Journal of Zoology

Zoological Society of London

ORIGINAL RESEARCH OPEN ACCESS

Repurposing Bird Bycatch From Camera Traps in Urban Landscapes: A Correlate of Avian and Mammalian Richness?

Flavio Monti[1] | Leonardo Ancillotto[2,3] | Andrea Viviano[2] | Martino Maggioni[3,4,5] | Olivia Dondina[2,6] | Tommaso Lipparelli[2] | Emiliano Mori[2,3]

[1]Research Institute on Terrestrial Ecosystems (IRET), National Research Council (CNR), Porano, Italy | [2]Research Institute on Terrestrial Ecosystems (IRET), National Research Council (CNR), Sesto Fiorentino, Italy | [3]National Biodiversity Future Center, Palermo, Italy | [4]Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Palermo, Italy | [5]Dipartimento di Biologia, Università degli Studi di Firenze, Florence, Italy | [6]Department of Earth and Environmental Sciences, Università degli Studi di Milano-Bicocca, Milan, Italy

Correspondence: Leonardo Ancillotto (leonardo.ancillotto@cnr.it)

Received: 6 January 2026 | **Revised:** 12 June 2026 | **Accepted:** 1 July 2026

Editor: Matthew W. Hayward | **Associate Editor:** Emerson Vieira

Keywords: avian communities | camera trapping bycatch | cities | point counts | remote cameras | species richness | urban ecology | urban ecosystems

ABSTRACT

Camera traps are extensively used to monitor medium- and large-bodied mammals, but the avian bycatch they generate remains largely untapped in biodiversity assessments. This underuse is particularly evident in urban ecosystems, despite the growing application of camera trapping in cities. Here, we evaluated the ecological value of bird detections obtained opportunistically from camera traps by comparing them with standardized point count surveys conducted in 2023–2024, across the metropolitan area of Firenze, central Italy, and explored their potential to indicate broader urban biodiversity patterns through cross-taxa relationship with mammal richness. Combining both methods, we recorded 72 bird species, with camera traps detecting two-thirds of total richness. Bird species richness estimated from camera traps was strongly and positively correlated with richness derived from point counts across sampling stations, indicating that camera-trap bycatch captures consistent spatial patterns in avian diversity. Bird communities detected by the two methods showed a high degree of species overlap (70%), although modest but significant differences in community composition were observed, reflecting method-specific detection biases. Using camera-trap data, we detected a positive association between mammal and bird richness values across sites. This relationship was confirmed after accounting for variation in sampling effort and seasonal effects, suggesting that local areas supporting a higher diversity of birds also tend to support a richer mammal community. Overall, our results show that avian bycatch from camera traps provides meaningful information on bird diversity and complements traditional survey methods, while also offering potential insights into multi-taxon biodiversity patterns. Repurposing existing camera-trap datasets can therefore enhance the efficiency and taxonomic breadth of urban biodiversity monitoring programs.

1 | Introduction

The use of technology for the remote monitoring of wildlife has been widely adopted for several decades and has undergone considerable development over time (Green et al. 2020; Chanev et al. 2023). Technological approaches have progressively complemented and, in some cases, integrated traditional wildlife monitoring methodologies (Fontúrbel et al. 2020). Among these tools, camera traps have become one of the most used non-invasive techniques for biodiversity monitoring, particularly for terrestrial vertebrates (Burton et al. 2015). Camera trapping has been employed predominantly to study medium- and large-sized mammal communities worldwide, providing valuable information on species occurrence, activity patterns, and community structure (Rovero and Zimmermann 2016), eventually supporting conservation (Rovero and Kays 2021).

However, camera traps are inherently non-selective and are therefore capable of recording other taxonomic groups, including birds. Despite this, camera trapping is generally not considered an appropriate or comprehensive method for avian monitoring, although it has proven useful in some studies targeting specific bird groups (Fontúrbel et al. 2020). Camera traps are likely to undersample many bird species. This limitation is particularly evident for species that primarily fly at higher vertical layers, inhabit the forest canopy, or exhibit elusive or highly specialized behaviors that reduce their probability of detection by ground-based cameras (O' Brien and Kinnaird 2008). Nevertheless, camera traps have been used in avian studies within specific ecological and methodological contexts, as to investigate the behavior of individual bird species (e.g., Ribeiro-Silva et al. 2018; Mori et al. 2021; Viviano, Lazzeri, et al. 2025), or to detect particularly rare or cryptic species, such as certain ground-dwelling or elusive birds for example, the critically endangered black-naped pheasant-pigeon *Otidiphaps insularis*, which was lost to science for 126 years before being rediscovered (Gregg et al. 2024). Yet, camera traps may also be used to monitor nests, breeding colonies, or sites where bird presence is already known and temporally predictable (Bird et al. 2022; Kiat et al. 2025).

Outside these targeted applications, camera-trapping surveys frequently yield opportunistic records of bird species that are often overlooked or excluded from analyses. In contrast, avian communities are typically monitored using established traditional techniques such as point counts, distance sampling, direct observations, or passive acoustic monitoring (Bibby et al. 2000; Fraissinet et al. 2023). While these methods are specifically designed to detect birds and are generally more effective, opportunistic bird records obtained from camera traps may still provide valuable ecological information, although their consistency and comparability with traditional methods may differ. For example, a recent study conducted in tropical forests found no correlation between the number of species recorded by camera traps and traditional point counts, suggesting that camera trapping has little potential to replace standard bird survey methods in forested habitats (Hernández-Ayala et al. 2025). In another study in forested habitats, camera traps used to assess understory bird diversity, provided results comparable to acoustic survey methods, suggesting it can be used as a complementary method to improve species richness estimations, at least for specific groups (Fontúrbel et al. 2020).

Opportunistic bird ancillary from camera traps may contribute to a better understanding of local avian assemblages, especially in specific environmental contexts where traditional monitoring methods are difficult to apply. Urban and metropolitan environments represent one such context. In these areas, several characteristics of the urban landscape can influence the effectiveness of bird-monitoring programs. Anthropogenic noise generated by traffic, industrial activities, and human presence may interfere with acoustic surveys, reducing the detectability of vocal species (e.g., Giuliani et al. 2024; Santos et al. 2024; Arzberger et al. 2025). At the same time, built infrastructure can obstruct lines of sight and limit the effectiveness of visual observations. Consequently, obtaining comprehensive information on urban bird assemblages may require the integration of complementary monitoring approaches.

Beyond their effects on sampling, urban environments also shape biodiversity patterns (Angold et al. 2006). Urbanization modifies landscape structure and ecological processes, influencing community composition, species richness, and the distribution of resources (e.g., Lowry et al. 2013; Herrera et al. 2021; Fraissinet et al. 2023; Alba et al. 2025; Mori et al. 2025). Metropolitan areas may favor a subset of urban-adapted species or attract certain species in specific urban features, such as green spaces, artificial wetlands, or areas characterized by urban heat islands, permanent water availability, and predictable food resources (Mori et al. 2025). Furthermore, cities are recognized as important hotspots for the introduction and establishment of non-native and invasive bird species, whether through intentional releases or accidental introductions (Viviano, Ancillotto, et al. 2025). In this context, camera trap records may contain important yet underexploited information on bird species occurring in urban and peri-urban landscapes. Although not designed for avian surveys, these data may nonetheless offer insights into species presence, habitat use, and community composition.

In this study, we aimed to investigate the complementarity of camera traps and point counts in the monitoring of urban bird communities, assessing whether their integration can improve the completeness and reliability of biodiversity assessments in urban environments. Specifically, our first objective was to assess whether bird richness recorded as opportunistic bycatch in camera traps correlates with bird richness estimated through traditional point counts, testing whether camera-bycatch data can serve as a reliable proxy for avian diversity. While similar approaches have been applied in natural landscapes, such as monitoring understory birds in forest habitats (Fontúrbel et al. 2020), this method remains uncommon, with limited information available, and to our knowledge it has not yet been explored in urban environments. Our second objective was to explore cross-taxa patterns by determining whether sites with higher bird richness recorded by camera bycatch also exhibit higher mammal richness, providing insights into the potential of using bird richness as an indicator of broader urban biodiversity. Together, these objectives allow us to evaluate the utility of camera traps for multi-taxa biodiversity assessments and to evaluate possible co-occurrence patterns of birds and mammals in urban ecosystems.

2 | Materials and Methods

2.1 | Study Area

We conducted our study in the metropolitan area of Firenze (central Italy), encompassing 11 municipalities (Firenze, Sesto Fiorentino, Calenzano, Campi Bisenzio, Fiesole, Impruneta, San Casciano Val di Pesa, Scandicci, Lastra a Signa, Empoli and Bagno a Ripoli; Figure 1). The area is generally medium-flat (~180 m a.s.l.), with some municipalities featuring medium-hilly

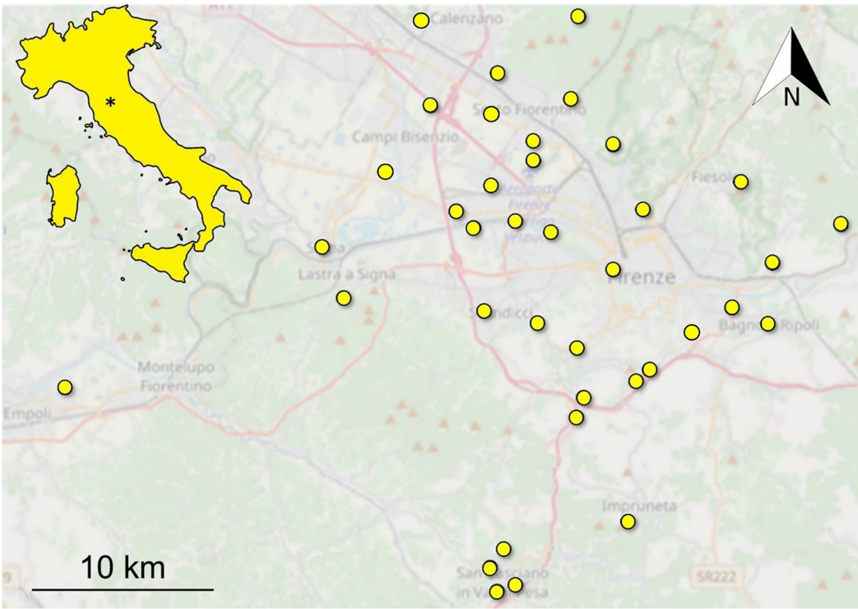

FIGURE 1 | Location of the 38 camera-trap and point count stations (yellow dots) of the monitoring conducted in the metropolitan area of Firenze (indicated by the asterisk—central Italy) between March 2023 and May 2024.

terrain above 200 m a.s.l. Land cover is dominated by human settlements, followed by urban parks and cultivated areas, including gardens, olive groves, and vineyards. Riverine habitats along the Arno, Mugnone, Zambra and Pesa rivers are mainly composed of *Populus nigra* L., *Populus tremula* L., and *Salix alba* L., while urban forests are dominated by *Populus nigra* L., *Quercus ilex* L., *Q. cerris* L., and *Robinia pseudoacacia* L. (Mori et al. 2025).

2.2 | Camera Trapping

Camera-trap surveys were conducted across the Firenze metropolitan area under the appropriate authorizations (Fondazione Capellino Project "Monitoring and Mitigation of Climate Change and Promotion of Biodiversity: the Florence Model", Prot. No. 26581/2023; Municipality of Calenzano, Doc. 140520/2023; Municipality of Sesto Fiorentino, Prot. Comunale No. 22101/2023), in the framework of the NRPP Project "National Biodiversity Future Center", Spoke 5, Urban Biodiversity. To comply with national and European privacy regulations (Italian Legislative Decree 196/2003 and EU Regulation 2016/679), informative panels were installed at park entrances (see Mori et al. 2025). Camera traps were strategically deployed along animal paths and fence openings, while avoiding narrow trails where incidental human captures were unavoidable (Herrera et al. 2021). The observed variation in camera trap effort among stations was mainly due to the premature removal of some cameras. Some cameras were removed earlier either because they were stolen or because they captured images of people in situations that raised privacy and ethical concerns, making continued monitoring at those sites inappropriate. Consequently, deployment duration varied substantially among stations. To further minimize disturbance and ensure privacy, cameras were placed away from roads and never oriented toward residential windows. In areas with potential human presence, camera traps were installed at knee height to reduce the likelihood of capturing identifiable images of human faces (Gelmi-Candusso et al. 2023).

A total of 38 camera-trap stations (Browning SpecOps) were deployed across the study area (Figure 1). The selection of the camera-trap stations followed a standardized sampling design based on a 1 × 1 km grid overlaying the Firenze metropolitan area. Sampling cells were then chosen to maximize representativeness across all size-fragmentation classes, ensuring coverage of the full gradient of urban green space configurations (Dondina et al. 2025). One camera trap was placed within each selected cell, at an opportunistically chosen location within the cell where a green area (e.g., an urban park, tree-lined street, or grassy margin) was present and where the passage of a wildlife species was considered more likely (Mori et al. 2025). Cameras were mounted approximately 30–80 cm above ground and operated continuously, 24 h per day, recording one 60-s video per detection event with a 5-s delay between successive recordings. Stations were spaced at least 800 m apart to reduce spatial autocorrelation and the risk of pseudoreplication (O′ Connell et al. 2011). Camera traps operated year-round from March 2023 to May 2024 (mean number of working days = 73 ± 30.15 days, standard deviation; range: 29–194 days; $n = 38$) and remained unattended between weekly checks, during which data were downloaded and batteries replaced. All video recordings in which species could not be reliably identified (4.3% of total records) were excluded from analyses. To further minimize temporal pseudoreplication, detections of the same species at the same station occurring within a 30-min interval were pooled into a single observation (Monterroso et al. 2014).

2.3 | Point Count Surveys

To assess spatial variation in bird species composition across camera-trap stations, we employed the point count method, a widely used approach for monitoring avian populations and community structure (Ralph et al. 1995; Diefenbach et al. 2003). During each point count, the observer records all bird species detected visually or acoustically from a fixed location within a predefined time interval (Ralph et al. 1995; Diefenbach et al. 2003). At each station, point count surveys were conducted twice per season (one at the beginning and one at the end) throughout the year, with surveys carried out in the morning (6:00–9:00 AM) and the evening (20:00–22:00 PM) accounting for seasonal variation in dawn and dusk. Each survey lasted 30 min; thus, each location was sampled for 4 h over the year. To reduce observer bias and improve detection accuracy, a team of three experienced observers conducted each survey during both sampling replicates per station.

2.4 | Statistical Analyses

All analyses were conducted in R (R version 4.3.1; R Core Team 2024). Two datasets were compiled. The first integrated camera-trap and point-count records to characterize bird species diversity at each station. The second, based exclusively on camera-trap data, included all vertebrate detections, with each event documented by date, time, site, season, species identity, and number of individuals. To quantify species richness, defined as the number of unique species, we first calculated site-level richness by counting the number of unique species per site for both birds and mammals. The number of unique trapping days per site (WorkingDays) was computed to correct for variation in sampling effort across sites. These richness estimates were then used to explore potential relationships between mammal and bird diversity, allowing us to assess cross-taxon associations in species richness within the study area at different levels.

For the first dataset, to assess the consistency between sampling methods, we evaluated the relationship between bird species richness derived from camera trapping and point count surveys across stations. Pairwise correlation between methods was quantified using Pearson's correlation coefficient, retaining zero values to avoid bias associated with the exclusion of true absences (NA). In addition, Spearman's rank correlation was computed as a robustness check against potential deviations from normality. Statistical significance was assessed using standard correlation tests (p-value set at 0.05). Moreover, to assess whether bird community composition differed between sampling methods, we followed the approach used by Fontúrbel et al. (2020) and compared assemblages detected by camera traps and point counts using a permutational non-parametric approach. For each site and sampling method, species occurrence data were encoded as binary matrices (1 = presence, 0 = absence).

Differences in community composition between sampling methods were tested using a two-way Analysis of Similarities (ANOSIM) implemented in the *vegan* package in R and using the Bray–Curtis dissimilarity index (Clarke 1993; Fontúrbel and Jiménez 2014; Fontúrbel et al. 2020). The sampling method (camera trap vs point count) was used as the grouping factor. ANOSIM was performed with 9999 permutations to estimate the significance of the observed R statistic. Rows containing no species records were excluded prior to analysis to avoid undefined dissimilarities. The ANOSIM R statistic ranges from −1 to +1, with values close to zero indicating little separation between groups, higher positive values indicating increasing compositional differentiation, and negative values indicating that within-group dissimilarities exceed between-group dissimilarities. In addition, following Fontúrbel et al. (2020), to quantify overall similarity in species composition between methods, we calculated the Sørensen similarity index (QS) based on total species richness detected by each method as follows: $QS = 2C/A+B$, where A and B represent the total number of species detected by camera traps and point counts, respectively, and C is the number of species detected by both methods. The Sørensen index ranges from 0 (no shared species) to 1 (identical species lists).

For the camera-trap dataset, we initially tested the relationship between bird and mammal richness using Spearman's rank correlation. To further investigate these relationships while accounting for overdispersion and hierarchical structure, we fitted generalized linear mixed models (GLMMs; Zuur and Ieno 2016). First, we explored the overall relationship between bird and mammal species richness using a negative binomial generalized linear model on site-level richness values. We then fitted a GLMM (family = negative binomial) using the *glmmTMB* package (Magnusson et al. 2017), including mammal species richness as response variable, bird richness, season and sampling effort (camera-trap working days) as covariates and site identity as a random effect to account for repeated seasonal measurements. All numeric predictors were scaled to facilitate model convergence. In all modeling approaches, model fit was evaluated using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Overdispersion was assessed using the Pearson chi-square statistic divided by the residual degrees of freedom. Fixed-effect parameter estimates were evaluated using Wald z-tests, and 95% confidence intervals were calculated to assess the precision of effect estimates. Predicted values for plotting were generated by marginalizing the random effect. Graphs were produced using *ggplot2* (Wickham 2011) and *ggeffects* (Lüdecke et al. 2020) packages.

3 | Results

3.1 | Comparison of Bird Species Richness Between Survey Methods

Seventytwo bird species were recorded when combining camera trap and point count data. Birds were detected in 33 of the 38 sampling stations. The five stations without bird detections were: Bagno a Ripoli, Cascine, Fonte Mezzina, Ponte all'Indiano 2 and San Casciano 2. Camera traps detected 48 species (66.6% of total richness), whereas point counts recorded 63 species (87.5%). Thirty-nine species were detected by both methods, while 24 species were unique to point counts (mostly high-flying or canopy species) and 9 species were unique to camera traps (Table S1). A strong and statistically significant positive correlation was found between species richness estimated using camera traps and point count surveys across all sampling stations (Pearson's correlation: $r = 0.76$, $t = 7.10$, $df = 36$, $p < 0.001$; 95% CI = 0.58–0.87), indicating a consistent positive relationship between the two methods. Spearman's rank correlation was moderate and positive ($\rho = 0.57$, $p < 0.001$), confirming the association while accounting for non-normality and tied values. Overall, sites with higher species richness opportunistically detected by camera traps also tended to have higher richness values from point count surveys.

Bird communities sampled using camera traps and point counts showed a high degree of species overlap, with a Sørensen similarity index of QS = 0.703, indicating that approximately 70% of species were shared between the two methods. Despite this high similarity, ANOSIM revealed a statistically significant difference in community composition between sampling methods (Bray–Curtis dissimilarity; $R = 0.107$, $p = 0.0001$, 9999 permutations). The relatively low R value indicates that differences between methods were modest in magnitude but consistent across sites, resulting in a significant separation of assemblages. Camera traps and point counts largely detected overlapping bird communities while still differing in the detection of a subset of species.

3.2 | Camera-Trap Detections and Cross-Taxon Richness Patterns

Across 38 sampling stations, camera traps recorded a total of 7883 detections of birds and mammals during the study period. Birds accounted for 1110 detections (14.0%), while mammals represented the majority of records (6762 detections). An additional eleven detections involved non-target taxa (common toad *Bufo bufo*, American pond slider *Trachemys scripta*, and Italian wall lizard *Podarcis siculus*), which were excluded from subsequent analyses. In total, 71 species were identified, including 48 bird species and 23 mammal species. Among birds, the mallard *Anas platyrhynchos* was the most frequently detected species followed by the Eurasian blackbird *Turdus merula* and the song thrush *Turdus philomelos*, whereas coypus *Myocastor coypus* and wild boar *Sus scrofa* were the most commonly recorded mammals, besides humans (Figure 2).

Spearman's rank correlation indicated a positive association between bird and mammal species richness ($\rho = 0.522$, $p = 0.0007$), suggesting that stations with higher bird richness tended to have higher mammal richness. The station with the highest species richness, birds and mammals combined, was Empoli-Serravalle, whereas Bagno a Ripoli exhibited the lowest values (Figure S1). The first explorative model showed that bird richness was a significant positive predictor of mammal richness (estimate = 0.208 ± 0.083, z = 2.495, 95% CI = 0.028 to 0.397; $p = 0.012$; Figure 3; Table 1). Model diagnostics indicated no overdispersion or residual structure.

In the full mixed-effects model accounting for season, sampling effort, and site identity, mammal species richness was positively associated with bird species richness ($\beta = 0.20 \pm 0.07$ SE, $p = 0.004$; Table 1). Seasonal effects were not statistically significant, and sampling effort did not influence mammal richness. Random intercept variance indicated moderate differences among sites (Table 1). Model diagnostics indicated no evidence of overdispersion or zero inflation, supporting the adequacy of the fitted model.

4 | Discussion

4.1 | Comparison of Bird Species Richness Between Survey Methods

Our results show that opportunistic avian detections from camera traps can provide meaningful insights into bird community patterns in urban environments. Bird species richness estimated using traditional bird-focused methods, such as point counts, was also captured, at least partially, by camera traps. Despite methodological differences, we found a strong and significant correlation between bird richness derived from camera-trap bycatch and point counts, indicating that both approaches recover consistent spatial patterns

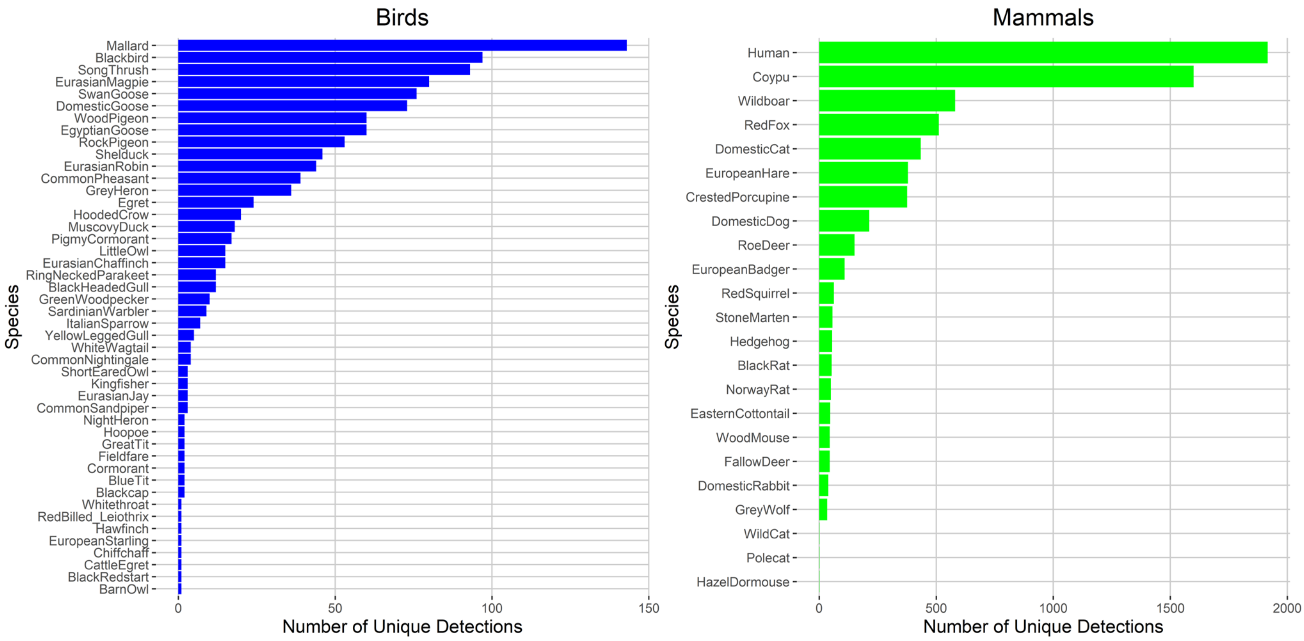

FIGURE 2 | Number of unique detections of each species in the metropolitan area of Firenze, for both birds and mammals, captured by camera traps during March 2023–May 2024.

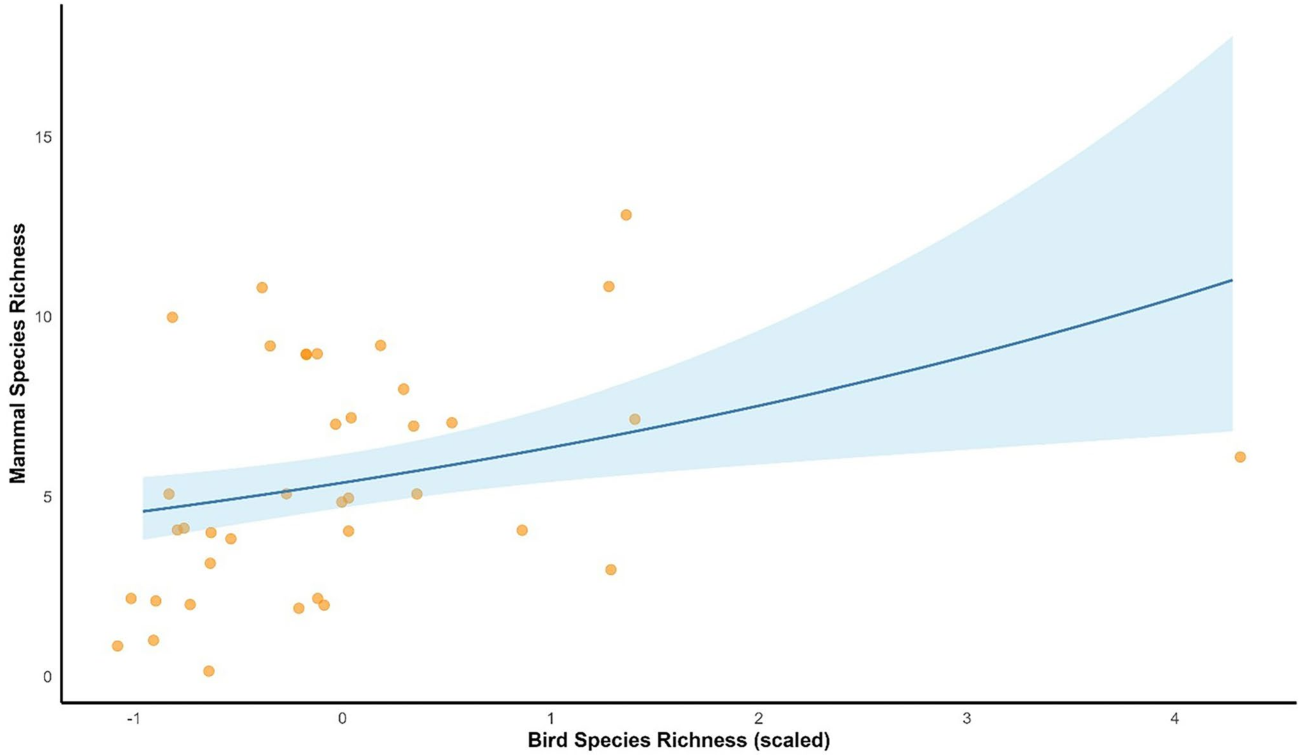

FIGURE 3 | Relationship between bird species richness and mammal species richness across study stations. Orange points represent observed mammal richness at each station. The blue line shows the predicted trend from the generalized linear model, and the shaded area represents the 95% confidence interval. Bird richness was scaled to match the predictor used in the model.

TABLE 1 | Parameters estimated from GLMMs predicting the mammal species richness in relation to bird species richness (1) year-round, across stations; (2) across seasons and stations while accounting for camera trap effort (Working_days): Variance of random intercepts (σ^2), predictors' coefficient estimates (β), and their 95% confidence intervals (CIs).

Model	Response variable	Predictor	β coefficient	95% CI
1	Mammal Richness *n* = *38*	Intercept	1.679	1.496 1.861 ***
		Bird Richness(s)	**0.208**	**0.027 0.397 ***
2	Mammal Richness *σ2 Site* = *0.21* *n* = *76*	Intercept	1.393	1.089 1.697 ***
		Bird Richness(s)	**0.195**	**0.063 0.328 ****
		Season: Summer	−0.078	−0.490 0.334
		Season: Winter	−0.070	−0.397 0.256
		Season: Spring	−0.249	−0.655 0.157
		Working_days(s)	0.077	−0.151 0.307

Note: The (s) indicates variables that were scaled. Asterisks mark coefficients whose CIs do not include "0".

of species richness, in line with previous findings (Fontúrbel et al. 2020). Thus, despite their limitations, camera traps detected a remarkable portion of the local avifauna, providing a reasonable proxy for bird community patterns in the metropolitan area of Firenze.

Furthermore, camera traps and point counts sampled highly similar but non-identical bird assemblages in urban environments. The high Sørensen similarity index indicates substantial overlap in species detection, suggesting that both methods capture the core bird community present at each site. However, ANOSIM results revealed consistent differences in community composition between methods, despite a small effect size, in agreement with Fontúrbel et al. (2020). These differences reflect method-specific detection biases, whereby certain species are more likely to be recorded by one method than the other does. In our study, high-flying species (e.g., barn swallow *Hirundo rustica*, common swift *Apus apus*, Eurasian crag martin *Ptyonoprogne rupestris*, European bee-eater *Merops apiaster*, peregrine falcon *Falco peregrinus*) and species strongly associated with canopy habitats (e.g., European goldfinch *Carduelis carduelis*) were not present in the camera-trap dataset, being detected exclusively through point counts. This pattern is expected, as point counts record all birds seen or heard and tend to favor vocally active and visually conspicuous species, whereas camera traps are more effective at detecting ground-dwelling, cryptic, or less vocal birds (e.g., Santos-Moreno et al. 2019; Viviano, Lazzeri, et al. 2025), particularly in structurally complex urban habitats. Notably, even relatively rare and elusive species, such as the short-eared owl *Asio flammeus*, were detected exclusively by camera traps, particularly because they are non-vocal species which cannot be reliably recorded through point count surveys, underscoring the value of this method for documenting unexpected or occasional urban avifauna. The combination of a low ANOSIM R value and a high Sørensen index suggests that the two approaches are complementary rather than redundant (Fontúrbel et al. 2020). While either method alone provides a reasonably accurate representation of the bird community, their combined use enhances overall species detection and improves community characterization. These findings support the growing recognition that multi-method sampling designs are particularly valuable for birds and mammals (Campbell et al. 2008; Fontúrbel et al. 2020), especially in heterogeneous and human-modified landscapes, where detectability varies widely across behavioral and ecological guilds (Mori et al. 2025). Integrating camera traps and point counts can therefore provide a more comprehensive and reliable assessment of urban bird communities, with important implications for biodiversity monitoring and conservation planning.

4.2 | Camera-Trap Detections and Cross-Taxon Richness Patterns

Across taxa, we observed a moderate positive correlation between bird and mammal species richness across urban sites, supported by generalized linear mixed models (GLMMs). We found a positive relationship between bird and mammal species-richness across camera-trap sites and seasons, suggesting that local areas supporting a higher diversity of birds also tend to support a richer mammal community. This pattern is consistent with the idea that bird richness can act as a proxy for overall habitat quality, reflecting structural complexity, resource availability, or lower levels of anthropogenic disturbance (Alba et al. 2025; Assandri et al. 2025). In heterogeneous or well-preserved urban and peri-urban green spaces, such conditions may simultaneously favor both avian and mammalian assemblages (Mori et al. 2025).

Contrary to expectations, mammal species richness did not differ significantly among seasons. This result suggests that, at the spatial and temporal scale of our study, seasonal variation in mammal detectability or activity did not translate into measurable differences in species richness. Most likely, this reflects heterogeneous sample sizes across seasons at individual sites and the fact that most mammal species in the study area are year-round residents (Table S2), contributing to relatively stable spatial patterns throughout the year. For example, aside from hibernating species such as the Western European hedgehog *Erinaceus europaeus*, all other mammals were active year-round. Alternatively, seasonal effects may be overshadowed by strong site-level characteristics, such as habitat configuration or connectivity, which were captured by the random site effect.

Avian richness derived from camera-trap bycatch may thus serve as a useful proxy for urban habitat features, although caution is warranted when using it as a predictor of mammal richness once methodological and spatial factors are incorporated. Future studies could refine this approach by incorporating fine-scale habitat descriptors, trait-based analyses distinguishing ground-associated and arboreal bird species, or complementary passive monitoring techniques such as acoustic recorders. Together, these approaches would help disentangle detection effects from ecological mechanisms and further enhance the potential of camera-trap surveys as multi-taxon monitoring tools in urban ecosystems.

Beyond their methodological implications, our findings have clear applied relevance for urban biodiversity monitoring. Camera-trap surveys are increasingly implemented in cities to monitor medium- and large-bodied mammals (Herrera et al. 2021; Gelmi-Candusso et al. 2023; Mori et al. 2025), often generating large volumes of ancillary data that remain largely unused. Opportunistic avian bycatch extracted from these datasets can provide a reliable, low-cost proxy of spatial variation in bird species richness, particularly in urban landscapes where suitable habitats are spatially constrained and wildlife activity is concentrated in predictable locations. In such contexts, green areas, riparian corridors, and semi-natural patches may act as focal points for multiple taxa, increasing local detectability by passive monitoring devices. However, the usefulness of camera-trap bird bycatch is likely to be context-dependent; thus, we stress that camera traps should be regarded as a complementary rather than substitutive tool for avian monitoring.

5 | Conclusions

Overall, our study highlights the potential of repurposing camera-trap datasets to assess avian community patterns, particularly in urban environments where habitat constraints may lead to spatially structured and predictable species assemblages. Although we detected signals of association between bird and mammal species richness, mammal richness may likely be influenced by ecological and anthropogenic factors that differ from those shaping bird communities, as well as dependent on survey effort across sites. Nevertheless, at specific sites, concordance between the two taxa may emerge where shared environmental features simultaneously support both groups. Future work incorporating finer-scale habitat descriptors and explicit measures of disturbance will be necessary to disentangle these mechanisms, better understand cross-taxon co-occurrence, and evaluate the reliability of birds as indicators of broader vertebrate biodiversity in urban landscapes.

Author Contributions

F.M., L.A. and E.M. conceived the ideas and designed methodology; A.V., O.D., T.L. and M.M. collected data; F.M. analyzed the data; F.M. wrote the first draft; all authors contributed critically to the drafts and all authors gave final approval for publication.

Acknowledgments

Authors would like to thank all citizens who allowed placement of camera traps in their gardens. E.M., M.M., O.D. and L.A. were funded by the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4-Call for tender No. 3138 of 16 December 2021, rectified by Decree No. 3175 of 18 December 2021 of Italian Ministry of University and Research funded by the European Union-NextGenerationEU; Project Code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP B83C22002930006 and H43C22000530001, Project title 'National Biodiversity Future Center-NBFC'. The authors also thank the Capellino Foundation (Fondazione Capellino) which conceived and financed the Project 'Monitoring and mitigation of climate change and promotion of biodiversity: the Florence model' (Prot. No. 26581 of 31 January 2023) and which allowed the implementation of monitoring with camera traps and the environmental characterization of the city of Florence. Open access publishing facilitated by Consiglio Nazionale delle Ricerche, as part of the Wiley - CRUI-CARE agreement.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data is available on request to the corresponding author.

References

Alba, R., F. Marcolin, G. Assandri, et al. 2025. "Different Traits Shape Winners and Losers in Urban Bird Assemblages Across Seasons." *Scientific Reports* 15, no. 1: 16181. https://doi.org/10.1038/s41598-025-00350-6.

Angold, P. G., J. P. Sadler, M. O. Hill, et al. 2006. "Biodiversity in Urban Habitat Patches." *Science of the Total Environment* 360, no. 1–3: 196–204. https://doi.org/10.1016/j.scitotenv.2005.08.035.

Arzberger, S., A. Fairbairn, M. Hemauer, M. Mühlbauer, J. Weissmann, and M. Egerer. 2025. "The Potential of Soundscapes as an Ecosystem Monitoring Tool for Urban Biodiversity." *Journal of Urban Ecology* 11: juaf002. https://doi.org/10.1093/jue/juaf002.

Assandri, G., R. Alba, L. Bajno, et al. 2025. "Designing the Biodiversity-Friendly City of the Future: An Avian Community Perspective on Land Sharing and Land Sparing." *Landscape and Urban Planning* 263: 105462. https://doi.org/10.1016/j.landurbplan.2025.105462.

Bibby, C. J., N. D. Burgess, D. A. Hill, and S. H. Mustoe. 2000. *Bird census techniques*. 2nd ed. Academic Press.

Bird, J. P., R. A. Fuller, P. P. Pascoe, and J. D. Shaw. 2022. "Trialling Camera Traps to Determine Occupancy and Breeding in Burrowing Seabirds." *Remote Sensing in Ecology and Conservation* 8, no. 2: 180–190. https://doi.org/10.1002/rse2.235.

Burton, A. C., E. Neilson, D. Moreira, et al. 2015. "Wildlife Camera Trapping: A Review and Recommendations for Linking Surveys to Ecological Processes." *Journal of Applied Ecology* 52, no. 3: 675–685. https://doi.org/10.1111/1365-2664.12432.

Campbell, L. A., R. A. Long, and W. J. Zielinski. 2008. "Integrating Multiple Methods to Achieve Survey Objectives." In *Noninvasive Survey Methods for Carnivores*, edited by R. A. Long, P. MacKay, W. J. Zielinski, and J. C. Ray, 223–237. Island Press.

Chanev, M., N. Dolapchiev, I. Kamenova, and L. Filchev. 2023. "Application of Remote Sensing Methods for Monitoring Wildlife Populations: A Review." *Ninth International Conference on Remote Sensing and Geoinformation of the Environment* 12786: 731–737. https://doi.org/10.1117/12.2681760.

Clarke, K. R. 1993. "Non-Parametric Multivariate Analyses of Changes in Community Structure." *Australian Journal of Ecology* 18: 117–143. https://doi.org/10.1111/j.1442-9993.1993.tb00438.x.

Diefenbach, D. R., D. W. Brauning, and J. A. Mattice. 2003. "Variability in Grassland Bird Counts Related to Observer Differences and Species Detection Rates." *Auk* 120: 1168–1179. https://doi.org/10.1642/0004-8038(2003)120[1168:Vigbcr]2.0.Co;2.

Dondina, O., P. Tirozzi, A. Viviano, et al. 2025. "Spatial and Habitat Determinants of Small-Mammal Biodiversity in Urban Green Areas: Lessons for Nature-Based Solutions." *Urban Forestry & Urban Greening* 104: 128641. https://doi.org/10.1016/j.ufug.2024.128641.

Fontúrbel, F. E., and J. E. Jiménez. 2014. "Does Bird Species Diversity Vary Among Forest Types? A Local-Scale Test in Southern Chile." *Naturwissenschaften* 101: 855–859. https://doi.org/10.1007/s00114-014-1222-y.

Fontúrbel, F. E., G. B. Rodríguez-Gómez, N. Fernández, B. García, J. I. Orellana, and G. J. Castaño-Villa. 2020. "Sampling Understory Birds in Different Habitat Types Using Point Counts and Camera Traps." *Ecological Indicators* 119: 106863. https://doi.org/10.1016/j.ecolind.2020.106863.

Fraissinet, M., L. Ancillotto, A. Migliozzi, et al. 2023. "Responses of Avian Assemblages to Spatiotemporal Landscape Dynamics in Urban Ecosystems." *Landscape Ecology* 38, no. 1: 293–305. https://doi.org/10.1007/s10980-022-01550-5.

Gelmi-Candusso, T. A., C. Brimacombe, G. Collinge Menard, and M. J. Fortin. 2023. "Building Urban Predator-Prey Networks Using Camera-Traps." *Food Webs* 37: e00305. https://doi.org/10.1016/j.fooweb.2023.e00305.

Giuliani, M., D. Mirante, E. Abbondanza, and L. Santini. 2024. "Acoustic Indices Fail to Represent Different Facets of Biodiversity." *Ecological Indicators* 166: 112451. https://doi.org/10.1016/j.ecolind.2024.112451.

Green, S. E., J. P. Rees, P. A. Stephens, R. A. Hill, and A. J. Giordano. 2020. "Innovations in Camera Trapping Technology and Approaches: The Integration of Citizen Science and Artificial Intelligence." *Animals* 10, no. 1: 132. https://doi.org/10.3390/ani10010132.

Gregg, J. J., J. Boersma, D. Nason, et al. 2024. "Lost to Science for 126 Years: Indigenous Knowledge and Camera Trapping Document the Critically Endangered Black-Naped Pheasant-Pigeon *Otidiphaps insularis*." *bioRxiv*, 2024-12. https://doi.org/10.1101/2024.12.17.628566.

Hernández-Ayala, G. A., C. González, J. Salgado-Ortiz, A. Ceja-Madrigal, J. E. Schondube, and E. Mendoza. 2025. "Camera Trapping Contributes Limitedly to Supplementing Point Count Surveys of Bird Species Richness in a Highly Threatened Tropical Forest." *Studies on Neotropical Fauna and Environment* 1: 1–12. https://doi.org/10.1080/01650521.2025.2479394.

Herrera, D. J., S. M. Moore, D. T. Tyler Flockhart, W. J. McShea, and M. V. Cove. 2021. "Thinking Outside the Park: Recommendations for Camera Trapping Mammal Communities in the Urban Matrix." *Journal of Urban Ecology* 6: 1–13. https://doi.org/10.1093/jue/juaa036.

Kiat, Y., O. Hatzofe, Y. Perlman, and I. Schekler. 2025. "Monitoring Breeding Seabird Colonies and Marked Individuals Using a Remote-Controlled Camera System." *Ornithological Applications* 2025: duaf073. https://doi.org/10.1093/ornithapp/duaf073.

Lowry, H., A. Lill, and B. B. Wong. 2013. "Behavioural Responses of Wildlife to Urban Environments." *Biological Reviews* 88, no. 3: 537–549. https://doi.org/10.1111/brv.12012.

Lüdecke, D., F. Aust, S. Crawley, and M. Ben-Shachar. 2020. "Package 'ggeffects'." Accessed December 22, 2025. https://download.nust.na/pub3/cran/web/packages/ggeffects/ggeffects.pdf.

Magnusson, A., H. Skaug, A. Nielsen, et al. 2017. "Package 'glmmtmb'. R Package Version 0.2:1–25." Accessed December 22, 2025. http://download.nust.na/pub3/cran/web/packages/glmmTMB/glmmTMB.pdf.

Monterroso, P., P. C. Alves, and P. Ferreras. 2014. "Plasticity in Circadian Activity Patterns of Mesocarnivores in Southwestern Europe: Implications for Species Coexistence." *Behavioral Ecology and Sociobiology* 68: 1403–1417. https://doi.org/10.1007/s00265-014-1748-1.

Mori, E., L. Lazzeri, F. Ferretti, L. Gordigiani, and D. Rubolini. 2021. "The Wild Boar *Sus scrofa* as a Threat to Ground-Nesting Species: An Artificial Nest Experiment." *Journal of Zoology* 314: 311–320. https://doi.org/10.1111/jzo.12887.

Mori, E., L. Lazzeri, M. Maggioni, et al. 2025. "Camera-Traps and the City: Spatiotemporal Adaptations of Wildlife to Urban Environments." *Ecological Solutions and Evidence* 6: e70115. https://doi.org/10.1002/2688-8319.70115.

O' Brien, T. G., and M. F. Kinnaird. 2008. "A Picture Is Worth a Thousand Words: The Application of Camera Trapping to the Study of Birds." *Bird Conservation International* 18, no. S1: S144–S162. https://doi.org/10.1017/S0959270908000348.

O' Connell, A. F., J. D. Nichols, and K. U. Karanth. 2011. *Camera Traps in Animal Ecology: Methods and Analyses*. Springer Science & Business Media.

R Core Team. 2024. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing Accessed November 30, 2025. https://www.R-project.org/.

Ralph, C. J., J. R. Sauer, and S. Droege. 1995. *Monitoring Bird Populations by Point Counts*. U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Ribeiro-Silva, L., D. F. Perrella, C. H. Biagolini-Jr, et al. 2018. "Testing Camera Traps as a Potential Tool for Detecting Nest Predation of Birds in a Tropical Rainforest Environment." *Zoologia* 35: e14678. https://doi.org/10.3897/zoologia.35.e14678.

Rovero, F., and R. Kays. 2021. "*Camera Trapping for Conservation*. Chapter 5." In *Conservation Technology*, edited by S. A. Wich and R. Kays, 79–104. Oxford University Press. https://doi.org/10.1093/oso/9780198850243.003.0005.

Rovero, F., and F. Zimmermann. 2016. *Camera Trapping for Wildlife Research*. Pelagic Publishing.

Santos, E. G., H. C. Wiederhecker, V. T. Pompermaier, et al. 2024. "Are Acoustic Indices Useful for Monitoring Urban Biodiversity?" *Urban Ecosystems* 27: 1975–1981. https://doi.org/10.1007/s11252-024-01567-5.

Santos-Moreno, A., G. Pérez-Irineo, and E. Ventura-Cristóbal. 2019. "Diversity of Understory Birds in a Perennial Tropical Forest at Los Chimalapas, Mexico." *Wilson Journal of Ornithology* 131, no. 3: 606–614.

Viviano, A., L. Ancillotto, O. Dondina, A. Burchielli, D. Miccolis, and E. Mori. 2025. "What a Camera Trap Survey Can Reveal About the Behaviour of an Invasive Species: Insights From Coypus *Myocastor coypus* in an Urban Park of Central Italy." *Applied Animal Behaviour Science* 284: 106534. https://doi.org/10.1016/j.applanim.2025.106534.

Viviano, A., L. Lazzeri, A. Vitale, and E. Mori. 2025. "Preliminary Data on the Activity of Male and Female Common Pheasants *Phasianus colchicus* During the Breeding Period in a Mediterranean Area." *Avocetta* 48: 2024115. https://doi.org/10.30456/AVO.2024115.

Wickham, H. 2011. "ggplot2." *Wiley Interdisciplinary Reviews: Computational Statistics* 3, no. 2: 180–185. https://doi.org/10.1002/wics.147.

Zuur, A. F., and E. N. Ieno. 2016. "A Protocol for Conducting and Presenting Results of Regression-Type Analyses." *Methods in Ecology and Evolution* 7, no. 6: 636–645. https://doi.org/10.1111/2041-210X.12577.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Species richness (mammals and birds combined) from camera traps at each of the 38 sites monitored between March 2023 and May 2024 in the metropolitan area of Firenze (central Italy). **Table S1:** Bird species detected by both survey methods, exclusively by point counts, or exclusively by camera traps during the study period from March 2023 to May 2024 in the metropolitan area of Firenze (central Italy). **Table S2:** Mammal species detected by camera traps during the study period from March 2023 to May 2024 in the metropolitan area of Firenze (central Italy).