,292	10,550	<,001 ^c
	Non-standardized residues	74,674	37	2,018		
	Total	117,258	39			
3	Regression	52,579	3	17,526	9,755	<,001 ^d
	Non-standardized residues	64,679	36	1,797		
	Total	117,258	39			
4	Regression	67,042	4	16,760	11,682	<,001 ^e
	Non-standardized residues	50,217	35	1,435		
	Total	117,258	39			
5	Regression	77,156	5	15,431	13,083	<,001 ^f
	Non-standardized residues	40,103	34	1,179		
	Total	117,258	39			
6	Regression	82,562	6	13,760	13,087	<,001 ^g
	Non-standardized residues	34,696	33	1,051		
	Total	117,258	39			
7	Regression	81,392	5	16,278	15,432	<,001 ^h
	Non-standardized residues	35,866	34	1,055		
	Total	117,258	39			

a. Dependent Variable: averageperday

b. Predictors: (Constant), Street

c. Predictors: (Constant), Street, Trail

d. Predictors: (Constant), Street, Trail, Hedge

e. Predictors: (Constant), Street, Trail, Hedge, Sidewalk

f. Predictors: (Constant), Street, Trail, Hedge, Sidewalk, Sand

g. Predictors: (Constant), Street, Trail, Hedge, Sidewalk, Sand, River

h. Predictors: (Constant), Street, Hedge, Sidewalk, Sand, River

Table 20: The table displays the ANOVA results for seven sequential regression models predicting the dependent variable averageperday. All models are statistically significant, with the F-statistic and explained variance increasing as additional habitat diversity predictors (Street, Trail, Hedge, Sidewalk, Sand, River) are added to the models.

To identify which habitat characteristics best explain differences in feeder use, multiple regression models were applied with average daily food consumption as the response variable and all measured habitat attributes, along with the Shannon diversity index, as predictors. In the full model, this set of variables explained a large proportion of the variation in feeding rates ($R = 0.867$, $R^2 = 0.751$, adjusted $R^2 = 0.626$, $F_{13,26} = 6.03$, $p < 0.001$), indicating that the surrounding habitat strongly influenced how intensively feeders were used. When the effects of all predictors were considered simultaneously, only a small number of habitat attributes showed clear individual relationships with food consumption. Higher proportions of street around a feeder were consistently associated with increased consumption, whereas greater coverage of sidewalks and hedges was linked to reduced feeding activity. A complementary stepwise regression retained a more parsimonious set of predictors (street, hedge, sidewalk, sand, and river) while still explaining a substantial proportion of the variance in daily consumption ($R = 0.833$, adjusted $R^2 = 0.649$, $F_{5,34} = 15.43$, $p < 0.001$). In this simplified model, feeders located near streets tended to receive more visits, whereas feeders surrounded by hedges, paved paths, sandy ground, or directly adjacent to the river showed lower food intake. Given the limited number of feeders and the strong correlations among several habitat variables, these results should be interpreted with caution. However, they suggest that a combination of habitat structure and human infrastructure shapes feeder use, not a single environmental attribute alone.

4.3.11 Correlation Average Day 2 and Day 8

4.3.11.1 Temporal patterns of feeder use

Food consumption at the feeding stations increased steadily over the course of the experiment. Across all sites, mean consumption rose from low values early in the study (Day 2) to higher values by Day 8, indicating that feeders were increasingly accepted and used over time. From an ecological perspective, the early measurement points likely reflect an initial phase of discovery and adjustment to the

novel feeding stations, whereas later measurements represent more established and consistent feeder use. By Day 8, feeding activity can therefore be interpreted as a measure of long-term feeder attractiveness rather than short-term novelty effects. It should be noted that mean daily consumption and total consumption at Day 8 describe the same underlying pattern in this dataset, as they are directly proportional. As a result, both variables reflect the same spatial differences in feeder use and can be interpreted interchangeably in terms of environmental effects.

4.3.11.2 Consistency of feeder use over time

Feeding activity at individual stations was highly consistent across the different observation days. Feeding stations that showed higher food consumption early in the experiment also tended to remain the most frequently used later on. This strong correlation between early and late consumption indicates that differences in feeder attractiveness became apparent quickly and persisted throughout the study period. Rather than all feeders gradually converging to similar levels of use as birds became familiar with them, relative differences between locations were already visible at early stages. This suggests that early feeder use reflects not only novelty responses but also underlying site characteristics, such as habitat structure, local bird activity, or habitual foraging routes. Consequently, early consumption values should be interpreted as a combination of initial acceptance and inherent location quality, rather than as a pure measure of neophobia alone.

5. Discussion

5.1 What explains a “good” feeder location in Viennese parks?

The findings from this study suggest that successful feeder locations in Viennese parks are characterized by a combination of structural diversity and moderate levels of human activity. Feeding stations that were surrounded by vegetation, such as shrubs, hedges, and trees, tended to attract more birds, likely because these features offer shelter and a sense of safety from potential predators.

Sites with higher habitat diversity, such as those on the Danube Island and sections of the Danube Canal near Klosterneuburg, consistently showed higher feeding activity. This supports previous findings that heterogeneous urban habitats support higher bird activity and resource use than structurally simplified environments (Evans et al., 2011; Aronson et al., 2014).

In contrast, open areas dominated by lawn, stones, or bike paths, typical of the inner-city Danube Canal, exhibited lower food consumption. This pattern suggests that birds prefer feeder locations that combine cover with sufficient visibility, while avoiding areas with high and unpredictable human disturbance, consistent with earlier studies on disturbance sensitivity in urban birds (Miller et al., 2015; Tryjanowski et al., 2016).

Observations at the Augarten were particularly telling: the birds approached the feeding stations very closely during setup, demonstrating a high level of curiosity and habituation to human presence. Many other artificial feeders were already present in this park, suggesting that the birds there are well adapted to supplemental feeding, showing minimal neophobia.

Across all sites, attempts to correlate habitat attributes such as proximity to the river with food intake revealed site-specific differences. For example, while the river attribute appeared negatively correlated overall, the result likely does not indicate a causal relationship. At certain sites, such as along the Danube Canal, proximity to

the river was positively associated with feeding, suggesting that other factors, like local bird behavior or habituation to human feeding, drive these patterns. During short observation periods at each location (approximately 10 minutes per site), common visitors were mainly Great Tits (*Parus major*) and Blue Tits (*Cyanistes caeruleus*). Given the diverse tree and shrub species at the locations, no clear preference for a specific plant species could be determined.

The inferential analyses complement and refine these descriptive patterns. The general linear model confirms that feeder location, rather than feeder height, is the main factor driving variation in seed consumption, with site identity explaining over 90% of the variance in total and average intake. In addition, both the Shannon–Wiener habitat diversity index and PCA-derived habitat components show that birds respond to the configuration of habitat elements around feeders. Feeders placed in structurally diverse, mixed habitats tended to be used more intensively, whereas locations at the extremes of certain gradients (e.g., very sandy, shrub-dominated edges or highly formalised riverbank park sections) were visited less. Multiple regression models further suggest that specific combinations of vegetation and infrastructure, such as edges near streets but not directly over sandy or heavily paved areas, are particularly favourable.

Taken together, these findings reinforce the idea that “good” feeder locations in Viennese parks combine structural habitat diversity with moderate, predictable human presence. Such sites allow birds to feel safe and comfortable while foraging, aligning with theoretical expectations from previous studies on urban bird feeding, neophobia, and habitat selection.

5.1.1 Interpretation in relation to neophobia

The observed pattern suggests that early use of feeding stations is influenced by both habituation to human activity and the availability of nearby cover. Feeding stations located in areas with frequent human movement, such as streets, sidewalks, or trails, tended to be accepted more quickly. This may indicate reduced neophobia

in birds that are regularly exposed to people, as novel objects in such environments are likely perceived as less threatening.

At the same time, a positive association between early food consumption and the presence of hedges points to the importance of structural cover. Nearby vegetation may allow birds to approach new feeding stations more readily by providing opportunities for concealment and rapid escape. Together, these findings suggest that early feeder acceptance reflects a balance between familiarity with human disturbance and perceived safety, rather than novelty avoidance alone.

5.2 How the findings compare with prior work

The findings of this study align with previous research highlighting the influence of habitat structure and human disturbance on urban bird feeding behavior. Similar to Goławski & Sytykiewicz (2021), who demonstrated that feeder design and placement affect visitation rates, our results show that structural cover such as shrubs and hedges increases feeding activity. Moreover, consistent with studies on neophobia in urban birds (e.g., Mettke-Hofmann et al., 2013), birds habituated to human presence, such as those at the Augarten, displayed minimal avoidance and were more willing to approach feeders. However, in contrast to some prior work that emphasizes species-specific responses, our observations suggest that generalist urban species like Great Tits and Blue Tits are the dominant visitors across sites, indicating that local adaptation and prior experience with supplemental feeding may outweigh species-specific traits in determining feeder use.

5.3 Mechanismus and conceptual implications

The observed feeding patterns can be interpreted through ecological and behavioral mechanisms. Birds appear to balance the need for food with perceived risk, selecting feeders that offer both visibility and protection. The correlation between high habitat diversity and increased feeding supports the notion that environmental complexity

enhances foraging opportunities while providing escape options from potential threats. Additionally, the high curiosity and low neophobia observed in the Augarten population indicate that repeated exposure to humans and feeders may facilitate rapid behavioral adaptation. Conceptually, this feature highlights the interaction between innate habitat preferences and learned behaviors, emphasizing that urban bird populations are highly flexible and capable of adjusting to novel resource distributions.

5.4 Management implications for Viennese parks

These findings have practical applications for urban wildlife management. To maximize feeding success and support native bird populations, feeders should be located in areas with natural cover and moderate human presence. Parks with diverse vegetation types, including hedges, shrubs, and trees, appear especially suitable. Consideration should also be given to existing human activity, as excessive disturbance can lead to a decrease in feeder usage. In sites like Augarten, where birds are accustomed to human presence, feeding stations may be more widely dispersed without negatively affecting visitation rates. Implementing such informed placement strategies can help urban planners and conservationists enhance the efficacy of supplemental feeding programs while promoting urban biodiversity.

5.5 Limitations

Several limitations of this study should be acknowledged. The number of feeding stations per site was relatively small, and observations were restricted to winter months, which may limit generalizability to other seasons. Additionally, while habitat attributes were carefully documented, variability in tree and shrub species may obscure potential preferences for specific plant types. Short observational periods at each feeder (approximately 10 minutes) provided a snapshot of visitation but may not fully capture temporal variability or less frequent species. Furthermore, the size of the

local avian community at each site was not quantified. As a result, higher food consumption at certain locations may partly reflect higher baseline bird abundance rather than habitat or feeder-related effects, highlighting the value of incorporating standardized bird censuses in future studies. Finally, the focus on common urban species may not reflect the behavior of less abundant or more sensitive bird species.

5.6 Future work

The present study offered preliminary observations about feeder use and habitat associations in urban Vienna, but several improvements would strengthen future replications and allow for more robust inference.

5.6.1 Increase sample size and replication.

Future studies would benefit from a larger number of feeding stations and broader spatial replication. Increasing the number of feeders per location (for example, from 10 to 15 - 25) and including additional sites along the full urban to semi-natural gradient would improve statistical power and enhance the generality of the results.

5.6.2 Synchronous deployment and seasonal comparison.

To minimize temporal variation, all feeders should be deployed simultaneously within a defined winter period, such as a 6 - 8 week window. Repeating the experiment during spring would allow direct seasonal comparisons and help assess whether reliance on supplemental feeding differs between winter and periods of higher natural food availability. Such a paired seasonal design would also enable the detection of phenological shifts in feeder use.

5.6.3 Increase vertical and horizontal spacing.

To more effectively test the influence of feeder height, vertical placement should span a wider range rather than being limited to small differences. Including several height categories (e.g. approximately 0.5 m, 1.5 m, and 3.0 m) would provide a clearer assessment of vertical preferences. In addition, increasing the horizontal

distance between feeders (for example, >10 - 30 m, depending on local bird mobility) would reduce interference between neighbouring units and improve the independence of observations.

5.6.4 Longer observation periods and higher temporal resolution.

Extending the observation period to several weeks per deployment and increasing the frequency of measurements would allow finer-scale temporal patterns to be captured. More frequent checks or continuous monitoring would improve the detection of short-term acclimation, diurnal variation, and less common visitation events, as well as increasing the likelihood of recording rarer species.

5.6.5 Automated monitoring and species identification.

Where possible, manual measurements should be complemented by automated methods such as motion-triggered cameras. These approaches would enable species-specific analyses, provide information on individual visitation patterns and repeatability, and allow more precise estimates of visit duration and feeding behaviour. Species-level data are essential for determining whether observed consumption patterns are driven by a few dominant species or by a broader assemblage.

5.6.6 Experimental controls and randomization.

Future experiments should incorporate stronger experimental controls, including randomised feeder placement and rotation of feeder characteristics (such as height, colour, or design) among positions. Control sites without feeders would also be valuable for assessing background bird activity and natural food availability, helping to separate feeder-driven effects from baseline habitat use.

5.6.7 Additional habitat and disturbance covariates.

Collecting a wider range of environmental and disturbance-related variables would allow more comprehensive modelling of feeder use. Potential covariates include microclimatic conditions, noise levels, pedestrian traffic, and predator presence.

Measuring proxies of natural food availability, such as insect abundance, would further clarify how supplemental feeding interacts with natural resource scarcity.

5.6.8 Health, ethics and public engagement.

Future studies should explicitly address hygiene and disease risks associated with feeding stations by applying standardised cleaning protocols and using appropriate seed types.

5.6.9 Power analysis and pre-registration.

Prior to replication, statistical power analyses should be conducted to determine the sample sizes required to detect meaningful effect sizes. Where possible, preregistering hypotheses and analysis plans would further improve transparency, reduce analytical bias, and enhance reproducibility.

Implementing these recommendations would improve data quality, enable species-level and seasonal inference, and provide a stronger empirical basis for understanding the role of supplemental feeding in urban bird populations. Ultimately, these measures would support more effective and evidence-based management and conservation strategies for birds in Vienna's urban environments.

6. Conclusion

This research demonstrates the value of habitat structure and bird habituation in determining feeder success in urban parks. Birds preferentially visited feeders that offered protective cover, such as shrubs, hedges, and trees, while avoiding highly open or heavily disturbed areas. Sites with high habitat diversity consistently supported higher feeding activity, indicating that birds benefit from a mix of environmental features.

The results also underscore the role of habituation and neophilia: in locations such as the Augarten, birds were highly accustomed to human presence and artificial feeding, approaching feeders confidently and demonstrating strong adaptability. Short observational periods confirmed that common urban species, including Great Tits and Blue Tits, were the main visitors to the feeders.

Overall, these findings suggest that urban bird feeding strategies should prioritize structural diversity and consider existing bird habituation to human activity. By selecting feeder sites with natural cover and moderate disturbance, urban planners and conservationists can enhance the efficacy of supplemental feeding programs, supporting native bird populations and potentially mitigating the decline of urban avifauna. Future work should expand on these findings by increasing the number of feeders, varying heights more widely, and repeating experiments across different seasons to fully understand seasonal feeding requirements.

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