

An examination of the relationship between urban green space,
human-nature connection, and wildlife populations

By

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A dissertation submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy
(Environment & Resources)

at the

UNIVERSITY OF WISCONSIN-MADISON

2023

Date of final oral examination: 7/27/2023

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Acknowledgements

Thank you to my advisor, David Drake, for providing guidance and encouragement throughout my academic journey. His willingness to explore and challenge my research interests resulted in many thought-provoking conversations that strengthened and shaped the quality of my research. I would also like to thank my committee members, Samuel Dennis, James LaGro, and Monica Turner. Their expectations, encouragement, and insight were essential to my growth as a researcher. Next, I would like to thank my coauthor on Chapter 2 & Chapter 3, Elizabeth Perry, for her indispensable advice, commitment, and inspiration. Her ability to find order in chaos elevated my critical thinking and time management skills. Two additional coauthors for Chapter 1, Mason Fidino, who tirelessly answered my questions regarding occupancy modeling, and Javan Bauder, who sent extensive and thoughtful emails explaining modeling theory, are greatly appreciated for their expertise and patience. I feel extremely fortunate to have had the privilege to engage with such knowledgeable and compassionate individuals.

There were many others that generously offered their time and expertise. Most notably, William Gartner, for helping me navigate ArcGIS, Karen Dunn, for guiding me through the literature review process, Maria Kamenetsky and Nicolas Keuler, for their statistical knowledge, and to the many friends and students who prioritized Saturday survey mornings, particularly Kyle Holbert, Cami Peterson, Crystal Sutheimer, and lab members Morgan Farmer and Jennifer Merems. I could not have conducted the park research project without their commitment and flexibility. I would like to extend a special thank you to Crystal Sutheimer for also assisting me with the identification of thousands of photographic images for Chapter 1.

Finally, I would like to thank my family for their endurance and support throughout my academic experience. They never hesitated when I asked for help, whether it involved color schemes, camera traps, or picking up a clipboard to fill in a gap on the survey team. I am truly grateful.

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Abstract

As urban populations continue to increase worldwide, there is growing emphasis to address the intersectionality between urban green space, human-nature connection, and wildlife populations. In Chapter 1, I focused on identifying the landscape factors, both anthropogenic and natural, associated with the presence of several common terrestrial mammal species. My goal was to present information toward understanding the taxa-specific landscape features associated with highly adaptable urban species as well as underscore the shortcomings of these areas for a broader range of taxa. Our results indicated that the presence of anthropogenic features rather than any particular natural land cover may be driving wildlife distribution in our study area, as none of our species demonstrated a positive association to natural land cover. In Chapter 2, I focused on people in green spaces, specifically visitors to community and conservation parks, and used surveys to identify explanatory factors associated with human-nature connection. My objective was to provide additional understanding of the role of urban green space, recreation activities, and wildlife literacy and sentiment in informing human-nature connection. Across the park response groups, the number and frequency of childhood and adult recreation experiences demonstrated significant positive associations to HNC, as did species literacy and sentiment, visiting a park for 'nature', and frequent and extended visitations. Throughout my research for Chapter 1 and Chapter 2, the potential of urban green space to provision a greater diversity of wildlife and cultivate human-nature connection was a recurring theme. In Chapter 3, I conducted a literature search to determine the extent that urban green space could support bird richness, specifically songbird richness. My goal was to provide urban practitioners with viable options to generate design ideas that have known positive effects on songbird richness and are feasible for densely populated areas. Based on our findings we present several recommendations: (1) allocate green space of any feasible size; (2) incorporate a variety of native plant species, particularly tree species; (3) incorporate native habitat diversity, including open grass areas; (4) integrate water; (5) place green spaces in historically under-resourced areas and connect spaces through green corridors; and (6) plan for the temporal transformation

of green spaces. Although it is doubtful that a single green space will have overwhelming appeal to people and wildlife, the tremendous potential of these communal spaces to keep people connected to and caring about nature is clear.

Introduction

Urbanization is commonly characterized by high human density and impervious cover concentrated around a core (Kaminsky et al., 2021, McDonnell & Pickett, 1990). However, the appearance of urbanization is dependent on many factors, natural (e.g., flooding) and anthropogenic (e.g., industrialization), that have occurred throughout the history of an area (Haase & Nuissl, 2010, Nuissl et al., 2021). In particular, factors such as urban age, geography, economics, human population dynamics, street networks, and water resources have shaped city-specific expansion and densification patterns (Barrington-Leigh & Millard-Ball, 2015, Leyk et al., 2020, Steele & Wolz, 2019). In addition, urban areas shaped by coinciding human choices can share a strong resemblance, one dominated by mowed turf, ornamental horticulture, and impervious surfaces, as has been noted in several U.S. metropolitan areas across multiple climates (Groffman et al., 2014). Understanding the patterns of urbanization provides valuable information regarding the range and magnitude of factors that have influenced human and wildlife populations over time, as well as prioritizes essential elements necessary to support humans and wildlife across varying degrees of urbanization (Beninde et al., 2015, Nilon et al., 2017, Seto et al., 2011).

Although differences in landscape patterns exist across cities, characterizing qualities of urbanization include natural habitat loss and fragmentation and a reduction in habitat connectivity that results in a decrease in native biodiversity and an increase in species homogenization (Beninde et al., 2017, Forman, 2016, Lepczyk et al., 2017). The drivers of these alterations are linked to multiple human activities, including land and water management practices, population growth, socioeconomic status, and lifestyle choices that can result in fragmented, simplified, and replicated urban ecosystems worldwide (Angel et al., 2021, Groffman et al., 2014). These landscape changes present multiple challenges to wildlife, including higher noise levels, artificial lighting, pollution, and collisions with vehicles and buildings (McPherson et al., 2021, Thatcher et al., 2019, Tuomainen & Candolin, 2011).

For humans, urbanization can offer social, cultural, and economic opportunities that are unrealized outside of a metropolitan area (Gebre & Gebremedhin, 2019). However, urban residents also experience

a higher risk for developing physical and mental health conditions, in large part from environmental pollutants generated by concentrated human populations and motorized transportation, but also from factors associated with a predominantly impervious landscape and a lack of proximity to nature (Dye 2008, Jennings et al., 2017, Lederbogen et al., 2011, Reyes et al., 2012). With the majority of the global human population projected to live in urban areas over the next three decades, cities are also becoming our primary source of contact with nature (Keniger et al., 2013, Soga & Gaston 2016, Standish et al., 2013). This connection, generally referred to as human-nature connection, is essential to the long-term valuation of the environment and global environmental sustainability (Restall & Conrad 2015, Whitburn et al., 2020).

For wildlife, alteration to the form and functionality of landscapes results in a transformation that often has a pronounced presentation when observed along an urban to rural gradient (Fidino et al., 2021). Typically, a pattern of habitat loss, degradation, and fragmentation intensifies from rural to urban areas, resulting in a reduction of essential resources for a broad range of taxa that can have persistent deleterious effects on native wildlife populations (Haddad et al., 2015, Liu et al., 2015, Nielsen et al., 2014). Specifically, changes can result in a proportional shift toward urban adaptive and urban dwelling species that are more tolerant of human activity (noise, light, traffic, and pollution) and are able to utilize anthropogenic food, water, and shelter resources (Beninde et al., 2015, Benitez-Lopez et al., 2010, Evans et al., 2011, Kaminski et al., 2021, McKinney 2002). A noticeable increase in species diversity can occur between rural and urban areas where a relatively greater abundance of natural and anthropogenically provided habitat, greater vegetative heterogeneity, and less human activity occurs (McKinney 2008). Yet, suburban areas remain inadequate for many wildlife species, including those that require lower human activity, forested and deadwood landscapes, ecological succession, or larger or connected native landscapes (McKinney 2008, McPherson et al., 2021, Patterson et al., 2018).

One of the solutions to supporting higher biodiversity, as well as humans, is by incorporating ecologically diverse landscapes into metropolitan areas (Beatley & Newman 2013, Connop et al., 2016, Jorgenson &

Gobster, 2010). In the past, the timing, placement, and criteria for incorporating public urban green space has been driven by social mediation, and land values (Loughran 2020, Rosenzweig and Blackmar, 1992). Green space allocation was often planned to simultaneously compensate for a lack of nature, reduce residential overcrowding, promote racial separation, and bolster current and future land values (Loughran 2020, Rosenzweig and Blackmar, 1992). More recently, these former objectives have been revised to prioritize the value of urban green space in supporting a wide range of human welfare and conservation goals through ecosystem services (Connop et al., 2016, Harnik 2010). Pocket parks, bioswales, green roofs, community gardens, and even unmanaged vacant lots provide thermal and water regulation, habitat for wildlife, and opportunities for residents to connect with nature and one another, among other ecosystem services (Connop et al., 2016, Rega-Brodsky et al., 2018).

Green space that has known positive effects on humans and wildlife can provide a necessary counterbalance to the anthropogenic influence in cities (Apfelbeck et al., 2020, Felappi, et al., 2020). Specifically, adding or expanding multi-species, native treescapes, establishing low and mid-level native vegetation, and incorporating ecologically based water installations may provide necessary resources to expand urban biotic assemblages that include less abundant species, such as amphibians, suburban or urban avoiding avian species, and small mammals (Ikin et al., 2013, Smallbone, et al., 2011). However, weighing species-specific resource requirements with the interactive effect of vegetative heterogeneity and functionality is necessary to avoid the overgeneralization of green space solutions (Stirnemann, et al., 2015). Parks are an example of public urban green spaces concurrently utilized by people and wildlife. These spaces also promote experiences in nature that are a predominant mechanism for the development of human-nature connection (Riechers et al., 2021). These overlapping consequences suggest tremendous potential for parks to simultaneously support human-nature connection and conservation objectives.

As urban populations continue to increase worldwide, there is growing need to address the intersecting potential of human-nature connection and biodiversity conservation in urban green space. Chapter 1 (Hayes Hursh et al., 2023) identified environmental features, both anthropogenic and natural, associated

with the presence of several urban mammal species. The goal was to provide recommendations to urban practitioners that will result in the design of urban green space with ecological elements that support a greater range of wildlife taxa. Chapter 2 (under revision) focused on identifying the explanatory factors associated with human-nature connection by surveying individuals that intentionally visited two contrasting urban green spaces, one with multiple physical and social amenities (community parks) and the other largely managed for wildlife (conservation parks). By examining a suite of factors identified as influential throughout the corresponding literature, the goal was to provide additional understanding of the role of urban green space, recreational activities, and wildlife in informing human-nature connection. Chapter 3 (in preparation) was a literature review of urban green space land cover and use factors and the species of songbirds associated with those spaces. This line of inquiry blended the objectives of the first two chapters and provided a useful reference to urban practitioners interested in expanding the conventional role of human-centered urban green space to include songbird conservation.

Although a single urban green space has limited capacity to appeal to all people and wildlife, the importance of these communal spaces remains a key strategy toward enhancing nature connections and can serve to reduce the impacts of anthropogenic landscapes on human and wildlife wellness. My dissertation examines the reinforcing relationship between urban landscapes, human-nature connection, and wildlife populations that is critical to understanding how to keep people connected to nature in our rapidly growing urban environments.

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Chapter 1: An urban cast of characters: Landscape use and cover influencing mammal occupancy in an American midwestern city

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Citation: Hayes Hursh, S., Bauder, J. M., Fidino, M., & Drake, D. (2023). An urban cast of characters: Landscape use and cover influencing mammal occupancy in an American midwestern city. *Landscape and Urban Planning*, 229, 104582. <https://doi.org/10.1016/j.landurbplan.2022.104582>

Abstract

With future human population growth concentrating in urban areas, cities are working to counterbalance ecological disturbances resulting from development by incorporating green space that supports greater biodiversity. An initial line of inquiry into designing wildlife-inclusive green space involves evaluating landscapes that are associated with the habitat use of urban species. In this study, we utilized occupancy modeling to estimate select terrestrial mammal presence in a fast-growing mid-sized midwestern city to determine possible taxa-specific associations with multiple land use and cover variables, specifically those associated with higher degrees of human activity. Using motion-triggered infrared trail cameras over eight seasons from winter 2017 to fall 2018, we applied a single-species, single season stacked design to estimate occupancy for eight urban dwelling mammals. Taxa-specific models contained one of three possible detection variables (null, percent green space, or percent impervious surface) and combinations of three species-specific variables, natural and anthropogenic. We hypothesized that large

species, coyote (*Canis latrans*) and white-tailed deer (*Odocoileus virginianus*), would exhibit the most positive association to natural land cover and the most negative association to anthropogenic land cover. We also hypothesized that small and medium sized species, eastern cottontail (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), opossum (*Didelphis virginiana*), raccoon (*Procyon lotor*), red fox (*Vulpes vulpes*), and striped skunk (*Mephitis mephitis*), would demonstrate a neutral association to land cover type, anthropogenic or natural. Our results indicated that the presence of anthropogenic features rather than any particular natural land cover may be driving wildlife distribution in our study area, as none of our species demonstrated a positive association to natural land cover (percent recreation, residential yards, vacant land, or woodland). Species with a wide range of body sizes showed a negative association with residential yards, indicating that this type of green space may be an unnecessary or unsuitable subsidizing resource in our study area. With our results in mind, we recommend increasing the amount of natural or less manicured green space to offset the intensity of impervious surface as well as encouraging the establishment of native vegetation in existing and newly constructed residential development to better connect urban green space and residential yards to larger adjoining tracts of natural landscapes. For our study area and other cities in similar phases of development, these suggestions may be essential first steps to reduce biodiversity loss and strengthen community ecology as urban areas continue to grow.

Introduction

The expansion of a city's human population and its corresponding physical footprint reshapes terrestrial ecosystems and resources (Güneralp et al., 2020, Liu et al., 2016, Magle et al., 2021). With each urban landscape presenting a dynamic combination of unique structural, ecological, and demographic properties, cities are experiencing a variety of sustainable development challenges, including the consequences of urbanization on flora and fauna (Aronson et al., 2017, Beninde et al., 2015, Lepczyk et al., 2017). For wildlife, the transformation of a natural or vegetated area into an anthropogenic environment can lead to habitat degradation, loss, or fragmentation, as well as endemic biodiversity loss, particularly where natural areas become isolated from one another (Liu et al., 2016, Nielsen et al., 2014).

In addition, environmental modifications, such as human structures, street lighting, and artificial acoustical amplification can alter a landscape's suitability for a broad range of taxa as well as inflict persistent and deleterious influences on ecosystem resilience and services, species dispersal patterns, and genetic and evolutionary responses to environmental change (Benitez-Lopez et al., 2010, Evans et al., 2011, Haddad et al., 2015, Johnson & Munshi-South, 2017).

While many wildlife species' life cycles are incompatible with the sights and sounds endemic to human-altered landscapes, other species gravitate toward novel urban environments, finding opportunities unrealized in their natural environment (Breck et al., 2019, Kark et al., 2007, Fleming & Bateman, 2018). Even species thought to be maladapted to human dominated landscapes can succeed there, which is often attributed to heightened resource availability, behavioral plasticity, and ingenuity (Breck et al., 2019, Kark et al., 2007). Mexican free-tail bats (*Tadarida brasiliensis*) roosting under highway bridges and peregrine falcons (*Falco peregrinus*) nesting on the ledges of skyscrapers, cathedrals, and university buildings across the United States and Europe are two of the many examples of synanthropic species capitalizing on anthropogenic assets (Caballero et al., 2016, Capoccia, et. al., 2018, Keeley & Tuttle, 1999). In addition, recurring assemblages of species often appear across distinct geographic regions and along varying degrees of urbanization (Fidino et al., 2021, Magle et al., 2019). Commonly observed species, such as red fox (*Vulpes vulpes*) and American crow (*Corvus brachyrhynchos*) repeatedly occur across regional cities and have a distribution that aligns positively with human-dominated landscapes (Leong and Trautwein, 2019).

Urban dwelling and urban utilizing species are equipped to take advantage of anthropogenic features that imitate nature or enhance survival strategies and often adjust their behavior in response to heightened human activity (Beninde et al., 2015, Fischer et al., 2015, Kettel et al., 2018). Individual skill sets vary by taxa, but species generally have advantageous niche positions or breadth and employ a broad range of behavioral strategies that are beneficial in multiple habitats or varying levels of disturbance, including cities (Devictor et al., 2008, Evans et al., 2011). Many urban avian species have adapted to exploit

anthropogenic food and nesting resources and avoid urban risks, exhibiting broader habitat breadth, nesting habits, and greater breeding attempts than urban avoiding species (Sol et al., 2014). One of the most prevalent attributes of urban dwelling and urban utilizing vertebrate species is lacking an aversion to environmental novelty, which allows those species to occupy a variety of modified habitats (Ducatez et al., 2018). Although the repertoire of urban species is not limitless, there is a portion of species that not only survive but thrive in a multitude of environmental alterations (Aronson et al., 2014, Johnson & Munshi-South, 2017, Shochat, 2004).

Despite some species being able to make use of select urban resources, landscapes with greater habitat heterogeneity can provide increased opportunities for food, shelter, and space which may increase taxonomic diversity among urban wildlife and enhance ecosystem resilience (Aronson et al., 2014, Beninde et al., 2015, Lovell & Taylor 2013, Stirnemann et al., 2015, Van Helden et al., 2020). In an effort to offset biodiversity loss and strengthen community ecology, there is a growing initiative to intentionally design urban green space to be wildlife-inclusive (Apfelbeck et al., 2020, Nilon et al., 2017, Weiss & Ray 2019). Although competing interests in urban real estate can make this objective challenging, cities are incorporating wildlife enhancing designs that promote greater biodiversity within existing urban areas and simultaneously deliver a broad range of benefits to humans (Ives et al., 2017, Twohig-Bennett & Jones, 2018). A springboard to understanding how anthropogenic landscapes shape wildlife community composition involves the synthesis of multiple lines of inquiry (Magle et al., 2021). Identifying resource preferences for multiple species to thrive in human-altered landscapes involves a comprehensive understanding of the complexities and nuances of individual species as well as the cities and surrounding areas where they reside (Fidino et al., 2021, Weiss & Ray 2019). This can be a challenging and imperfect process. However, investigations comparing urban matrices of varying sizes are key to identifying environmental variables associated with synanthropic species (Aronson et al., 2014, Fidino et al., 2021, Greenspan et al., 2018). When applied collectively, these multi-taxa studies can have

numerous applications, including how to modify cityscapes to be more inclusive for a broader range of taxa (Filazzola et al., 2019, Pierce et al., 2020).

Exploring more specific associations in urban environments, such as distance to wooded areas, access to natural water sources, or density of roadways or buildings helps provide a more complete narrative of the factors influencing species presence (Fidino et al., 2016, Stirnmann et al., 2015). For example, coyote (*Canis latrans*) and raccoon (*Procyon lotor*) are more likely to be present on golf courses compared to white-tailed deer (*Mephitis mephitis*) (Gallo et al., 2017). For other common urban species, such as Virginia opossum (*Didelphis virginiana*, hereafter opossum) and striped skunk (*Mephitis mephitis*), the connectivity of green space to forest patches or access to water has a dominant effect on occupancy (Greenspan et al., 2018, Lesmeister et al., 2015). Identifying the landscape features, both natural and anthropogenic, that are associated with urban dwellers can provide insight into landscape deficiencies that likely need to be addressed by urban practitioners to support urban avoiding species and increase biodiversity and resilience (Greenspan et al., 2018, Lesmeister et al., 2015, Sol et al., 2014). As each city has a unique history that has shaped its spatial configuration, human demographic, and in turn, its wildlife diversity, it is imperative to explore how species ecology differs in varying sized cities (Łopucki & Kitowski, 2017, Steele & Wolz, 2019). Studies based in larger cities generate a disproportionate share of urban wildlife research, while small and mid-sized cities remain largely underrepresented in the literature (Kendal, et al., 2020). In conjunction with less representation, many of these smaller urban areas are also experiencing some of the fastest growth rates, further emphasizing the importance of identifying attributes that positively influence wildlife so they can be incorporated in planning decisions as growth occurs.

The goal of our study was to address knowledge gaps regarding the presence of terrestrial mammals in fast-growing mid-sized cities and identify the urban land use and cover associated with mammal presence. Our specific objective was to use occupancy models to estimate habitat use rates across terrestrial mammal species and determine possible species-specific associations with multiple land use and cover variables, particularly those associated with higher degrees of human presence. We

hypothesized that coyote and white-tailed deer, the large species in our study, would most frequently use areas with high levels of green space and would have the strongest positive associations to natural land cover and the strongest negative associations to anthropogenic land cover. (Greenspan et al., 2018, Grund et al., 2002). Both of these species are known to have large home ranges and are more likely to be associated with wooded areas and larger vegetated corridor habitats that provide food and cover (Atwood et al., 2004, Grund et al., 2002). We also hypothesized that small and medium sized urban dwelling species — eastern cottontail (*Sylvilagus floridanus*), gray squirrel (*Sciurus carolinensis*), opossum, raccoon, red fox, and striped skunk — would be widespread throughout our study area and have neither a strong positive nor a strong negative association with natural or anthropogenic land cover (Fidino et al., 2021, Johnson 2016). As urban dwellers, these species are likely making multiple adjustments depending on landscape opportunities, utilizing food and shelter resources in natural areas, as well as anthropogenic substitutes found in urban areas (Abu Baker et al., 2015, Bonnington et al., 2014, Greenspan et al., 2018, Lesmeister et al., 2015). By examining the landscape associations of common and widespread North American mammals in a fast-growing mid-sized city, we hope that our findings will provide insight into mammal responses to current levels of urbanization, as well as provide guidance for offsetting a decline of wildlife diversity as urbanization expands.

Methods

Our study was conducted along a 29 km transect in Dane County, Wisconsin, USA, and extended through the greater Madison area (Figure 1). The transect traversed a corridor containing varying proportions of land cover and use such as buildings, transportation, residential yards, impervious surfaces, and green space. Madison has a population of approximately 260,000 residents covering approximately 260 km² and is located in south central Wisconsin in the four county Madison Metropolitan Statistical Area (US Census Bureau, 2019). Madison is currently the fastest growing city in Wisconsin with population growth of 1.5 times the national average (US Census Bureau, 2019). Madison is home to the state capital and the University of Wisconsin-Madison and is within the Yahara Watershed, now largely dominated by

agricultural (65%) and urban land cover (20%), with the remainder in scattered remnants of forest, wetland, or open water (Carpenter et al., 2007). The area experiences four distinct seasons, with temperatures averaging 7.7 C in spring (March/April/May), 20.7 C in summer (June/July/August), 9.3 C in autumn (September/October/November), and -5.7 C in winter (December/January/February) (Wisconsin State Climatology Office, 2010). Rainfall and snowfall averages, respectively, are 7.75 cm and 8.46 cm in spring (March/April/May), 10.98 cm and 0 cm in summer (June/July/August), 6.71 cm and 4.24 cm in autumn (September/October/November), and 3.73 cm and 32.18 cm in winter (December/January/February) (Wisconsin State Climatology Office, 2010).

We placed twenty-four Bushnell TrophyCam© motion-triggered infrared trail cameras (Model #119436C, Overland Park, Kansas, USA) along the transect, with 17 cameras placed along shared-use paved trails, the Southwest Commuter Trail, Capital City Trail, and Starkweather Creek Path. Four cameras were placed north of the Starkweather Creek Path and the remaining three cameras were placed south of the Southwest Commuter Trail along the Badger State Trail. Cameras were positioned on public and private land and placed at a minimum of 800 m apart to reduce the probability of detecting the same individual at multiple cameras.

Camera traps were placed at each location for at least 28 consecutive days in January, April, July, and October in 2017 and 2018 (8 seasons total, details in Vernon et al., 2014). Cameras were strapped approximately 1 m from the base of a tree, light post, or utility pole and angled downward to contain the field of view to < 8 m. Cameras were positioned away from areas of higher human activity (e.g., trail access points or parking lots) to reduce the incidences of vandalism or theft and to reduce the number of human images on the memory cards that result in rapid battery depletion. Batteries and memory cards were changed two weeks after each seasonal deployment. A synthetic fatty acid disk (United States Department of Agriculture, Pocatello, Idaho) was placed in a mesh bag and attached to vegetation approximately 30 cm from the ground and ≤ 6 m from the camera directly within the camera's field of view, resulting in the virtual presentation of the disk at the center of the photo images (Magle et al.,

2016). As this lure likely does not increase the detectability of these species (Fidino et al., 2020), we did not expect the use of lure to influence the results of our analysis. Photo data were uploaded and evaluated with a customized Access (Microsoft, Redmond, Washington) database designed for camera imagery research (Ivan & Newkirk, 2016). We then created detection histories for each study species and site using each camera deployment day within the 28-day sampling period as a repeated site visit. A detection history was coded '1' if a species was detected during a given day, '0' if a species was not detected, and '.' if the camera was not operable or not present (i.e., stolen).

We calculated the percent coverage of ten land cover covariates within a 400-m and 800-m diameter buffer around each camera site using ArcGIS 10.6.1 (Esri, Redlands, California) and Dane LandUse 2015 and Dane Buildings YE2016 through Dane County's online geoportal at GeoData@Wisconsin (UW-Madison Robinson Map Library, Madison, WI) (Appendix A). Using a t-test with $p < 0.05$, we found no significant differences when comparing our ten covariates across the two different buffer sizes, so we used the 800-meter diameter buffer size in order to examine the largest amount of area possible. We calculated percent impervious surface as the sum of percentage of buildings (%buildings), transportation (%transportation), sidewalks, and parking areas (Appendix A). We also calculated the percentage of green space (%green space) as the sum of percentage of agriculture (%agriculture), recreation (%recreation), open land (%open land), vacant land (%vacant land), and woodland (%woodland) (Appendix A). Finally, we measured the Euclidean distance of each camera site to the nearest water, rail and road edge using ArcGIS 10.6.1 and GeoData@Wisconsin.

Our sample sizes were insufficient to evaluate a dynamic occupancy model estimating among-season colonization and extinction rates (McKann et al., 2013). We therefore modeled data for our study species using single-species, single-season occupancy models and used a stacked design by including sampling site as a random effect for occupancy and detection to account for repeat sampling among sites (Crum et al. 2017, MacKenzie et al., 2003). Because the habitat patches we surveyed were likely too small to permit site closure and may not be of sufficient size to house a local population of a given species, we

interpreted occupancy and detection as habitat use and intensity of use, respectively. We fit our models using the package *unmarked* (Fiske & Chandler, 2011) in Program R (v. 3.6.1, R Core Team 2019). We calculated a Pearson's correlation coefficient between all covariates and did not include variables with $|r| > 0.60$ in the same model (Table 1). All continuous covariates were z-score standardized before analysis.

We developed our models using a two-stage process for each species. In Stage 1, three detection models (null, percent green space, and percent impervious) were evaluated and ranked using Akaike's information criterion, adjusted for small sample size (AICc), to determine the optimal detection model. The best fit detection model was paired with the species-specific occupancy models generated in the next stage. In Stage 2, we modeled occupancy using two models (hereafter Yards & Transportation Model or Buildings Model), each of which contained all combinations of three species-specific variables. We selected the variables for each species based on previous research from natural and urban environments in combination with the local knowledge of our study area. We attempted to minimize model overfitting and the selection of inconsequential variables due to excessive model testing, particularly given our limited sample size (Appendix C, Burnham and Anderson, 2003). In order to include both anthropogenic and natural species-specific landscape features with $|r| \leq 0.60$, limit covariates to accommodate smaller sample sizes, examine the role of residential yards, and maximize model convergence, the Yards & Transportation Model contained percent residential yards and percent transportation along with a third species-specific covariate (percent woodland, distance to water, or percent recreation) and the Buildings Model contained percent buildings and two additional species-specific covariates (percent recreation, percent vacant land, distance to water, distance to road edge, or distance to rail edge). Percent transportation and percent buildings present different considerations for wildlife and as such were included in the Yards & Transportation Model and the Buildings Model, respectively (Elmore et al., 2021, van der Ree et al., 2011). We therefore fit eight occupancy models (seven models with a detection variable and one to three occupancy variables, plus a null [i.e., random intercept-only] model for occupancy) from the Yards & Transportation Model and eight models from the Buildings Model for each

species. We ranked models using AICc and excluded models that failed to converge. The models with an $\Delta AICc \leq 2$ were selected as the models that best explained our data and model weights were calculated for all competitive models. We drew inferences from covariates within competitive models whose 95% CI excluded zero.

Results

We detected 14 mammal species but excluded eastern chipmunk (*Tamias striatus*), mink (*Neovison vison*), muskrat (*Ondatra zibethicus*), thirteen-lined ground squirrel (*Ictidomys tridecemlineatus*), woodchuck (*Marmota monax*), and mice (unknown species) from analysis due to inadequate numbers of detections. We recorded 11,565 detections of eight focal mammal species at 24 camera trap locations over 224 trap nights in 2017 and 2018: 5410 gray squirrel, 4379 eastern cottontail, 772 raccoon, 757 opossum, 107 white-tailed deer, 67 coyote, 48 striped skunk, and 25 red fox. The percentage of sites where focal species were detected at least once across the entire study varied: eastern cottontail (95.8%), gray squirrel (91.7%), opossum (91.7%), raccoon (79.2%), red fox (50.0%), coyote (45.8%), striped skunk (45.8%), and white-tailed deer (37.5%) (Table 2).

Components of impervious surface were in the top models for four of the eight species: coyote, eastern cottontail, striped skunk, and white-tailed deer (Table 3, Appendix A). Eastern cottontail and coyote had percent buildings in their top model, with percent buildings being positively associated with eastern cottontail ($\beta = 1.60$, 95% CI = 0.69 — 2.52) and negatively associated with coyote ($\beta = -3.28$, 95% CI = -4.44 — -2.13) (Table 4, Figure 2). Eastern cottontail and red fox had distance to water in their top model, with distance to water being negatively associated with eastern cottontail occupancy ($\beta = -0.86$, 95% CI = -1.58 — -0.13), and weakly but positively associated with fox occupancy ($\beta = 1.15$, 95% CI = -0.28 — 2.58) (Table 4, Figure 2). Eastern cottontail and coyote had distance to road edge or distance to rail edge in their top model, with distance to road edge positively associated with Eastern cottontail occupancy ($\beta = 1.04$, 95% CI = 0.10 — 1.98) and distance to rail edge positively associate with coyote occupancy ($\beta =$

3.72, 95% CI = 2.16 — 5.27) (Table 4). Both striped skunk and white-tailed deer had percent transportation in their top model, with striped skunk having a weak but positive association ($\beta=1.07$, 95% CI = -0.27 — 2.40) and white-tailed deer having a weak but negative association ($\beta= -1.29$, 95% CI = -2.95 — 0.37) (Table 4).

Percent residential yards was present in the top model for four of our eight species: gray squirrel, opossum, striped skunk, and white-tailed deer (Table 4). The relationship between percent residential yards and species occupancy was negative for all species, gray squirrel ($\beta= -1.25$, 95% CI = -1.51 — -1.00), opossum ($\beta= -0.62$, 95% CI = -1.18 — -0.07), striped skunk ($\beta= -1.38$, 95% CI = -2.46 — -0.30), and white-tailed deer ($\beta= -1.61$, 95% CI = -2.88 — -0.34) (Table 4, Figure 2). Coyote was the only species with percent recreation in the top model and that association was negative ($\beta= -1.64$, 95% CI = -2.24 — -1.04) (Table 4). For raccoon, the null model was the top explanatory model with high estimated occupancy (mean= 0.92, 95% CI = 0.91 — 0.93) (Table 4). Coyote, red fox, striped skunk, and white-tailed deer had more than one competitive model. Cumulative AICc weights across competitive models ranged from 0.30 to 0.70 for coyote, 0.46 to 0.70 for red fox, 0.36 to 0.64 for striped skunk, and 0.47 to 0.67 for white-tailed deer (Table 3, Appendix B). The remaining four focal species had a single competitive model whose weight ranged from 0.55 for eastern cottontail to 0.87 for opossum (Table 3).

The top model evaluating covariate effects on detection included either percent green space or percent impervious for five of the eight focal species (Table 3). Gray squirrel, raccoon, and red fox each had the null model with a site random effect as the top detection model. Coyote, opossum, and striped skunk detection probability decreased with increasing percent impervious, whereas eastern cottontail detection probability decreased and white-tailed deer detection probability increased with increasing percent green space (Table 3).

Discussion

Eight urban dwelling mammal species common throughout Madison, WI had dramatic differences in their landscape associations, including an unexpected negative association with residential yards. As predicted, the two large species, coyote and white-tailed deer, persisted in areas of our transect with the highest degree of green space, with each species having a negative association to anthropogenic land cover. However, neither species had a positive association to natural land cover, which may indicate that the presence of urban development rather than any particular natural land cover is the primary driver of urban distribution of these species. Coyote showed the strongest negative association with both percent buildings and percent recreation among our study species. In addition, white-tailed deer demonstrated a negative association with percent transportation and percent residential yards. As both of these species are known to utilize low disturbance areas that provide food and cover, the lack of a positive association with recreation areas or residential yards may be a result of lesser habitat quality or connectivity within these types of green spaces (Mueller et al., 2018, Potapov et al., 2014). It is also possible that increased human activity associated with recreation areas and residential yards may be contributing to a lack of coyote and white-tailed deer presence. However, these species, as well as many other urban dwelling species, are known to utilize areas with relatively high human density by developing a habituation to humans or through temporal avoidance (Gaynor et al., 2018).

Our hypothesis that small and medium urban dwelling species would be present throughout our transect, having neither a strong positive nor strong negative association with any particular natural or anthropogenic land cover, was only supported by raccoon. Raccoon were nearly ubiquitous throughout our transect. Madison still has a low human population density relative to its area combined with a high amount of greenspace, so development intensities may be insufficient to affect raccoon habitat use (Fidino et al. 2021). Given the pervasive nature of raccoon in anthropogenic landscapes along with a lack of competition for food resources utilized by guild members, this species is provided with a wide range of opportunities that allow them to successfully occupy a diverse range of habitats (Gehrt & Prange,

2007, Gross et al., 2012, Lesmeister et al., 2015). Interestingly, for three of the remaining four species in this group, gray squirrel, opossum, and striped skunk, we found a strong negative association to residential yards, a contradiction with the many studies showing the subsidizing role of residential yards to urban wildlife (Lerman et al., 2021, Van Helden et al., 2020).

Six of our eight focal species (gray squirrel, opossum, raccoon, red fox, striped skunk and white-tailed deer) had no strong association with impervious cover and were detected at sites with impervious cover ranging from 10-93%, an outcome that corresponds with the ability of these urban dwelling species to utilize a broad range of available natural and anthropogenic resources (Table 2) (Fidino et al., 2021, Greenspan et al., 2018). Eastern cottontail and striped skunk demonstrated a positive relationship corresponding to the percent buildings and percent transportation, respectively, and occurred at sites with the highest percent impervious surface. For eastern cottontail, this association may be attributed to supplementary food, shelter, and nesting resources that often accompany buildings in the form of canopy cover or landscaping in addition to a reduction in predator presence in areas with higher percentages of buildings (Abu Baker et al., 2015, Gallo et al., 2019). For striped skunk, a positive, albeit weak, association with percent transportation may also be attributed to supplementary resources associated with buildings, as the percent transportation and percent buildings had a correlation coefficient of $|r| = 0.75$ (Table 1). Our study did not evaluate specific qualities of roadways and further investigation into road ecology may provide a stronger explanation of striped skunk association with areas containing higher percentages of transportation (Barthelmess 2014, Lesmeister et al., 2015, van der Ree et al., 2011). However, striped skunk are known to be urban dwellers so their lack of detection at nearly 60% of our sites may be due to our camera placement as opposed to any pronounced landscape variables (Fisher & Stankowich, 2018, Prange & Gehrt, 2007).

None of our species demonstrated a positive association with natural land cover, percent recreation, residential yards, vacant land, or woodland. In fact, one of the most pronounced outcomes of our study was the negative association with residential yards for four species with a wide range of body sizes (gray

squirrel, opossum, striped skunk, and white-tailed deer). Initially, this finding seems to contradict evidence corroborating the supportive role of residential yards, especially given that these species are common denizens of residential landscapes (Bonnington et al., 2014, Lerman et al., 2021, Van Helden et al., 2020). However, additional studies have found that residential development can have a negative association with mammal occupancy because natural areas that provided understory and canopy cover are replaced with new or expanding housing developments and associated roadways (Haskell et al., 2013, Murray & St. Clair 2017, Ossola et al., 2019). Although beyond the scope of this study, further investigation into the size, vegetative heterogeneity, and connectivity of residential yards may explain the negative association our species had to residential resources. For example, residential yards that are less manicured and contain greater amounts of native vegetation and cover have been shown to have higher biodiversity, including species that generally avoid urban environments (Farr et al., 2020, Lerman et al., 2021). Residential green space in rapidly expanding cities like Madison may lack these design qualities and instead contain higher amounts of manicured lawns, less established vegetation because of the young age of newly constructed residential areas, and non-native vegetation that provides inadequate food and shelter resources.

Although the quality of residential yards may explain the lack of positive association to this type of green space for four of our species, the outcome may also be a result of green space availability in Madison. Throughout the city's development, there has been a commitment to increasing and preserving natural drainageways and natural area acreage (City of Madison Parks Division, 2022). Today, the City of Madison Parks Division oversees more than 270 parks that comprise more than 5,600 acres of land, including over 1,750 acres of conservation areas that are largely managed to preserve native landscapes, wildlife, and vegetation (City of Madison Parks Division, 2022). Madison and cities of similar size and development are currently experiencing more dispersed forms of expansion and likely have different types and sizes of natural and semi-natural green spaces, relative to larger cities experiencing higher rates of infill development (Vogler & Vukomanovic, 2021). Wildlife species that may commonly use

residential yards in other cities may not be obligated to do so in Madison because much of the green space is interspersed throughout the city, in close proximity to residential areas, or connected by way of natural and anthropogenic corridors, such as waterways or shared-use paved trails.

Although our study was able to identify landscape features associated with use by several urban dwelling mammals, our results are limited by a relatively small sample size. As such, our model development required us to broadly categorize green space, such as percent recreational areas and percent residential yards, and did not allow us to incorporate less abundant land cover classes such as agricultural areas, open land, vacant land, and woodland, where our target species were detected. In addition, we did not evaluate the quality or connectivity of green spaces, which are known to influence species presence (Greenspan et al., 2018, Lesmeister et al., 2015, Markovchick-Nicholls et al., 2008). Small sample sizes and model convergence issues also prevented us from assessing seasonal variation in mammal-landscape associations, which could occur given Madison's seasonal differences. Finally, evaluating relationships between urban landscape features and wildlife behaviors, such as foraging, mating, or transitory movements, could provide additional insights into how wildlife use urban environments yet was beyond the scope of our study.

Conclusions

Overall, our findings present valuable information toward understanding the taxa-specific landscape features associated with highly adaptable urban species as well as underscore the shortcomings of generalizing the potential benefit of green space, particularly residential yards. As Madison and cities in similar phases of development continue to grow, they have a time sensitive opportunity to proactively plan for and strategically incorporate green space that is functional, connected, and designed to expand urban biotic assemblages (Apfelbeck et al., 2020, Nilon et al., 2017, Weiss & Ray 2019). In particular, if urban species are responding more negatively to anthropogenic land cover than positively to natural land cover, as was found in our study, reducing the intensity of impervious surface through the integration of

natural or less manicured green space may be an essential first step. In conjunction with increasing the quality of green space, incentivizing the coordination of neighborhood initiatives that incorporate landscapes containing native vegetation can help to establish more contiguous wildlife habitat, connecting urban green space and residential yards to larger adjoining tracts of natural landscapes (Farr et al., 2017, Lerman et al., 2021, Ossola et al., 2019, Van Helden et al., 2020). These types of suggestions will likely necessitate a change in the narrative of traditional thinking and practices across city collaborators and will require ecologists, landscape architects, and urban planners to work together to demonstrate the possibilities of blending aesthetics and ecology into multifunctional spaces (Connop et al., 2016, Gobster et al., 2007).

Acknowledgements

We want to thank Crystal Sutheimer for her tireless effort verifying photographic images, Ana Hayes Hursh for her graphics expertise, and the Urban Wildlife Information Network for their partnership in wildlife monitoring. Funding for Mason Fidino was provided by the Abra Prentice-Wilkin Foundation and the EJK Foundation. We sincerely appreciate the willingness of the private and public property owners that allowed us access to install and monitor our cameras.

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Figures

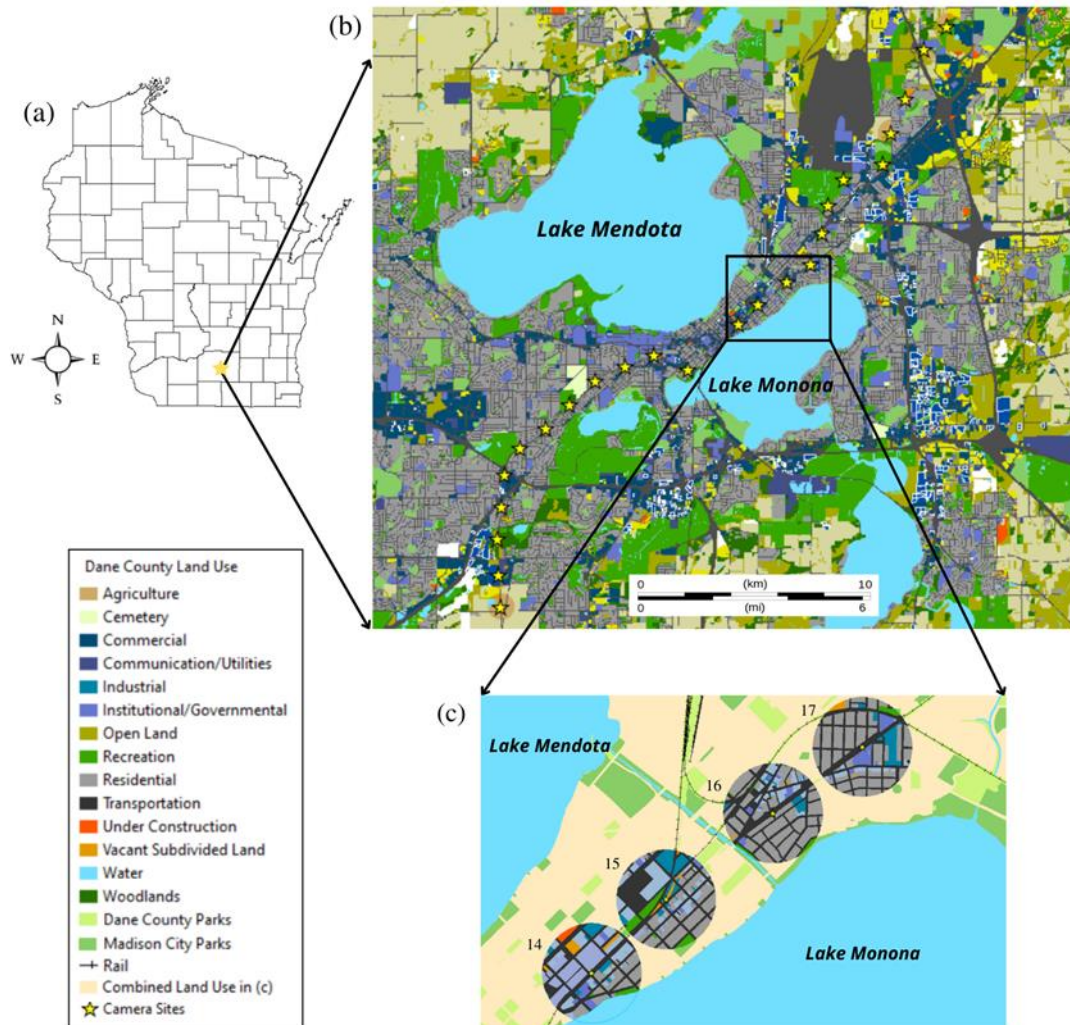


Figure 1. Map of state of Wisconsin and Dane County (starred) (a), camera site transect covering 29 km (b), and (c) land cover detail of four camera sites with 800-meter diameter buffers evaluated using ArcGIS 10.6.1 (Esri, Redlands, California), Dane LandUse 2015, Parks, City of Madison 2017, Dane County Parks 2018, and Transportation (MPO) Dane County, WI 2016 through Dane County's online geoportal at GeoData@Wisconsin (UW-Madison Robinson Map Library, Madison, WI).

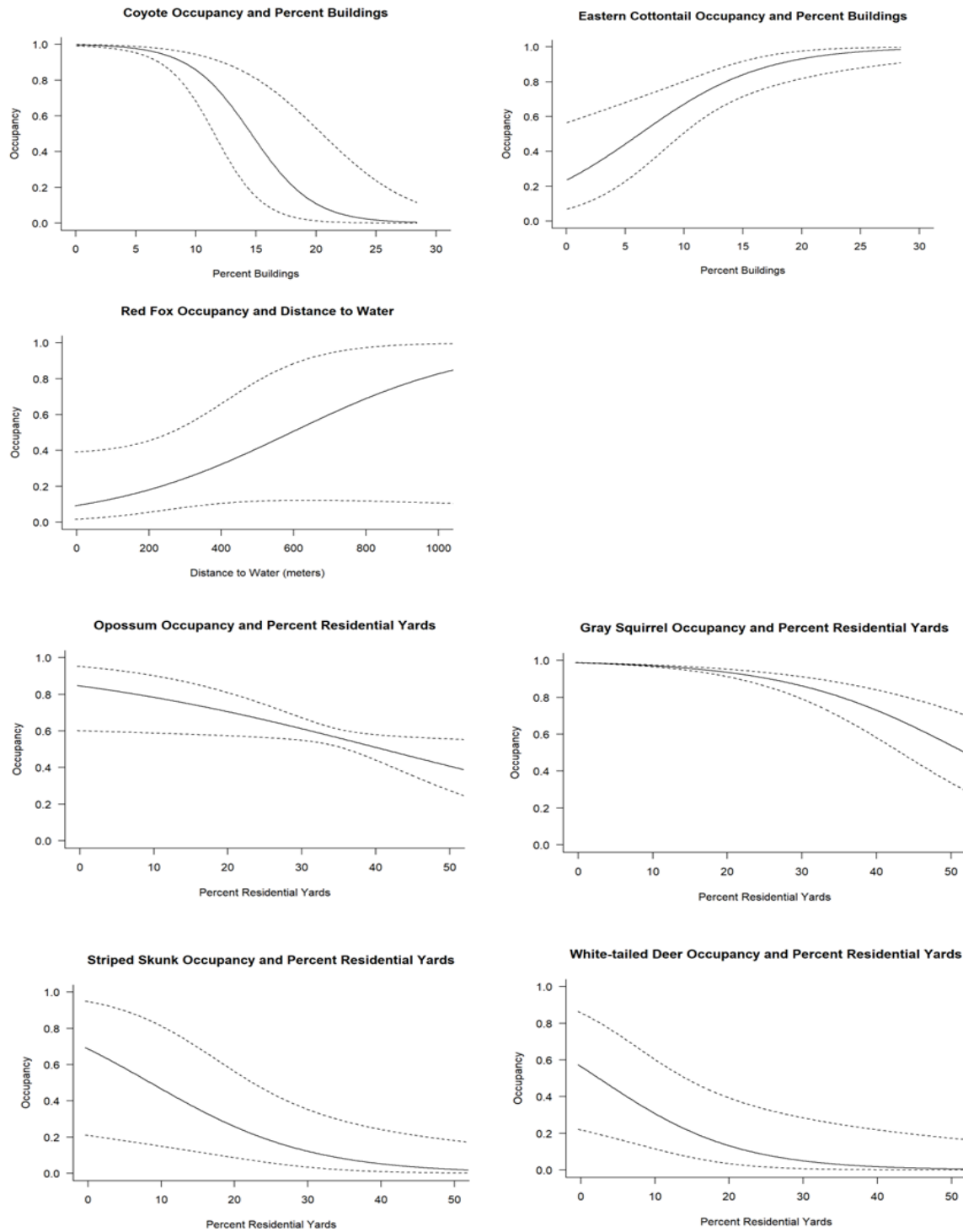


Figure 2. Estimated occupancy probability for top models with covariates for coyote and eastern cottontail as a function of percent buildings, red fox as a function of distance to water, and opossum, gray squirrel, striped skunk, and white-tailed deer as a function of percent residential yards, Madison, WI,

2017-2018. The solid line represents the average predicted occupancy, and the dashed lines represent 95% confidence intervals.

Tables

Table 1. Pearson's correlation coefficients between all covariates used in species-specific models, Madison, WI, 2017-2018. See Appendix A for a complete list of covariates and their descriptions.

	%buildings	%green space	%impervious	Distance to rail edge	%recreation	%residential yards	Distance to road edge	%transportation	%vacant land	Distance to water	%woodlands
%buildings		-0.65	0.83	-0.44	-0.48	0.31	-0.46	0.75	-0.19	0.29	-0.41
%green space	-0.65		-0.73	0.51	-0.16	-0.58	0.45	-0.71	0.15	-0.30	0.56
%impervious	0.83	-0.73		-0.63	-0.25	0.25	-0.44	0.87	-0.34	0.37	-0.46
Distance to rail edge	-0.44	0.51	-0.63		-0.13	-0.24	0.59	-0.46	0.22	-0.18	0.42
%recreation	-0.48	-0.16	-0.25	-0.13		-0.13	0.23	-0.36	0.03	-0.04	0.01
%residential yards	0.31	-0.58	0.25	-0.24	-0.13		-0.57	0.50	-0.03	0.39	-0.38
Distance to road edge	-0.46	0.45	-0.44	0.59	0.23	-0.57		-0.52	-0.01	-0.20	0.73
%transportation	0.75	-0.71	0.87	-0.46	-0.36	0.50	-0.52		-0.39	0.26	-0.45
%vacant land	-0.19	0.15	-0.34	0.22	0.03	-0.03	-0.01	-0.39		-0.17	-0.06
Distance to water	0.29	-0.30	0.37	-0.18	-0.04	0.39	-0.20	0.26	-0.17		-0.25
%woodlands	-0.41	0.56	-0.46	0.42	0.01	-0.38	0.73	-0.45	-0.06	-0.25	

Table 2. Species detection (dark squares) and absence (white squares) for eight mammal species at 24 camera sites within the greater Madison, Wisconsin area (2017-2018) and the associated percent impervious and percent green space. The state capital (icon) is located at the center of the study transect between camera site 12 and camera site 14. See Appendix A for a complete list of covariates and their descriptions.



Camera Site	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	21	22	23	24	25
Species																								
Coyote																								
E. Cottontail																								
Gray Squirrel																								
Opossum																								
Raccoon																								
Red Fox																								
Striped Skunk																								
Wt. Deer																								
Percent Impervious	10.48	38.38	14.08	60.55	74.30	36.85	54.26	32.41	54.29	71.43	92.96	71.94	75.44	87.77	67.13	64.42	63.35	35.58	50.24	51.60	22.26	28.89	43.39	11.07
Percent Green Space	81.26	10.42	67.27	7.87	4.17	27.90	3.61	40.42	0.83	0.12	0.74	10.96	4.93	7.16	1.95	2.79	6.01	47.66	49.39	48.04	48.35	34.87	45.05	87.25

Table 3. Top model predicting occupancy (ψ) and detection (p) for eight mammal species within the greater Madison, Wisconsin area (2017-2018) based on Akaike's Information Criterion for small sample size (AICc). K is the number of estimable parameters. Wt. is the AICc weight of the top model. Cum. Wt. is the cumulative AICc weight of the competitive models ($\Delta\text{AICc} \leq 2$) for each species. Variables with an asterisk (*) specify covariates whose 95% CI do not overlap zero. See Appendix A for a complete list of covariates and their descriptions.

Species	Top Model	K	AICc	Wt.	Cum. Wt.
Coyote	$\sim p(\text{site} + \% \text{impervious}^*) \sim \Psi(\text{site} + \% \text{building}^* + \% \text{recreation}^* + \text{distance to rail edge}^*)$	8	591.16	0.30	0.70
Eastern cottontail	$\sim p(\% \text{green space}) \sim \Psi(\% \text{buildings}^* + \text{distance to water}^* + \text{distance to road edge}^*)$	8	4645.81	0.55	0.55
Gray Squirrel	$\sim p(1 \text{site}) \sim \Psi(\% \text{residential yards}^*)$	5	4877.79	0.66	0.66
Opossum	$\sim p(\% \text{impervious}^*) \sim \Psi(\% \text{residential yards}^*)$	6	2436.87	0.87	0.87
Raccoon	$\sim p(1 \text{site}) \sim \Psi(1 \text{site})$	4	1993.04	0.84	0.84
Red Fox	$\sim p(1 \text{site}) \sim \Psi(\text{distance to water})$	5	369.49	0.46	0.70
Striped Skunk	$\sim p(\% \text{impervious}) \sim \Psi(\% \text{residential yards}^* + \% \text{transportation})$	7	399.83	0.36	0.64
White-tailed Deer	$\sim p(\% \text{green}) \sim \Psi(\% \text{residential yards}^* + \% \text{transportation})$	7	531.16	0.47	0.67

Table 4. Top model for each of eight species within the greater Madison, WI area (2017-2018), along with coefficient estimates (β), standard error (SE), and 95% confidence intervals (CI). Symbols: p =detection probability, Ψ = occupancy, with abbreviations in parentheses indicating covariates included in the model. Variables with an asterisk (*) specify covariates whose 95% CI do not overlap zero. See Appendix A for a complete list of covariates and their descriptions.

Species	Top model and covariates	β	SE	CI
Coyote	$\sim p(\text{site} + \% \text{impervious}^*) \sim \Psi(\text{site} + \% \text{building}^* + \% \text{recreation}^* + \text{distance to rail edge}^*)$			
$\sim p$	(1 site)	-4.19	0.25	(-4.69, -3.68)
	%impervious	-0.40	0.17	(-0.73, -0.06)
$\sim \Psi$	(1 site)	0.37	0.73	(-1.07, 1.80)
	%building	-3.28	0.59	(-4.44, -2.13)
	%recreation	-1.64	0.31	(-2.24, -1.04)
	distance to rail edge	3.72	0.79	(2.16, 5.27)
Eastern cottontail	$\sim p(\text{site} + \% \text{green space}) \sim \Psi(\text{site} + \% \text{buildings}^* + \text{distance to water}^* + \text{distance to road edge}^*)$			
$\sim p$	(1 site)	-1.13	0.19	(-1.51, -.076)
	%green space	-0.27	0.18	(-0.63, 0.09)
$\sim \Psi$	(1 site)	1.41	0.35	(0.60, 2.14)
	%buildings	1.60	0.47	(0.69, 2.52)

	distance to water	-0.86	0.37	(-1.58, -0.13)
	distance to road edge	1.04	0.48	(0.10, 1.98)
Gray Squirrel	$\sim p(1 \text{site}) \sim \Psi(\text{site} + \% \text{residential yards}^*)$			
$\sim p$	(1 site)	-0.96	0.05	(-1.06, -0.86)
$\sim \Psi$	(1 site)	2.55	0.18	(2.18, 2.90)
	%residential yards	-1.25	0.13	(-1.51, -1.00)
Opossum	$\sim p(\text{site} + \% \text{impervious}^*) \sim \Psi(\text{site} + \% \text{residential yards}^*)$			
$\sim p$	(1 site)	-2.53	0.20	(-2.92, -2.13)
	%impervious	-0.74	0.20	(-1.14, -0.33)
$\sim \Psi$	(1 site)	0.81	0.27	(0.29, 1.33)
	%residential yards	-0.62	0.28	(-1.18, -0.07)
Raccoon	$\sim p(1 \text{site}) \sim \Psi(1 \text{site})$			
$\sim p$	(1 site)	-3.22	0.02	(-3.26, -3.18)
$\sim \Psi$	(1 site)	2.44	0.04	(2.36, 2.52)
Red Fox	$\sim p(1 \text{site}) \sim \Psi(\text{site} + \text{distance to water})$			
$\sim p$	(1 site)	-4.29	0.44	(-5.14, -3.43)
$\sim \Psi$	(1 site)	-0.47	0.80	(-2.05, 1.10)

	distance to water	1.15	0.73	(-0.28, 2.58)
Striped Skunk	$\sim p(\text{site} + \% \text{impervious}^*) \sim \Psi(\text{site} + \% \text{residential yards}^* + \% \text{transportation})$			
$\sim p$	(1 site)	-4.15	0.54	(-5.21, -3.09)
	%impervious	-1.24	0.38	(-1.99, -0.50)
$\sim \Psi$	(1 site)	-1.18	0.66	(-2.47, 0.10)
	%residential yards	-1.38	0.55	(-2.46, -0.30)
	%transportation	1.07	0.68	(-0.27, 2.40)
White-tailed Deer	$\sim p(\text{site} + \% \text{green space}) \sim \Psi(\text{site} + \% \text{residential yards}^* + \% \text{transportation})$			
$\sim p$	$\sim p(\text{site})$	-4.46	0.85	(-6.11, -2.80)
	%green space	0.75	0.53	(-0.28, 1.79)
$\sim \Psi$	(1 site)	-2.03	0.77	(-3.54, -0.52)
	%residential yards	-1.61	0.65	(-2.88, -0.34)
	%transportation	-1.29	0.85	(-2.95, 0.37)

Appendices

Appendix A. List of covariates and their descriptions used in the occupancy models for Madison, WI, 2017-2018. Each description is calculated within an 800-meter buffer for individual camera sites. Range (R), mean ($\bar{x}$), and standard deviation (SD) are listed. Covariate descriptions (*) are derived from Dane LandUse 2015 and Dane Buildings YE2016 at GeoData@Wisconsin (UW-Madison Robinson Map Library, Madison, WI).

Covariate	Description	Range (R)	Mean ($\bar{x}$)	Standard Deviation (SD)
%agriculture*	Agriculture: Combine percent area including grain farming, animal production, and food production.	0% to 75.76%	6.32%	17.33
%buildings*	Buildings: Percent buildings calculated from building footprints, including commercial, industrial, institutional, and residential.	0.32% to 28.97%	13.67%	8.46
%green space*	Greenspace: The cumulative percent of areas designated as recreation, open land, vacant land, woodland, and agriculture.	0.13% to 87.25%	18.06%	17.88
%impervious*	Impervious surface: Cumulative percentages of areas designated as buildings and transportation, as well as percent sidewalks and percent parking not included in transportation.	10.48% to 92.96%	52.12%	24.33
%openland*	Open land: Percent area not subdivided, not cultivated, and no pasture.	0% to 28.01%	3.31%	7.99
distance to rail edge	Distance to rail: Euclidean distance of each camera to the nearest rail edge.	10.30 m to 5761.6 m	2058.40 m	1910.51
%recreation*	Recreation: Combined percent	0% to	12.70%	16.38

	area including greenways, drainageways, playgrounds, playfields, athletic fields, golf courses, and conservation areas	51.39%		
<i>%residential yards*</i>	Residential: Percent parcel after removal of single, two, and multi-family housing units.	0.02% to 51.34%	21.42%	15.02
<i>distance to road edge</i>	Distance to road: Euclidean distance of each camera to the nearest paved road edge.	2.20 m to 294.50 m	65.50 m	66.47
<i>%transportation*</i>	Transportation: The cumulative percent of areas designated as public roadway, road right-of-way, rail right-of-way, bicycle path or right-of-way for bicycle path, and automobile parking.	0% to 37.22%	24.61%	9.97
<i>%vacant land*</i>	Vacant land: Percent undeveloped and unused subdivided land area.	0% to 10.95%	1.53%	2.52
<i>distance to water</i>	Distance to water: Euclidean distance of each camera site to nearest perennial water source; lakes, rivers, ponds, and streams	4.05 m to 1097.30 m	469.41 m	298.92
<i>%woodland*</i>	Woodland: Percent wooded area designated as 80% or more canopy coverage of .81+ ha (2+ acres) of connectivity	0% to 40.59%	2.85%	8.73

Appendix B. Results of occupancy model testing for four species of terrestrial mammals in Madison, Wisconsin resulting in more than one explanatory model with AICc delta ≤ 2 (ΔAICc) are listed. K is the number of estimable parameters. Wt. is the cumulative weights of ΔAICc . Symbols: p =detection probability, Ψ = occupancy, with abbreviations in parentheses indicating covariates included in the model. Variables with an asterisk (*) specify covariates whose 95% CI do not overlap zero. See Appendix A for a complete list of covariates and their descriptions.

Species	Top models with $\Delta\text{AICc} \leq 2$	K	AICc	ΔAICc	Wt.
Coyote	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site} + \% \text{buildings}^* + \% \text{recreation}^* + \text{distance to rail edge}^*)$	8	591.16	0.00	0.30
	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site})$	5	592.42	1.25	0.46
	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site} + \text{distance to water})$	6	592.90	1.74	0.58
	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site} + \% \text{recreation})$	6	592.96	1.80	0.70
Red Fox	$\sim p(\text{site})$ $\sim \Psi(\text{site} + \text{distance to water})$	5	369.49	0.00	0.46
	$\sim p(\text{site})$ $\sim \Psi(\text{site} + \text{distance to water}^* + \% \text{vacant land})$	6	370.78	1.29	0.70
Striped Skunk	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site} + \% \text{residential yards}^* + \% \text{transportation})$	7	399.83	0.00	0.36
	$\sim p(\text{site} + \% \text{impervious}^*)$ $\sim \Psi(\text{site} + \% \text{residential yards})$	6	400.36	0.53	0.64
White-tailed Deer	$\sim p(\text{site} + \% \text{green space})$ $\sim \Psi(\text{site} + \% \text{residential yards}^* + \% \text{transportation})$	7	531.16	0.00	0.47
	$\sim p(\text{site} + \% \text{green space})$ $\sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	8	532.92	1.76	0.67

Appendix C. Yards & Transportation Model and Buildings Model for eight mammal species in Madison, Wisconsin, 2017-2018. Sampling site was used as a random effect for detection (p) and occupancy (Ψ).

See Appendix A for a complete list of covariates and their descriptions.

Species	Yards & Transportation Model	Buildings Model
Coyote	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \text{distance to water})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \% \text{recreation} + \text{distance to rail edge})$
Eastern Cottontail	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \text{distance to road edge})$
Gray Squirrel	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{woodland})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \% \text{recreation})$
Opossum	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \text{distance to water})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \% \text{recreation} + \% \text{vacant land})$
Raccoon	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \% \text{vacant land})$
Red Fox	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \% \text{vacant land})$
Striped Skunk	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \% \text{vacant land})$
White-tailed Deer	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{residential yards} + \% \text{transportation} + \% \text{recreation})$	$\sim p(\text{site}) \sim \Psi(\text{site} + \% \text{buildings} + \text{distance to water} + \% \text{vacant land})$

Chapter 2: What informs human-nature connection? An exploration of factors in the context of urban park visitors and wildlife

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Under revision: People and Nature (as of 22 July 2023)

Abstract

Human-nature connection (HNC) is a concept derived from investigating the formulation and extent of an individual's identification with the natural world. This relationship is often characterized as an emotional bond to nature that develops from the contextualized, physical interactions of an individual, beginning in childhood. This outcome presents complexity in evaluating the development of HNC but suggests optimism in the pathways for enhancing lifelong HNC. As urban populations increase, there is a growing recognition worldwide of the potential for urban green space to cultivate HNC and thus shape the environmental identity of urban residents. The results of an online survey of 560 visitors to three community parks (managed primarily to provide a variety of physical, social and cultural opportunities) and three conservation parks (managed primarily to protect native plants and wildlife) in Madison, Wisconsin, USA, were used to investigate HNC. Linear mixed effects models evaluated visitors' HNC as a function of their (1) literacy and sentiment about wildlife species, (2) park experience, (3) number and frequency of nine childhood and adult recreation experiences, and (4) demographics. Across the park response groups, the number and frequency of childhood and adult recreation experiences demonstrated significant positive associations to HNC, and this positive association persisted in multiple recreation activities. Furthermore, species literacy and sentiment, visiting a park for 'nature', and frequent and

extended visitation also significantly predicted HNC by park type. Our research demonstrates the importance of lifelong recreation experiences in the development and enhancement of HNC and provides evidence for differences in the expression of HNC associated with particular attributes of urban park visitors and their views of wildlife.

Introduction

Human-nature connection (HNC) is a concept derived from a comprehensive body of research investigating the formulation and extent of an individual's identification with the natural world (Cleary et al., 2020; Ives et al., 2017; Keniger et al., 2013). This relationship is often characterized as an emotional bond with nature that develops from an individual's physical and contextual interactions with the natural world, beginning in childhood (Giusti 2019; Otto et al., 2016). However, the establishment and progression of this bond is neither linear, fixed, nor generalizable, but susceptible to life experiences and individual characteristics (Giusti, 2019; Rosa et al., 2018; van Heezik et al., 2021; van Vliet et al., 2021). This lack of predictability presents challenges, as well as opportunities, for evaluating HNC and expanding the framework necessary to enhance HNC throughout an individual's lifetime (Cleary et al., 2020; Krěpelková et al., 2020).

As urban populations continue to increase worldwide, there is a growing emphasis on addressing the shifting baselines experienced by residents (Klein & Thurstan, 2016; Papworth et al., 2009; Soga & Gaston, 2018). That is, increasingly nonnative or manicured nature containing low species richness becomes the benchmark of a natural state, with progressive generations having increasingly less endemic natural conditions as their reference of nature (Klein & Thurstan, 2016; Papworth et al., 2009; Soga & Gaston, 2018). One means of addressing this generational decline is recognizing that access to more natural and biodiverse urban green space holds considerable promise for facilitating HNC (Karacor & Parlar, 2017; Klein et al., 2021; Lumber et al., 2017; Nardo et al., 2010; Papworth et al., 2009; Turner et al., 2004). Prioritizing the potential for urban nature to shape the environmental identity of urban

residents may be key to advance pro-environmental engagement and securing global environmental sustainability (Mackay & Schmitt, 2019; Whitburn et al., 2020; Wilkie & Trotter, 2022).

Green Space Experiences as Contact with Nature

Contact with nature appears throughout HNC research, yet the definition of ‘nature’ or ‘nature-based’ is not bound by established criteria. Rather, it is more loosely applied across natural elements and landscapes and varies by an individual’s personal conceptualization of nature (Holland et al., 2021; Papworth et al., 2009; Taylor & Hochuli, 2017). Therefore, urban green space that cultivates HNC is diverse and can serve a multitude of objectives (Beatley & Newman, 2013; Felappi et al., 2020; Talal et al., 2021). For example, vertical and public gardens, neighborhood parks, a higher number of street trees, stream corridors, and landscapes with greater biodiversity provide daily opportunities for urban residents to connect with nature and their community (Kardan et al., 2015; Nardo et al., 2010; Sorace 2001; Takano et al., 2002; van den Berg et al., 2017). Urban parks can be divided into those that focus more on the community (designed to provide a variety of physical, social, and cultural opportunities) or conservation (designed to conserve native species and wildlife).

An increase in the amount of time spent in natural or vegetated green space, hereafter referred to as nature-based green space, has been associated with positive psychological, cognitive, physiological and social effects (Fuller et al., 2007; Keniger et al., 2013; Wyles et al., 2020). Studies often focus on identifying specific factors that influence an individual’s experience in nature-based settings, such as perceived biodiversity or vegetation structure, and the resulting change in an individual’s perceptions, such as improved cognitive function, nature connectedness, or restorative value (Bele & Chakradeo, 2021; Keniger et al., 2013; Muratet et al., 2015; Richardson et al., 2020; Talal et al., 2021; Wood et al., 2018). One of the most consistent outcomes found is the relationship between an individual’s environmental identity and time spent in a structurally complex and biodiverse green space (Beery & Wolf-Watz, 2014; Coldwell & Evans, 2017; Colléony et al., 2019; Scopelliti et al., 2016).

Just as nature-based urban green space occurs in various configurations, so do nature-based experiences (Keniger et al., 2013; Papworth et al., 2009; Turvey et al., 2010; van Vliet et al., 2021). Interactions with nature can be experienced through 'indirect' (views through a window), 'incidental' (stepping outside during a work break), or 'intentional' (visiting a public park) ways (Cox et al., 2017; Keniger et al., 2013). Intentional visitation likely occurs least often, suggesting a possible landscape characteristic, proximity, accessibility, or perception discrepancy between individuals (de Bell et al., 2018; Hamstead et al., 2018). This area of research requires greater attention, as it has substantial implications for the allocation and role of urban green space, particularly public parks, in shaping human-nature interactions (Baur et al., 2013, Ives et al., 2017). Furthermore, people who intentionally seek a nature-based green space, such as a community or conservation park, experience nature in a multitude of ways that are classified based on an assortment of criteria (Çetinkaya et al., 2017; Metin et al., 2017; Sampath et al., 2020). Broad categories of classification, such as 'passive' or low-effort activities (e.g., socializing, picnicking) or 'active' or high-effort activities (e.g., walking / hiking, disc golf), can be used to assess the physical and/or psychological health benefits of recreation (Çetinkaya et al., 2017; Metin et al., 2017; Sampath et al., 2020). Other classification methods are interested in determining an individual's relationship with nature and may categorize activities based on appreciative (birdwatching), consumptive (fishing), or mechanistic (riding all-terrain vehicles) qualities or as a demonstration of anthropocentric (prosperity) or cosmocentric (stewardship) behavior (Berns & Simpson, 2009; Pascual et al., 2022). However, there is no standardized methodology for recreation classification and determining clear associations between types of recreation activities and the benefits accrued by a participant remains largely inconclusive (Berns & Simpson, 2009; Cooper et al., 2015). Therefore, efforts may be better focused on encouraging residents to participate in any type of nature-based recreation. Lastly, the type and range of nature-based interactions that individuals experience further emphasizes the importance and potential of incorporating daily human-nature connections containing physical, conceptual, and visual elements (Hess 2010; Ishibashi et al., 2020).

Green Space Wildlife Experiences as Contact with Nature

Urban green space can also provide habitat resources to a broad range of taxa and result in an increased likelihood of people encountering wildlife in these shared spaces (Fidino et al., 2021; Ishibashi et al.; Liordos et al., 2020). The accurate identification and positive appeal of wildlife in urban green space is inconsistent and varies across human attributes, including age, educational level, and gender, with individuals generally having positive sentiment for species such as songbirds (Passeri) and butterflies (Lepidoptera) and a strong dislike of species such as snakes (Serpentes) and mice (*Mus* spp.) (Liordos et al., 2020; Zsido et al., 2022). As a suite of species are known to play vital roles in ecosystem function and resilience, addressing the circumstances that contribute to taxonomic knowledge and sentiment in urban residents is an essential component to understanding HNC (Basak et al., 2022; Connop et al., 2016; Liordos et al., 2020; Straka et al., 2022; Zsido et al., 2022). The type of urban green space, how it is experienced, and the role of wildlife sentiment associated with HNC, combined with the rest of an individual's experiences throughout their lifetime, demonstrates some of the many challenges to increasing human-nature contact with broad resonance (Gerrish & Watkins, 2018; Jennings et al., 2017; Rigolon et al., 2018; Taylor & Hochuli, 2017). However, given the tremendous value nature has for human health and wildlife conservation, understanding the pathways of the human-nature relationship is crucial to developing urban spaces that support both objectives.

Human-nature Connection Relationships with Demographics

HNC is studied both for the predictive properties of perceived wellness and pro-environmental behavior and for determining associations with demographic or individual characteristics, such as age or curiosity (Dean et al., 2018; Merino et al., 2020; Nisbet et al., 2011). For example, nature connection measures are often higher in older, female, and more educated respondents and in those who engage in pro-environmental behavior, though research with children shows high nature connection with younger-aged populations as well (Dean et al., 2018, Hughes et al., 2019; Mackay & Schmitt, 2019, Whitburn et al.,

2020). Beyond predictive qualities, HNC is studied for influential factors prominent in its development and expression (Cleary et al., 2020; Colléony et al., 2019; Rosa et al., 2018). For example, nature-based education and play are linked to improved student well-being, cognitive ability, and higher nature connection (Dadvand et al., 2015; Otto & Pensini, 2017). Childhood experiences in nature are often positively associated with adult experiences in nature and adult pro-environmental attitudes and behavior (Lohr & Pearson-Mims, 2005; Rosa et al., 2018). However, the type and frequency of childhood experiences are broad and vary in the degree of positive association (Ewhert et al., 2005; Molinario et al., 2020). Understanding the interconnectivity of factors involved in the evolution of the human-nature bond is necessary to provide effective physical, social, and educational opportunities to facilitate HNC (Molinario et al., 2020; Palmberg & Kuru, 2000; Steg & Vlek, 2009).

Human-nature Connection Measures

There are several corroborated scales to assess an individual's degree of HNC, including Connectedness to Nature, Inclusion of Nature and Self, and the New Ecological Paradigm (Keaulana et al., 2021; Restall & Conrad, 2015; Tam 2015). Each of these tools, administered by surveys, has a defined intention and application to measure perceptions, emotions, motives, values, cultural or spiritual identity, or ecological knowledge surrounding one's environmental identity (Ewert et al., 2005; Keaulana et al., 2021; Soga et al., 2016; Wood et al., 2018). Despite some distinctions between the objectives and the predictive value of the nature-relatedness tools, each assesses an individual's relationship with nature (Keaulana et al., 2021; Restall & Conrad, 2015; Tam, 2015). This knowledge can be used to develop targeted strategies and effective programming, including evaluations of ecologically based educational programs to improve HNC or to understand the sentiments of a specific population (Tam, 2013).

The Nature Relatedness Scale (NR-21) was designed with acknowledgement of the core principles of HNC methodology but focuses on measuring nature identity through questions of 'self' (how strongly people identify with nature), 'perspective' (how an individual's relationship with the environment is

expressed through opinion or behavior), and 'experience' (physical contact and attraction to nature) (Nisbet et al., 2009). The NR-21 scale is a reliable and commonly applied tool to acquire data from points of interest associated with HNC (Dean et al., 2018; Keaulana et al., 2021; Whitburn et al., 2020). As with other latent social concepts, lengthy banks of nature-relatedness measures have been empirically tested and refined over time (Aruta & Pakingan, 2022; Bartholomew et al., 2023; Dean et al., 2018; Keaulana et al., 2021; Nisbet & Zelenski, 2013; Whitburn et al., 2020). The abbreviated short form of six items (NR-6) of the Nature Relatedness Scale retains the predictive strength of the NR-21 scale and has the added benefit of limiting question redundancy and improving survey completion rates (Aruta & Pakingan, 2022; Bartholomew et al., 2023; Nisbet et al., 2009; Nisbet & Zelenski, 2013; Tam, 2013).

Objectives and Hypotheses

Our goal was to examine the influence of wildlife species literacy and sentiment regarding six mammal species, recreation activities, park experience, and demographics on HNC of visitors to two types of urban green space (community and conservation parks). We hypothesized that HNC would have a significant positive association with five independent factors: (1) wildlife species literacy and positive species sentiment; (2) number, frequency, and type of recreation activities in childhood and adulthood; (3) park experience measured by a) the main reason for visitation as 'Nature', b) greater prior visitation, c) longer duration of visit, and d) residence closer to the survey park; (4) respondents who are a) older, b) female, and/or c) have a higher degree of education; and (5) type of park, with conservation park visitors demonstrating a stronger positive association with each factor listed in hypotheses 1-4 compared to community park visitors.

By concurrently examining a suite of key factors identified as influential throughout the corresponding literature, we hope that our findings provide additional understanding of the intersectionality of factors associated with individuals who intentionally visit urban green space, specifically community and conservation parks, and the contributing role of wildlife in HNC.

Methodology

Study Area

Madison has a population of approximately 270,000 residents, covers approximately 260 km², and is located in south central Wisconsin, USA (US Census Bureau, 2022). Madison is currently the fastest growing city in Wisconsin and is home to the state capital and the University of Wisconsin-Madison (US Census Bureau, 2022). The study area is within the Yahara Watershed, now largely dominated by agricultural and urban land cover, and experiences four distinct seasons (Carpenter et al., 2007, Wisconsin State Climatology Office, 2010).

The six selected parks were based on their classification as a community or conservation park; an estimated visitation rate; a central, western or eastern location in Madison; and approval from the Madison Parks Division of the City of Madison (Figure 1). The size of the community parks ranged from 19.07 ha to 101.50 ha, and the size of the conservation parks ranged from 24.39 ha to 39.17 ha. The parks can be broadly described as mixed forest ecosystems with open grass areas and low levels of pavement and structural development. Conservation parks contain native grasslands whereas community parks may contain native grasslands or mowed turf. By definition, conservation parks are managed to protect native plant and wildlife species, resulting in the inclusion of vegetation and management practices supporting that objective (City of Madison Parks Division, 2022). As a result of their conservation status, recreation therein is limited to physical activities such as hiking and snowshoeing and nature-based activities such as watching birds / wildlife and photography. Dogs are not allowed in conservation parks. Community parks are designed to provide a variety of physical, social, and cultural opportunities, including athletic fields and courts, playgrounds, and picnic shelters. Community parks allow dogs that are leashed and licensed (City of Madison Parks Division, 2022).

Study Population and Survey

We conducted an online survey to park visitors in three conservation parks and three community parks in Madison. We developed the survey in Google Forms and administered it in the parks using a park-specific quick response (QR) code printed either (1) on posters that were statically accessible to park visitors throughout the study period or (2) on postcards dynamically handed to park visitors at selected times during the study period. The posters were visible outdoors in all six parks from 2021-09-04 through 2021-10-24 (high-use fall period) and from 2022-06-09 through 2022-08-24 (high-use summer period). Postcards were distributed in the six parks on four Saturdays in both September and July from 10.00 to 12.00. These dates and times were selected to coincide with the days and times with the highest number of park visitors, the availability of surveyors, and the approval of the Madison City Parks Division. Each postcard had a unique three-digit number required to access the online survey. Adults (18 years or older) were approached by the surveyor and invited to participate. After verbally agreeing to participate, each potential respondent was asked three questions used to check for nonresponse bias: (1) zip code, (2) year of birth, and (3) main reason for visitation.

The online survey consisted of 30 questions, grouped into four categories: (1) literacy and sentiment about wildlife species, (2) recreation and park experience, (3) HNC, and (4) demographics. For species literacy and sentiment, respondents were asked questions evaluating (1) the correct photographic identification of six mammal species, each considered a generalist and likely present in the study parks, and (2) visitor sentiment about each species (Figure 2). For recreation activity, respondents were asked questions about (1) the number and frequency of childhood and adult experiences with bird / wildlife watching, camping, canoeing / kayaking, fishing, gardening, hiking, hunting, nature photography, and picnicking; (2) the main reason for visitation; (3) previous visitation; (4) length of visit; and (5) distance of residence to the park. For HNC, the abbreviated six-item short form of the Nature Relatedness Scale (NR-6) was used, with four statements from NR-Self (1-4) and two statements from NR-Experience (5 and 6):

1. My connection to nature and the environment is a part of my spirituality.
2. My relationship to nature is an important part of who I am.
3. I feel very connected to all living things and the earth.
4. I always think about how my actions affect the environment.
5. My ideal vacation spot would be a remote, wilderness area.
6. I take notice of wildlife wherever I am.

Demographic questions included age group, educational level, and gender.

The survey responses were in the form of a short answer (only identification of species), exclusionary checkboxes, or a 5-point Likert scale response (“Never” to “Very Often” or “Disagree Strongly” to “Agree Strongly”). Wildlife literacy and sentiment questions were accompanied by a corresponding species-specific color photo (Figure 2). Species sentiment was measured by species-specific exclusionary responses: 'I am happy they live at the park', 'I think they are important for the park ecosystem', 'I am concerned about their impact on human safety', 'I am concerned that they bring disease', 'I think they are a nuisance', or 'I am unsure how I feel or do not care'. We piloted the survey with a focus group before administering it in the six parks to identify possible issues such as unclear language or challenges in viewing on mobile devices and adjusted our final survey accordingly. All survey responses were anonymous.

Analysis

Initial exploratory analysis included a random effect for park type (community and conservation) and a random effect and interaction term for survey type (postcard and poster). The type of park was a significant factor, and the models afterwards were separated into two model sets, one for community park visitors and one for conservation park visitors. A random effect was included for the parks sampled (3 community parks or 3 conservation parks) within the corresponding model set. The type of survey was

not a significant random effect, and the data of each type of survey were combined based on the type of park. No differences were found between the potential and actual respondents by postcard with respect to zip code, year of birth, and main reason for visitation. This suggests that nonresponse bias was unlikely. For categorical predictor variables, if the overall F-test was significant, the means were separated using Tukey's HSD method.

Mixed-effects linear models were applied using the 'lme' function in the 'nlme' package (v3. 1-152; Pinheiro et al., 2021) of the R software, version 4.2.1 (R Core Team, 2019). As our work forwards investigation on the specific factors that are associated with HNC (using the mean NR-6 score of a respondent) rather than the conventional application of NR-6 as a predictor of pro-environmental behavior or self-assessed well-being, we evaluated factors independently rather than collectively. Separate models were developed for community and conservation park survey data to evaluate HNC as a function of factors within four categories: (1) species literacy and positive species sentiment; (2) number, frequency, and type of outdoor recreation activities of childhood and adulthood; (3) main reason for visitation, previous visitation, length of visit and distance of residence to the park; and (4) demographic factors (age category, educational level, and gender). Species literacy was calculated as the average of responses recorded in six species: '1' for a correct answer and '0' for an incorrect answer. Positive sentiment species was calculated as '1' for 'I am happy they live at the park' or 'I think they are important for the park ecosystem' or '0' for all other responses, recorded in six species. The frequency of participation in childhood and adult recreation activities was calculated for each respondent as the average of responses from 1 (never) to 5 (very often) for the three activities respondents listed as the most frequent. This method was chosen to reduce penalties for individuals who participated in fewer activities compared to those who participated in a greater number of activities. The main reason for visiting had one of three options: 'Passive' included playground, picnic, and socialization, 'Active' included walking, exercise, and sports, and a third category 'Nature' included responses specific to nature-based activities (enjoying nature, watching birds / wildlife and nature photography). The category 'Nature' is a subset of

activities derived from activities otherwise categorized as 'Passive' but specific to nature-related recreation (Çetinkaya et al., 2017; Metin et al., 2017; Sampath et al., 2020). The assumptions for the models, including linearity and normality, were graphically checked using residual versus fitted value plots and QQ plots of residuals. The significance level was taken to be $p < 0.05$.

Results

In total, 628 surveys were distributed. Of these, 252 park visitors completed the survey (40.1% completion rate): 163 community and 89 conservation park visitors. An additional 343 park visitors completed the survey through the QR code poster: 151 community and 188 conservation park visitors. Surveys with duplicate respondents, submitted by those under 18 years of age as self-identified by age category, or containing incomplete responses to focal factors were eliminated from the analysis. This resulted in 560 viable surveys: 291 community and 269 conservation park surveys. We calculated a Pearson's correlation coefficient or Cramer's V for all the corresponding explanatory factors. The correlation between the number and frequency of activities participated in during childhood by visitors to community parks resulted in the strongest correlation ($r = 0.68$).

Gender was split between men and women, with a ratio of 51% women to 49% men in Madison, the same ratio in community parks, and 55% women to 42% men in conservation parks. Eighty-four percent of Madison residents are 18 years of age or older, with a median age of 32 years (US Census Bureau, 2022). The respondents were on average older than adult Madison residents: respondents to community parks averaged 35 years and the respondents to conservation parks averaged 42 years. The respondents were also more educated, on average, than Madison residents: 59% of Madison residents have a 4-year or higher degree, compared to 80% of the community park respondents and 84% of the conservation park respondents (US Census Bureau, 2022). There were no significant differences for gender in community or conservation parks relative to the area population ($\chi^2 = 0.037$, $df = 1$, $p = 0.85$ and $\chi^2 = 2.20$, $df = 1$, $p = 0.14$). There was a higher proportion of respondents 35 years or older at community parks ($\chi^2 = 7.2586$,

df = 1, p-value = 0.00705) and at conservation parks ($\chi^2=15.143$, df = 1, p-value = <0.0001) relative to the area population. The level of education was significantly higher for community park respondents ($\chi^2=24.669$, df = 1, p-value = <0.0001) and conservation park respondents ($\chi^2 = 65.155$, df = 1, p-value = <0.0001) compared to the area population.

Community Park Respondents

Positive species sentiment was a significant explanatory factor for NR-6 scores in respondents from community park respondents (p<0.0001) (Figure 3, Appendix A). Respondents who recorded 'Nature' as the main reason for visiting had significantly higher HNC than respondents who recorded 'Passive' as the main reason for visitation (p=0.03) (Figure 4, Appendix B). Respondents who spent more than two hours during visitation had significantly higher HNC than respondents who spent less than one hour (p=0.02) (Figure 4, Appendix B). The respondents in the community parks 55 to 64 years had significantly higher HNC ($\bar{x}=4.51$) than the respondents aged 18 to 44 years ($x = 4.03-4.05$) (p=0.01) (Figure 4, Appendix B). Educational level, gender, previous visitation, or distance of residence from the park were not significant explanatory factors for HNC.

Recreation Activities: Childhood

Recreation activities in childhood for community park respondents were significant factors explaining HNC for the nine activities: watching birds / wildlife (p<0.0001), camping (p=0.002), canoeing / kayaking (p=0.0005), fishing (p=0.001), gardening (p<0.0001), hiking (p=0.001), hunting (p=0.04), nature photography (p<0.0001), and picnicking (p<0.0001) (Figure 5, Appendix E). Respondents who recorded Sometimes (p= 0.01), Often (p= 0.001) or Very Often (p< 0.0001) for bird / wildlife watching had higher HNC than respondents who recorded Never. Respondents who recorded Very Often for bird / wildlife watching also had a higher HNC than respondents who recorded Sometimes (p=0.0003). Respondents who recorded Often (p= 0.01; p=0.02; p=0.001) or Very Often (p< 0.0001; p=0.003; p=0.03), for bird / wildlife watching, camping, or canoeing / kayaking, respectively, had higher HNC than

respondents who recorded Rarely. For fishing, respondents who recorded Sometimes ($p=0.01$) or Very Often ($p=0.01$) had higher HNC than those who recorded Never. Respondents who recorded Very Often ($p=0.04$) for fishing also had a higher HNC than respondents who recorded Rarely. Respondents who recorded Very Often for gardening had higher HNC than respondents who recorded Never ($p<0.0001$), Rarely ($p=0.0001$), Sometimes ($p=0.0003$) or Often ($p=0.01$). Respondents who recorded Often ($p=0.03$) for gardening also had higher HNC than those who recorded Never. Respondents who recorded Very Often for hiking had higher HNC than respondents who recorded Never ($p=0.001$), Rarely ($p=0.003$) or Sometimes ($p=0.0001$). Respondents who recorded Very Often for nature photography had higher HNC than those who recorded Never ($p<0.0001$) or Rarely ($p=0.03$). Respondents who recorded Rarely ($p=0.01$) or Sometimes ($p=0.0001$) for nature photography also had higher HNC than respondents who recorded Never. For picnicking, respondents who recorded Sometimes ($p=0.002$), Often ($p=0.003$), or Very Often ($p<0.0001$) had higher HNC than those who recorded Never. Respondents who recorded Very Often for picnicking also had a higher HNC than respondents who recorded Rarely ($p=0.002$). The respondents who recorded any level of hunting during childhood were not different from each other.

Recreation Activities: Adulthood

Recreation activities in adulthood for the community park respondents were significant for all activities, excluding hunting—bird / wildlife watching ($p<0.0001$), camping ($p=0.001$), canoeing / kayaking ($p=0.01$), fishing ($p=0.02$), gardening ($p<0.001$), hiking ($p=0.0001$), nature photography ($p<0.0001$), and picnicking ($p=0.02$) (Figure 5, Appendix F). Respondents who recorded Sometimes ($p=0.004$), Often ($p=0.02$), or Very Often ($p<0.0001$) for bird / wildlife watching had higher HNC than those who responded Never. Respondents who recorded Very Often for bird / wildlife watching also had higher HNC than those who recorded Rarely ($p=0.001$). Respondents who recorded Very Often for camping had a higher HNC than those who responded Never ($p=0.01$) or Rarely ($p=0.01$). Respondents who recorded Sometimes ($p=0.02$) for camping also had higher HNC than those who recorded Rarely. For canoeing / kayaking, respondents who recorded Often had higher HNC than respondents who recorded

Never ($p=0.01$). For fishing, respondents who recorded Very Often had higher HNC than the respondents who recorded Rarely ($p=0.04$). Respondents who recorded Very Often for gardening had a higher HNC than those who recorded Never ($p=0.003$) or Rarely ($p=0.004$). For hiking, respondents who recorded Very Often had higher HNC than those who recorded Rarely ($p=0.001$), Sometimes ($p=0.02$), or Often ($p=0.002$). For nature photography, the respondents who recorded Rarely ($p=0.03$), Sometimes ($p=0.003$), Often ($p=0.002$), or Very Often ($p<0.0001$) had higher HNC than those who recorded Never. For respondents who recorded Very Often ($p=0.01$) for picnicking, HNC was higher than for respondents who recorded Never.

Conservation Park Respondents

Knowledge of wildlife species was a significant explanatory factor for HNC in conservation park respondents ($p=0.01$) (Figure 3, Appendix C). The conservation park respondents who recorded 20 or more visits had significantly higher HNC than the respondents who recorded zero prior visits ($p = 0.03$) (Figure 4, Appendix D). Furthermore, respondents to conservation parks aged 65 to 74 had significantly higher HNC than respondents aged 25 to 34 ($p = 0.001$) (Figure 4, Appendix D). Educational level, gender, main reason for visitation, duration of visit, distance from residence to the park were not significant explanatory factors for HNC in conservation park respondents.

Recreation Activities: Childhood

Childhood recreation activities for conservation park respondents were significant for five activities: bird / wildlife watching ($p=0.004$), camping ($p=0.003$), canoeing / kayaking ($p=0.01$), gardening ($p = 0.002$) and picnicking ($p=0.02$) (Figure 5, Appendix G). Respondents who recorded Often ($p=0.03$) or Very Often ($p=0.03$) for bird / wildlife watching had a higher HNC than those who recorded Never. For camping, the respondents who recorded Sometimes ($p=0.04$), Often ($p=0.02$), or Very Often ($p=0.02$) had higher HNC than the respondents who recorded Never. For canoeing / kayaking, respondents who recorded Sometimes ($p=0.03$) or Very Often ($p=0.04$) had higher HNC than those who recorded Never.

Respondents who recorded Often ($p=0.03$) or Very Often ($p=0.001$) for gardening had higher HNC than those who recorded Never. Respondents who recorded Very Often for gardening also had higher HNC than those who recorded Sometimes ($p=0.04$). For picnicking, respondents who recorded Often ($p=0.01$) had a higher HNC than those who recorded Rarely.

Recreation Activities: Adulthood

Recreation activities in adulthood for respondents to conservation parks were significant for five activities: bird / wildlife watching ($p = 0.0001$), camping ($p=0.002$), canoeing / kayaking ($p=0.0001$), gardening ($p=0.01$), and nature photography ($p=0.0001$) (Figure 5, Appendix H). Respondents who recorded Sometimes ($p=0.001$), Often ($p=0.002$), or Very Often ($p<0.0001$) for bird / wildlife watching had higher HNC than respondents who recorded Never. Respondents who recorded Very Often for bird / wildlife watching also had higher HNC than respondents who recorded Rarely ($p=0.01$). For camping, the respondents who recorded Very Often had higher HNC than those who responded Never ($p=0.01$) or Rarely ($p=0.02$). For the canoeing / kayaking respondents who recorded Rarely ($p=0.004$), Sometimes ($p<0.0001$), or Often ($p = 0.001$), had higher HNC than those who recorded Never. Respondents who recorded Sometimes ($p=0.02$) or Very Often ($p=0.01$) for gardening had higher HNC than respondents who recorded Never. For nature photography, the respondents who recorded Very Often had higher HNC than those who recorded Never ($p<0.0001$) or Sometimes ($p=0.01$).

Discussion

The purpose of our study was to examine a set of explanatory factors associated with HNC relative to visitors to community and conservation parks. Our hypotheses that HNC would have a significant positive association with (1) wildlife species literacy and sentiment, (2) the number, frequency, and type of childhood and adult recreation activities, (3) park experience, and (4) the demographics of visitors were only partially supported. Conservation park visitors demonstrated a stronger positive association with species literacy, previous visitation, and age. However, respondents from community parks

demonstrated a comparable or stronger positive association with positive species sentiment, 'Nature' as the main reason for visitation, duration of visit, and recreation experiences. Below, we interpret these major results in light of the study context and conceptual advancements they offer. Our results generally contribute to understanding the complexity of factors in human-nature connection and offer points of corroboration and refute for connections previously detailed in the literature.

Community Park Respondents

Contrary to our prediction, HNC was not associated with species literacy among respondents visiting community parks. However, the respondents showed strong positive species sentiment. For this group of park visitors, how they feel about wildlife, not species literacy, seemed to be driving HNC. Sixty-eight percent of respondents from the community parks answered 'I am happy they live at the park' or 'I think they are important for the park ecosystem' for the six species of wildlife. It is important to note that the sentiment for coyote (*Canis latrans*) had the highest number of respondents (19%) who saw them as a concern for human health or safety or as a nuisance. These same respondents had a misidentification rate of 29% and most mistook a coyote for a wolf (*Canis lupus*). Recognizing that a sector of park visitors has a contrasting sentiment toward certain species, possibly reinforced by false identification, is critical for park managers trying to balance the mutual benefits of urban green space for humans and wildlife (Basak et al., 2022). Because the value of environmental education in the promotion and maintenance of HNC has mixed results in the literature, programming that strives to increase the literacy and knowledge of wildlife species while making concessions for the emotional connection and/or concern people have toward nature and wildlife may be more effective at instilling long-term value of the environment than a conventional approach void of this accommodation (Barragan-Jason et al., 2022; Krěpelková et al., 2020; Soulsbury & White, 2019).

Of the proportion of people who recorded a visit duration greater than two hours, most respondents (79%) recorded being in the park for 'Passive' or 'Active' reasons, not 'Nature'. However, as predicted and

supported by the corresponding literature, ‘Nature’ as the main reason for visitation and duration of visit were significant factors associated with HNC for community park visitors (Beery & Wolf-Watz, 2014; Coldwell & Evans, 2017, Colléony et al., 2019, Scopelliti et al., 2016). It is worth mentioning that the community parks in this study include trailed natural areas and areas designated for specific activities (e.g., basketball courts, playgrounds), attracting visitors looking to interact with nature and/or participate in alternate activities. Some activities, such as disc golf, may inherently require more time, as well as include social and cultural elements that strengthen HNC. It is also possible that respondents selected ‘Active’ instead of ‘Nature’ as the main reason for their visit if they were walking in the park (‘Active’). Restricting a response to a single choice may be underestimating visitation for ‘Nature’ or overlooking the dual intentions of park visitors (walking in nature). Regardless, respondents who visited the park for ‘Nature’ and/or spent more time in the park had higher HNC. This outcome supports the broad appeal and value of nature-based green space that includes a variety of engagement opportunities and emphasizes that park classification does not inherently preclude or predict park visitor interests or motivations. Finally, age was a significant explanatory factor for HNC, with respondents 44 years or younger having significantly lower HNC than individuals 55-64. Although this result agrees with previous research, the nearly identical mean HNC for this large group of respondents (72%) lends itself to further examination and suggests an opportunity to increase HNC for a wide age range of adults (Dean et al., 2018, Hughes et al., 2019).

Conservation Park Respondents

As predicted, the respondents had a significant positive association with wildlife species literacy and HNC. Environmental or ecological knowledge, frequently measured using species literacy, is often higher in individuals with higher nature relatedness (Gifford & Nilsson, 2014). Furthermore, individuals who correctly identify species are more likely to be aware of species-specific habitat requirements (Hooykaas et al., 2022). Contrary to our prediction and supported in the literature, positive species sentiment did not explain HNC in this group of visitors, likely due to an overwhelming positive view of

wildlife (mean positive species sentiment of 95%) (Liordos et al., 2020). Understanding the broader ecological context of wildlife, opposed to sentiment, was a stronger predictor of HNC in conservation park respondents (Zsido et al., 2022).

Also contrary to our predictions and previous research, ‘Nature’ as the main reason for visitation, the duration of visit and the distance to residence were not significant factors associated with HNC (Beery & Wolf-Watz, 2014, Coldwell & Evans, 2017, Colléony et al., 2019, Scopelliti et al., 2016). Only previous visits were explanatory for conservation park visitors, and respondents who reported the highest level of visitation had significantly higher HNC than individuals who had never visited the park before. Teasing apart whether visiting a conservation park enhances HNC or if visitors who frequent conservation parks already have higher HNC is worthy of further investigation. If the former occurs, park managers can work to expand the appeal of conservation parks to a broader audience. If the latter is likely, there is an opportunity to examine factors not evaluated in this study that may explain the higher HNC in visitors to conservation parks.

Our final hypothesis that respondents to conservation parks would demonstrate a stronger positive association between HNC and wildlife species literacy, positive species sentiment, recreation experience, and demographics was not fully supported. In fact, visitors to conservation parks only demonstrated a stronger positive association with species literacy, prior visitation, and age. However, this result is not entirely unexpected given the higher HNC of our respondents, the higher educational level, and the fact that the respondents intentionally visited a green space.

Recreation Activities: Community and Conservation Park Respondents

Consistent with previous studies, childhood and adult recreation experiences for community and conservation park visitors had a strong positive association with HNC (Cleary et al., 2020; Ewert et al., 2005; Molinario et al., 2020; Rosa et al., 2018). However, contrary to our prediction, the number of

significant recreation experiences was fewer for visitors to conservation parks, with only four of the nine recreation activities being significant in childhood and adulthood. Including hunting in adulthood, the other eight recreation activities were significant in childhood and adulthood for visitors to the community parks. Generally, respondents in both types of parks who never or rarely participated in recreation activities in childhood or as adults had significantly lower HNC compared to respondents who participated at higher frequencies. We are not suggesting that a particular type of childhood or adult recreation activity for visitors to the community or conservation parks is causative or predictive of adult HNC. On the contrary, our results suggest that a variety of nature-based recreation activities as children and adults are associated with higher HNC, providing a compelling reason for communities to encourage and incorporate lifelong recreation for a wide range of interests and abilities (Cooper et al., 2015; Havlick et al., 2021).

Contrary to comparable research and our predictions, neither education nor gender were significant factors explaining HNC in conservation or community park visitors (Dean et al., 2018, Mackay & Schmitt, 2019, Whitburn et al., 2020). A significant proportion of our survey respondents recorded having a four-year or higher degree and this likely explains why educational level was not an explanatory factor. Future studies that include a more representative educational range may provide a better distinction for the role of education. Lastly, the results of our study are derived from a single visit and do not presume exclusive use by park type. However, of the respondents who indicated a tendency to visit community, conservation, or both types of parks in the last 12 months, 38% of the respondents from community park respondents and conservation park respondents visited both types of parks. The highest rate of visitation was in the same type of park where individuals were surveyed (55% of respondents from community park respondents and 47% of conservation park respondents) and the lowest rate of visitation was in the alternative type of park where individuals were surveyed (8% of respondents from community park respondents and 15% of conservation park respondents). The factors that determine preferences for park choice may be largely attributed to recreation interests and opportunities. As such, broadening

community engagement in conservation parks through organized nature-based activities (star gazing or monitoring urban wildlife populations) with cultural and social components can increase public awareness and support for natural areas and wildlife while simultaneously developing stronger HNC.

Limitations and recommendations

As in other retrospective self-reporting studies, it is possible that the frame of reference on a specific visit was unclear in the memory of the respondent or generalized to other park visits. Furthermore, the answers to questions, particularly regarding the number and/or frequency of recreation activities, may be distorted due to emotional bias or social desirability (Krěpelková et al., 2020). It is also possible that the online format of the survey limited responses to individuals with technological access and/or ability. An additional limitation may have been the time of day and month when the survey was administered, as well as inconsistencies in the behavior of the surveyor. However, our breadth of questions, survey access modes and parks, as well as the patterns demonstrated across the two types of parks, speak to the success of mitigating these limitations. Possible next steps would be to extend the survey to residents broadly, not simply visitor intercepts, as well as further explore the role of wildlife and HNC by examining additional factors associated with wildlife sentiment, such as previous interactions.

Conclusions

Overall, our findings provide valuable information to understand the influential factors associated with HNC in urban park visitors, particularly with respect to recreation activities. Although a feedback relationship between experiences in nature and HNC likely exists, distinguishing the degree to which any set of experiences or characteristics predicates HNC is cause for further investigation, but should not preclude implementing actions derived from the central theme of this and the corresponding research: frequent interaction with nature throughout our lifetime cultivates and enhances HNC (Rosa & Collado, 2019). The results of our study promote participation in nature-based recreation activities and encourage communities to allocate the necessary resources to ensure equitable access throughout the population.

Additionally, although it is unlikely that a single green space will have universal appeal to people and wildlife, prioritizing educational programming that emphasizes ecological knowledge while accommodating a wide range of sentiments toward wildlife holds promise for human health and wildlife conservation in these shared spaces. Lastly, as people who intentionally seek nature are relatively rare, weaving nature into the daily routine of urban residents in accessible, creative, and relatable ways remains a key strategy to improve HNC, improve environmental references, and simply get people to care about nature (Cox et al., 2017; Prévot et al., 2018; Tam 2013).

Ethics

Our research was exempted from (university IRB redacted for review). Students assisted in the distribution of postcards and each was certified by the Institutional Review Board and participated in project-specific training.

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Figures

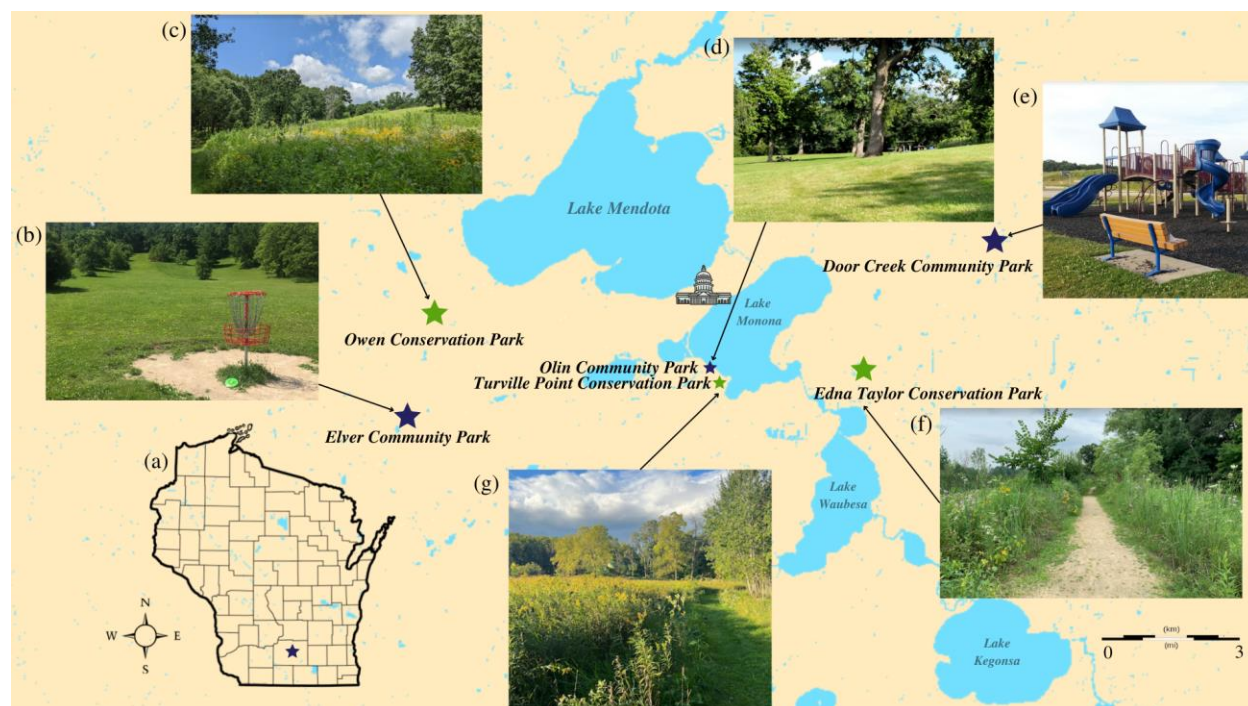


Figure 1. Map of the state of Wisconsin and Dane County (starred) (a) and community parks (blue stars b, d, e) and conservation parks (green stars c, f, g), with detail of land cover using ArcGIS 10.6.1 (Esri, Redlands, California) and Dane LandUse 2015 and Parks, City of Madison 2017 through the online geoportal of Dane County at GeoData@Wisconsin (UW-Madison Robinson Map Library, Madison, WI).



Figure 2. Six species of mammals referenced in survey questions regarding species literacy and positive species sentiment, 2021-2022, Madison, Wisconsin, USA.

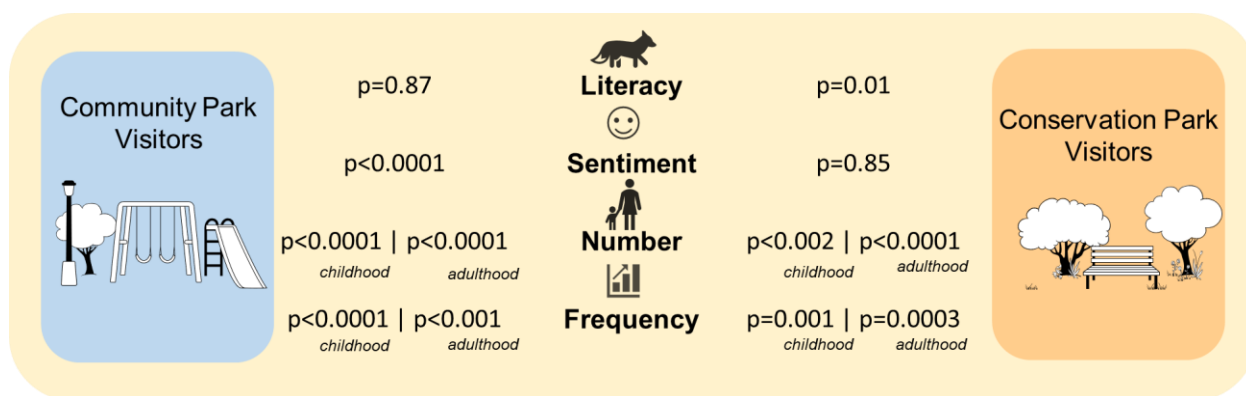


Figure 3. HNC as a factor of species literacy, positive species sentiment, and number and frequency of recreation activities in childhood and adulthood for community and conservation park visitors.

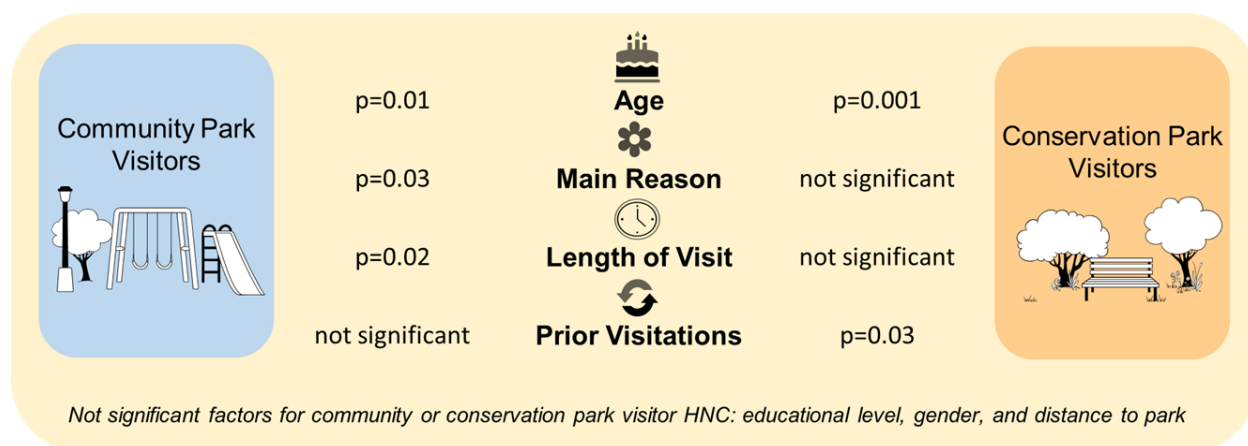


Figure 4. HNC as a factor of age, main reason for visitation, length of visit, and prior visitations for community and conservation park visitors.

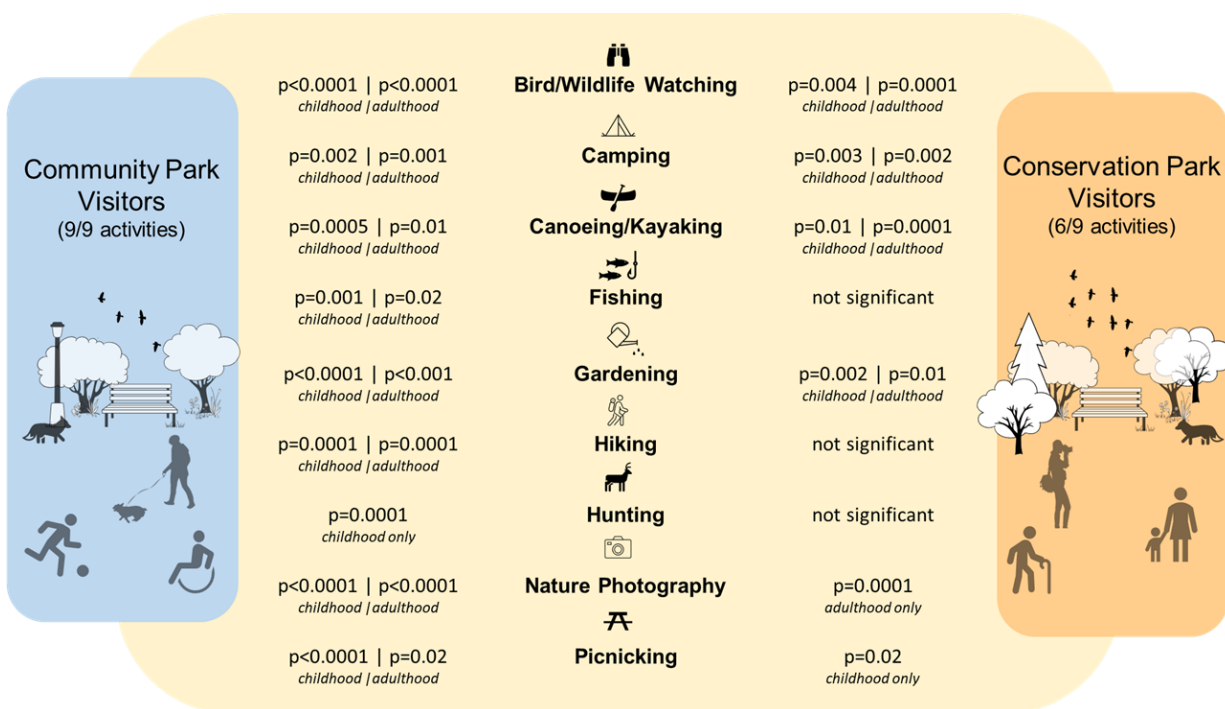


Figure 5. HNC as a factor of frequency of participation in nine recreation activities during childhood and adulthood for community and conservation park visitors.

Appendices

Appendix A. Linear model estimates of human-nature connection (NR-6 scores) for respondents from community parks, with intercept (I), estimate (β), standard error of the estimate (SEE), confidence interval for estimate (CI), and p-value (p) for continuous factors examined.

Factor ¹	Intercept (I)	Estimate (β)	Standard Error (SEE)	Confidence Interval for β (CI)	p-value (p)
Species literacy	4.17	-0.05	0.31	(-0.65,0.55)	0.87
Positive Species Sentiment	2.96	1.29	0.21	(0.87,1.71)	<0.0001
Number of Childhood Recreation Experiences	3.49	0.09	0.02	(0.06,0.13)	<0.0001
Number of Adult Recreation Experiences	3.32	0.14	0.02	(0.10,0.18)	<0.0001
Frequency of Childhood Recreation Experiences	3.58	0.89	0.16	(0.57,1.21)	<0.0001
Frequency of Adult Recreation Experiences	3.39	1.16	0.26	(0.64,1.67)	<0.001

¹ Degrees of freedom (df) = 287 for each, except df = 114 for “Frequency of Adult Recreation Experiences”

Appendix B. Significant human-nature connection factors (NR-6 scores) for respondents from community parks, with sample size (n), mean NR-6 ($\bar{x}$), standard error of the mean (SEM) and 95% confidence interval (CI) specifying significant differences between nominal data categories.

Categorical Factor ¹		Sample size (n)	Mean ($\bar{x}$)	Standard Error of the mean (SEM)	95% Confidence Interval (CI)
Age ²	18-24	39	4.05	0.11	(3.60,4.50)
	25-34	101	4.05	0.07	(3.76,4.33)
	35-44	70	4.03	0.08	(3.69,4.37)
	45-54	24	4.21	0.13	(3.64,4.78)
	55-64	34	4.51	0.11	(4.03,5.00)
	65-74	17	4.20	0.16	(3.53,4.88)
	75 and older	6	3.97	0.26	(2.83,5.11)
Main Reason ³	Passive	52	3.98	0.09	(3.58,4.39)
	Active	185	4.10	0.05	(3.87,4.34)
	Nature	54	4.31	0.09	(3.91,4.71)
Length of Visit ⁴	Less than 1 hour	104	4.01	0.01	(3.67,4.35)
	1 to 2 hours	159	4.15	0.07	(3.85,4.44)
	> 2 hours	28	4.41	0.13	(3.85,4.97)

¹ Factors examined but not significant: educational level ($p = 0.29$; $df = 283$), gender ($p = 0.80$; $df = 287$), previous visitation ($p = 0.37$; $df = 248$), and distance from residence to park ($p = 0.54$; $df = 283$).

² $p = 0.01$; $df = 282$. Respondents aged 18-24, 25-34, and 35-44 had significantly lower NR-6 scores than respondents aged 55-64.

³ $p = 0.03$; $df = 286$. Respondents who recorded 'Passive' as the main reason for visitation had significantly lower NR-6 scores than respondents who recorded 'Active' as the main reason.

⁴ $p = 0.02$; $df = 286$. Respondents who spent < 1 hour had significantly lower NR-6 scores than respondents who spent > 2 hours.

Appendix C. Linear model estimates of human-nature connection (NR-6 scores) for respondents from conservation parks, with intercept (I), estimate (β), standard error of the estimate (SEE), 95% confidence interval for estimate (CI), and p-value (p) for continuous factors examined.

Factor ¹	Intercept (I)	Estimate (β)	Standard Error of the Estimate (SEE)	95% Confidence Interval for β (CI)	p-value (p)
Species literacy	3.60	0.81	0.31	(0.17,1.45)	0.01
Positive Species Sentiment	4.32	0.05	0.27	(-0.48,0.58)	0.85
Number of Childhood Recreation Experiences	3.99	0.06	0.02	(0.02,0.09)	<0.002
Number of Adult Recreation Experiences	3.65	0.11	0.02	(0.07,0.15)	<0.0001
Frequency of Childhood Recreation Experiences	3.99	0.60	0.15	(0.30,0.91)	0.0001
Frequency of Adult Recreation Experiences	3.59	1.00	0.27	(0.48,1.52)	0.0003

¹ Degrees of freedom (df) = 265 for each, except df = 122 for “Frequency of Adult Recreation Experiences”

Appendix D. Significant factors of human-nature connection (NR-6 scores) for respondents from conservation parks, with sample size (n), mean NR-6 ($\bar{x}$), standard error of the mean (SEM), 95% confidence interval (CI) and comments specifying significant differences between specific categories of nominal data.

Categorical Factor ¹		Sample size (n)	Mean ($\bar{x}$)	Standard Error of the mean (SEM)	95% Confidence Interval (CI)
Age ²	18-24	25	4.33	0.11	(3.85,4.80)
	25-34	60	4.11	0.07	(3.81,4.42)
	35-44	58	4.37	0.07	(4.06,4.68)
	45-54	40	4.49	0.09	(4.11,4.86)
	55-64	46	4.41	0.08	(4.06,4.75)
	65-74	35	4.62	0.09	(4.22,5.02)
	75 and older	5	4.27	0.25	(3.21,5.32)
Prior Visitation ³	0 times	20	4.12	0.12	(3.59,4.66)
	1 time	33	4.29	0.10	(3.88,4.71)
	2 to 5 times	55	4.28	0.07	(3.96,4.60)
	6 to 10 times	38	4.38	0.09	(3.99,4.77)
	11-20 times	26	4.36	0.11	(3.89,4.83)
	> 20 times	72	4.54	0.07	(4.26,4.82)

¹ Factors examined but not significant: educational level ($p = 0.56$; $df = 261$), gender ($p = 0.37$; $df = 265$), main reason ($p=0.22$; $df= 236$), duration of visit ($p = 0.22$; $df = 264$) and distance from residence to park ($p = 0.39$; $df = 261$).

² $p = 0.001$; $df = 260$. Respondents aged 25-34 had significantly lower NR-6 scores than respondents aged 65-74.

³ $p = 0.03$; $df = 236$. Respondents who recorded zero prior visits had significantly lower NR-6 scores than respondents with more than 20 prior visits.

Appendix E. Frequency of participation in recreation activities in childhood for respondents from community parks using a Likert scale Never, Rarely, Sometimes, Often and Very Often with sample size (n), mean NR-6 score ($\bar{x}$), standard error of the mean (SEM) and 95% confidence interval (CI).

Categorical Factor		Sample size (n)	Mean NR-6 ($\bar{x}$)	Standard Error of the mean (SEM)	95% Confidence Interval (CI)
Bird or Wildlife Watching ¹	Never	61	3.85	0.09	(3.48,4.21)
	Rarely	80	3.99	0.08	(3.66,4.32)
	Sometimes	103	4.16	0.07	(3.86,4.46)
	Often	22	4.47	0.13	(3.89,5.05)
	Very Often	25	4.74	0.13	(4.19,5.28)
Camping ²	Never	44	4.03	0.11	(3.57,4.50)
	Rarely	69	3.91	0.09	(3.52,4.30)
	Sometimes	103	4.16	0.08	(3.81,4.50)
	Often	48	4.27	0.10	(3.82,4.72)
	Very Often	27	4.44	0.13	(3.87,5.01)
Canoeing or Kayaking ³	Never	55	4.11	0.09	(3.71,4.51)
	Rarely	95	3.95	0.08	(3.63,4.27)
	Sometimes	94	4.12	0.08	(3.80,4.45)
	Often	33	4.47	0.12	(3.96,4.97)
	Very Often	14	4.48	0.17	(3.72,5.23)
Fishing ⁴	Never	62	3.91	0.09	(3.51,4.30)
	Rarely	75	4.02	0.08	(3.66,4.39)
	Sometimes	99	4.24	0.08	(3.91,4.57)

	Often	37	4.17	0.11	(3.68,4.66)
	Very Often	18	4.5	0.16	(3.83,5.17)
Gardening ⁵	Never	39	3.81	0.11	(3.34,4.27)
	Rarely	81	4.06	0.08	(3.71,4.41)
	Sometimes	105	4.12	0.07	(3.80,4.43)
	Often	45	4.22	0.10	(3.78,4.65)
	Very Often	21	4.75	0.14	(4.14,5.37)
Hiking ⁶	Never	31	3.93	0.12	(3.40,4.46)
	Rarely	43	4.03	0.11	(3.57,4.49)
	Sometimes	108	4.01	0.08	(3.68,4.34)
	Often	67	4.19	0.09	(3.80,4.58)
	Very Often	42	4.54	0.11	(4.07,5.00)
Hunting ⁷	Never	210	4.06	0.06	(3.80,4.33)
	Rarely	35	4.19	0.12	(3.68,4.69)
	Sometimes	33	4.25	0.12	(3.74,4.77)
	Often	9	4.34	0.22	(3.39,5.28)
	Very Often	4	4.89	0.33	(3.48,6.29)
Nature Photography ⁸	Never	131	3.90	0.06	(3.63,4.17)
	Rarely	66	4.22	0.08	(3.86,4.57)
	Sometimes	60	4.33	0.09	(3.96,4.70)
	Often	23	4.24	0.13	(3.66,4.81)
	Very Often	11	4.80	0.19	(3.99,5.62)
Picnicking ⁹	Never	19	3.59	0.15	(2.95,4.23)
	Rarely	78	3.98	0.08	(3.64,4.33)

	Sometimes	111	4.18	0.07	(3.88,4.48)
	Often	58	4.19	0.09	(3.81,4.58)
	Very Often	25	4.53	0.13	(3.97,5.09)

¹ $p < 0.0001$; $df = 284$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes, Often, or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Often or Very Often. Respondents who recorded Sometimes had significantly lower NR-6 scores than respondents who recorded Very Often.

² $p = 0.002$; $df = 284$. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Often or Very Often.

³ $p = 0.0005$; $df = 284$. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Often or Very Often.

⁴ $p = 0.001$; $df = 284$. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Often or Very Often.

⁵ $p < 0.0001$; $df = 284$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

⁶ $p = 0.0001$; $df = 284$. Respondents who recorded Never, Rarely, Sometimes or Often had significantly lower NR-6 scores than respondents who recorded Very Often.

⁷ $p = 0.0001$; $df = 284$. Never, Rarely, or Sometimes had significantly lower NR-6 scores than respondents who recorded Very Often.

⁸ $p < 0.0001$; $df = 284$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Rarely, Sometimes, or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

⁹ $p < 0.0001$; $df = 284$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes, Often, or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

Appendix F. Frequency of participation in recreation activities in adulthood for respondents from community parks using a Likert scale Never, Rarely, Sometimes, Often and Very Often with sample size (n), mean NR-6 score ($\bar{x}$), standard error of the mean (SEM) and 95% confidence interval (CI).

Categorical Factor ¹		Sample size (n)	Mean NR-6 ($\bar{x}$)	Standard Error of the mean (SEM)	95% Confidence Interval (CI)
Bird or Wildlife Watching ²	Never	17	3.68	0.14	(3.08,4.29)
	Rarely	19	3.88	0.13	(3.30,4.450)
	Sometimes	47	4.27	0.09	(3.90,4.65)
	Often	21	4.28	0.13	(3.73,4.83)
	Very Often	14	4.70	0.16	(4.03,5.37)
Camping ³	Never	27	3.96	0.12	(3.46,4.47)
	Rarely	28	3.92	0.11	(3.43,4.42)
	Sometimes	37	4.38	0.10	(3.94,4.81)
	Often	14	4.16	0.16	(3.47,4.85)
	Very Often	12	4.64	0.17	(3.90,5.39)
Canoeing or Kayaking ⁴	Never	17	3.81	0.16	(3.13,4.50)
	Rarely	28	4.11	0.13	(3.56,4.67)
	Sometimes	48	4.15	0.11	(3.69,4.61)
	Often	14	4.52	0.17	(3.77,5.26)
	Very Often	11	4.46	0.19	(3.63,5.28)
Fishing ⁵	Never	46	4.23	0.11	(3.76,4.69)
	Rarely	35	4.02	0.12	(3.51,4.54)
	Sometimes	26	4.04	0.14	(3.46,4.62)

	Often	7	4.47	0.24	(3.43,5.50)
	Very Often	4	4.94	0.31	(3.59,6.28)
Gardening ⁶	Never	27	3.92	0.13	(3.37,4.46)
	Rarely	19	3.89	0.15	(3.26,4.53)
	Sometimes	36	4.24	0.12	(3.74,4.73)
	Often	16	4.25	0.16	(3.56,4.93)
	Very Often	20	4.57	0.15	(3.95,5.19)
Hiking ⁷	Never	2	2.14	0.41	(2.14,5.69)
	Rarely	8	2.69	0.21	(2.69,4.48)
	Sometimes	35	3.65	0.11	(3.65,4.56)
	Often	38	3.59	0.10	(3.59,4.46)
	Very Often	35	4.09	0.11	(4.09,5.00)
Nature Photography ⁸	Never	33	3.74	0.10	(3.30,4.19)
	Rarely	23	4.19	0.12	(3.66,4.72)
	Sometimes	32	4.27	0.11	(3.81,4.72)
	Often	16	4.42	0.15	(3.79,5.05)
	Very Often	14	4.67	0.16	(4.00,5.35)
Picnicking ⁹	Never	9	3.63	0.20	(2.75,4.51)
	Rarely	24	4.07	0.12	(3.57,4.57)
	Sometimes	44	4.26	0.09	(3.86,4.66)
	Often	23	4.17	0.13	(3.62,4.72)
	Very Often	14	4.50	0.16	(3.79,5.21)

¹Factor examined but not significant: hunting (p=0.85; df=111)

² p < 0.0001; df = 111. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes, Often, or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

³ $p = 0.001$; $df = 111$. Respondents who recorded Never or Rarely had significantly lower NR-6 scores than respondents who recorded Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Sometimes.

⁴ $p = 0.01$; $df = 111$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Often.

⁵ $p = 0.02$; $df = 111$. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

⁶ $p < 0.001$; $df = 111$. Respondents who recorded Never or Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

⁷ $p = 0.0001$; $df = 111$. Respondents who recorded Rarely, Sometimes, or Often had significantly lower NR-6 scores than respondents who recorded Very Often.

⁸ $p < 0.0001$; $df = 111$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Rarely, Sometimes, Often or Very Often.

⁹ $p = 0.02$; $df = 111$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Very Often.

Appendix G. Frequency of participation in recreation activities in childhood for respondents from conservation parks using a Likert scale Never, Rarely, Sometimes, Often and Very Often with sample size (n), mean NR-6 score ($\bar{x}$), standard error of the mean (SEM) and 95% confidence interval (CI).

Categorical Factor ¹		Sample size (n)	Mean NR-6 ($\bar{x}$)	Standard Error of the mean (SEM)	Confidence Interval (CI)
Bird or Wildlife Watching ²	Never	40	3.78	0.09	(3.78,4.54)
	Rarely	61	3.94	0.07	(3.94,4.55)
	Sometimes	99	4.40	0.06	(4.16,4.64)
	Often	45	4.51	0.08	(4.15,4.86)
	Very Often	24	4.58	0.11	(4.10,5.07)
Camping ³	Never	56	4.16	0.07	(3.85,4.48)
	Rarely	70	4.29	0.07	(4.01,4.58)
	Sometimes	90	4.43	0.06	(4.18,4.68)
	Often	39	4.51	0.09	(4.13,4.89)
	Very Often	14	4.67	0.15	(4.03,5.30)
Canoeing or Kayaking ⁴	Never	69	4.21	0.07	(3.93,4.50)
	Rarely	85	4.31	0.06	(4.05,4.57)
	Sometimes	84	4.48	0.06	(4.22,4.74)
	Often	20	4.40	0.12	(3.87,4.93)
	Very Often	11	4.73	0.17	(4.01,5.45)
Gardening ⁵	Never	29	4.10	0.10	(3.66,4.54)
	Rarely	68	4.33	0.07	(4.04,4.62)
	Sometimes	111	4.34	0.05	(4.11,4.56)

	Often	36	4.50	0.09	(4.11,4.90)
	Very Often	25	4.68	0.11	(4.21,5.16)
Picnicking ⁶	Never	15	4.24	0.14	(3.63,4.86)
	Rarely	61	4.17	0.07	(3.87,4.48)
	Sometimes	124	4.40	0.05	(4.18,4.61)
	Often	54	4.51	0.08	(4.18,4.84)
	Very Often	15	4.47	0.14	(3.85,5.09)

¹Factors examined but not significant: fishing ($p=0.12$; $df=262$), hiking ($p=0.06$; $df=262$), hunting ($p=0.62$; $df=262$), nature photography ($p=0.35$; $df=262$).

² $p=0.004$; $df=262$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Often or Very Often.

³ $p=0.003$; $df=262$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes, Often, or Very Often.

⁴ $p=0.01$; $df=262$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes or Very Often.

⁵ $p=0.002$; $df=262$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Often or Very Often. Respondents who recorded Sometimes had significantly lower NR-6 scores than respondents who recorded Very Often.

⁶ $p=0.02$; $df=262$. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Often.

Appendix H. Frequency of participation in recreation activities in adulthood for conservation park respondents using a Likert scale Never, Rarely, Sometimes, Often and Very Often with sample size (n), mean NR-6 score ($\bar{x}$), standard error of the mean (SEM) and 95% confidence interval (CI).

Categorical Factor ¹		Sample size (n)	Mean NR-6 ($\bar{x}$)	Standard Error of the mean (SEM)	95% Confidence Interval (CI)
Bird or Wildlife Watching ²	Never	8	3.52	0.18	(2.74,4.30)
	Rarely	14	4.12	0.14	(3.53,4.71)
	Sometimes	40	4.32	0.08	(3.97,4.66)
	Often	39	4.40	0.08	(4.05,4.75)
	Very Often	25	4.68	0.10	(4.24,5.12)
Camping ³	Never	18	4.06	0.13	(3.52,4.61)
	Rarely	39	4.16	0.09	(3.79,4.53)
	Sometimes	46	4.44	0.08	(4.10,4.78)
	Often	14	4.60	0.14	(3.98,5.21)
	Very Often	9	4.78	0.18	(4.01,5.55)
Canoeing or Kayaking ⁴	Never	14	3.70	0.14	(3.10,4.31)
	Rarely	28	4.32	0.10	(3.89,4.75)
	Sometimes	60	4.47	0.07	(4.18,4.76)
	Often	18	4.48	0.12	(3.95,5.02)
	Very Often	6	4.22	0.22	(3.30,5.15)
Gardening ⁵	Never	12	3.88	0.16	(3.20,4.55)
	Rarely	20	4.14	0.12	(3.62,4.67)
	Sometimes	44	4.43	0.08	(4.08,4.79)

	Often	24	4.38	0.11	(3.90,4.85)
	Very Often	26	4.53	0.11	(4.07,4.99)
Nature Photography ⁶	Never	24	3.99	0.11	(3.52,4.45)
	Rarely	18	4.37	0.12	(3.84,4.90)
	Sometimes	43	4.31	0.08	(3.96,4.66)
	Often	22	4.36	0.11	(3.88,4.85)
	Very Often	19	4.81	0.12	(4.29,5.33)

¹Factors examined but not significant: fishing ($p=0.85$; $df=119$), hiking ($p=0.09$; $df=119$), hunting ($p=0.61$; $df=119$), picnicking ($p=0.64$; $df=119$).

² $p=0.0001$; $df=119$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes, Often, or Very Often. Respondents who recorded Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

³ $p=0.002$; $df=119$. Respondents who recorded Never or Rarely had significantly lower NR-6 scores than respondents who recorded Very Often.

⁴ $p=0.0001$; $df=119$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Rarely, Sometimes, or Often.

⁵ $p=0.01$; $df=119$. Respondents who recorded Never had significantly lower NR-6 scores than respondents who recorded Sometimes or Very Often.

⁶ $p=0.0001$; $df=119$. Respondents who recorded Never or Sometimes had significantly lower NR-6 scores than respondents who recorded Very Often.

Chapter 3: *A common chord: To what extent can small urban green space support people and songbirds?*

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In preparation: Journal of Urban Ecology

Abstract

Large, vegetatively diverse, and connected green space is frequently viewed as paramount to conservation. Yet these criteria are often impractical when applied to densely populated or under-resourced urban areas and evoke mixed sentiments from people. Typically, people prefer urban green space that is smaller, minimally vegetated, and contains open mowed areas. Such conventional spaces are often inadequate for many wildlife species and fail to provide opportunities for nature connection in biodiverse environments yet have the potential to incorporate features that better support human and wildlife wellness. As songbirds are well-liked and globally distributed, they present an opportunity to rethink urban green spaces, particularly small urban green spaces (< 2 ha), that contain landscape qualities where the needs of people and songbirds converge. We conducted a comprehensive search of peer-reviewed publications to examine the anthropogenic, structural, and natural factors associated with songbird richness in small urban green space. Overall, small urban green spaces that incorporated a variety of habitats, including open grass areas, and native plant species, particularly trees, supported songbird richness. In some cases, songbird richness in small green spaces was equivalent to richness reported in larger green spaces. Interestingly, connectivity between green spaces was not significant ($p > 0.05$) in the majority of articles that examined the factor. This outcome removes a possible obstruction to

green space allocation and has the potential to jumpstart the placement of green space into historically and perpetually under-resourced communities. Finally, associations with anthropogenic factors had few positive associations with songbird richness but this category of factors were also reported the least often, likely indicating the importance of vegetatively diverse environments. Collectively, these results can empower urban practitioners with feasible options to improve human health, nature connections, and songbird conservation.

Introduction

Urban green space is an area containing varying degrees of vegetation that is associated with human-dominated landscapes (Taylor & Hochuli 2017). This highly inclusive definition results in the placement of urban green space along a broad and complex spectrum that includes vacant lots and conservation areas (Taylor & Hochuli 2017). Historically, the timing, placement, and criteria for incorporating public urban green space has been driven by social mediation, cultural objectives, and land values (Loughran 2020, Rosenzweig, 1992). Green space allocation was often planned to simultaneously compensate for a lack of nature, reduce residential overcrowding, promote racial separation, and bolster current and future land values (Loughran 2020, Rosenzweig, 1992, Schell et al., 2020). More recently, these former objectives have been revised to prioritize the value of urban green space in supporting a wide range of human welfare and conservation goals (Connop et al., 2016, Harnik 2010).

Urban green space can be private or public and vary in size, function, connectivity, biodiversity, accessibility, and history (McIntyre et al., 2008, Taylor & Hochuli, 2017). As a result, each green space presents different types and degrees of ecological and ecosystem value to humans and wildlife and the benefits accrued through one green space may not be equivalent to those of another (Felappi et al, 2020, Filazzola et al., 2019, Wood et al., 2018). A neighborhood park, for example, may offer recreation opportunities and mitigate seasonal precipitation events, yet it still may not provide habitat for a wide range of taxa due to fragmentation or lack of suitable vegetation for shelter or nesting (Apfelbeck et al.,

2020, Beninde et al., 2015). Alternatively, a conservation area may support a resilient and biodiverse ecosystem, yet only appeal to a small subset of people due to perceptions of safety, recreation interests, or lack of accessibility (Porcherie et al., 2019). Both scenarios highlight the importance of educational interventions to improve human understanding of the multitude of benefits provided by ecologically valuable spaces and better unite the goals of residents, ecologists, and urban practitioners (Connop et al., 2016, Shanahan et al., 2015).

Although often multifaceted in the benefits they provide, green space installations that are designed to be biodiverse and resilient ecosystems provide a broader and more effective scope of solutions (Beninde et al., 2015, Connop et al., 2016, Ives et al., 2017, Lepczyk et al., 2017). Specifically, nature-based solutions can simultaneously offset the costs associated with maintaining air and water quality; contribute habitat for a variety of species; and offer mental restoration, physical recreation, and enhanced nature connection for people (Connop et al., 2016, Felappi et al., 2020, Ives et al., 2017, Kardan et al. 2015, Nardo et al. 2010, Weisser & Hauck 2017). Collectively, these benefits are thought to be key to establishing a strong pathway toward environmental sustainability (Barragan-Jason et al., 2022, Beatley & Newman 2013, Rosa & Collado, 2019). In addition, synergies between supporting wildlife and human health have been found with multiple factors, including increased tree cover, reduced noise, presence of water, and higher diversity of habitats (Felappi et al., 2020). However, human aesthetic preferences for smaller, open, and mowed greenspaces are in sharp contrast to the needs of many wildlife species (Beninde et al., 2015, Felappi et al., 2020, Ives et al., 2017, Whitburn et al., 2020). By balancing the importance of size and landscape composition that are key to wildlife conservation and also associated with human preferences, urban green space may simultaneously meet the needs of wildlife and humans and strengthen nature connections (Beninde et al., 2015, Ives et al., 2017, Whitburn et al., 2020).

Urban green space is commonly planned and developed to offer a variety of amenities to people, the focal audience for urban planning. However, this type of green space is often unsuitable for a broad range of

wildlife taxa and can instead result in smaller assemblages of urban utilizing (e.g., northern cardinal (*Cardinalis cardinalis*) and American robin (*Turdus migratorius*)) and urban dwelling (e.g., rock pigeon (*Columba livia*) and house sparrow (*Passer domesticus*)) species (Aronson et al., 2014, Beninde et al., 2015, Fidino et al., 2021, Ikin et al., 2013, Lepczyk, et al., 2017). This outcome neither provides conservation from more 'biodiversity-led' or 'wildlife inclusive' designs nor enhances nature connection by allowing people to interact with more nature-based ecosystems (Connop et al., 2016, Dunn et al., 2006, Klein & Thurstan, 2016, Weisser & Hauck, 2017). Demonstrating to practitioners, policy makers, and residents the value and feasibility of designing green space to be ecologically and socially functional is a first step to incorporating these standards into master planning processes (Kay et al., 2022, Connop et al., 2016, Gobster et al., 2007). This step will likely necessitate a change in the narrative of conventional thinking and practices between city collaborators, requiring ecologists, landscape architects, and urban planners to collaboratively demonstrate the possibilities of blending aesthetics and ecology into multifunctional spaces (Kay et al., 2022, Connop et al., 2016, Gobster et al., 2007). Solutions will not be formulaic. Indeed, they must remain adaptable to address multiple competing interests and/or challenges that change over time, including local and regional ecologies, policies, funding, and land availability (Kay et al., 2022, Garcia-Garcia et al., 2020, Rega-Brodsky et al., 2018).

One of the priorities in reimagining urban green space is to address the expectations of urban residents (Dunn et al., 2006, Klein & Thurstan, 2016, Papworth et al., 2009, Soga & Gaston, 2018). That is, increasingly nonnative or manicured nature containing low species richness becomes the benchmark of a natural state, with progressive generations having increasingly less endemic natural conditions as their reference of nature (Klein & Thurstan, 2016; Papworth et al., 2009; Soga & Gaston, 2018). One means of addressing this generational decline is recognizing that access to more natural and biodiverse urban green space is integral to our relationship with nature (Karacor & Parlar, 2017; Klein et al., 2021; Lumber et al., 2017; Nardo et al., 2010; Papworth et al., 2009; Turner et al., 2004). This relationship, hereafter referred to as human-nature connection (HNC), is often described as an emotional bond developing from the

physical and contextual interactions that we experience throughout our lives (Giusti 2019; Otto et al., 2016). Increasing nature-based interactions in urban settings has the potential to shape and strengthen this bond and may be key to advancing pro-environmental engagement and securing global environmental sustainability (Mackay & Schmitt, 2019; Whitburn et al., 2020; Wilkie & Trotter, 2022).

An emerging area of investigation seeking to balance urban growth and wildlife conservation objectives involves exploring the relationship between HNC and songbirds (Order Passeriformes) (Collins et al., 2021, Cox & Gaston, 2016, Hedblom et al., 2014). Much of this research has been conducted with humans in laboratories, classroom settings, and/or via surveys investigating bird species likeability, biodiversity perceptions, or restorative self-assessments associated with viewing virtual landscapes, bird species, and/or experiencing auditory playbacks of songbirds (Cameron et al., 2020, Deng et al., 2020, Fisher et al., 2021, Liordos et al., 2020, Ratcliffe et al., 2013). Collectively, this research demonstrates greater enjoyment and restorative value associated with vegetatively diverse landscapes containing higher songbird diversity (Cameron et al., 2020, Deng et al., 2020, Hedblom et al., 2014). Integrating evidence from nature-related experimentation and nature-based experiences may provide a guide to mitigating the effects of urbanization on avian conservation and increase HNC, particularly in urban areas where residents may have relatively few opportunities to engage with nature (Cox et al., 2017, Schell et al., 2020).

One of the most consistent outcomes from nature-based experiences is the relationship between HNC and time spent in a structurally complex and biodiverse green space (Beery & Wolf-Watz, 2014; Coldwell & Evans, 2017; Colléony et al., 2019; Scopelliti et al., 2016). Individuals who spend time in these types of spaces report positive psychological, cognitive, physiological, and social effects (Fuller et al., 2007; Keniger et al., 2013; Wyles et al., 2020). Additionally, individuals who experience nature through recreation or in appreciative (bird watching) or consumptive (hunting) ways demonstrate increased engagement in a broad range of conservation behaviors and have greater positive sentiment and higher

tolerance towards wildlife (Cleary et al., 2020, Cooper et al., 2015, Liordos et al., 2020). Watching, feeding, and listening to bird taxa, specifically songbirds, whether in private gardens or public green space, has shown positive effects on people's appreciation of nature and multiple measures of well-being (Cox & Gaston, 2015, Cox & Gaston, 2016, Zhu et al., 2020).

As songbirds are predominantly well liked, small-bodied, highly diverse, and globally ranging, with many demonstrating behavioral and/or phenotypic qualities that allow them to utilize urban landscapes, they are seemingly ideal candidates to navigate the possibilities of blending HNC and avian conservation into public urban green space (Chamberlain et al., 2009, Collins et al., 2021, Cox & Gaston, 2015, Liordos et al., 2020, Sol et al., 2014). Studies have shown that large urban areas with native vegetative heterogeneity, greater shrub and tree canopy cover, and perennial water are associated with greater avian richness (Aronson et al., 2014, Clergeau et al., 2001, Ferenc et al., 2014, La Sorte et al., 2020, Morelli et al., 2017, de Toledo et al., 2012). Yet, these components are not always applied in cities experiencing high demands for densification from population growth, land values, and limited available vacant areas (Aronson et al., 2014, Clergeau et al., 2001, Ferenc et al., 2014, La Sorte et al., 2020, Morelli et al., 2017, de Toledo et al., 2012).

Abundant research exists on urban avian populations, including investigations of avian species richness, composition, and abundance associated with varying degrees of urbanization and the potential role of urban green space in avian conservation (Marzluff 2017). Far fewer studies have examined the duality of small (< 2 ha) urban green space to enhance HNC and/or support resident songbird populations, though notable examples do exist (Amaya-Espinel et al., 2019, Carbó-Ramirez & Zuria, 2011, Ferreira et al., 2021, Jasmani et al., 2017, Stagoll et al., 2012, Strobach et al., 2013). With growing competition for available space within densely built and expanding cities, understanding the attributes of public urban green space, specifically small urban green space, that support avian populations may simultaneously support human well-being and HNC and provide a useful reference to urban practitioners interested in

expanding beyond the conventional role of human-centered urban green space (Cox et al., 2017, Ferreira et al., 2021, Jasmani et al., 2017, Miller & Hobbs, 2022, Strohbach et al., 2013). Therefore, the objective of our study was to conduct a systematic review of the literature to extract site level (e.g., vegetation structure within a green space) and landscape level (e.g., connectivity across green spaces) land cover and use factors in urban green space associated with increased resident bird diversity, particularly songbird populations in small urban green space. The primary outcome of our study is to provide urban practitioners with a reference when planning, designing, and constructing urban greenspaces to maximize songbird diversity and HNC.

Methodology

Search Terms and Filters

We conducted a comprehensive search of peer-reviewed publications to determine the factors associated with increased songbird diversity in urban green space, particularly small urban green space. All articles were searched within four databases: Web of Science and EBSCOhost Information Services, specifically GreenFILE, Urban Studies Abstracts, and Wildlife and Ecological Studies. The articles were searched using the term sequence (passeri* or songbird or (avian diversity) or (avian richness) or (bird diversity) or (bird richness)) AND (urban or city or cities or metropolitan or (urban area) or (urban landscape) or (urban landscape matri*) or (urban landscape attribute) or (urban landscape factor)) AND (greenspace or (green space) or (outdoor space) or (natural area) or parks). The literature filters applied to the search included English, full text, and available online access.

Eligibility Criteria

These search terms and filters resulted in 678 articles: 315 from EBSCOhost and 363 from Web of Science. We further evaluated each relevant article using the following criteria: (1) did the article examine the richness of urban avian resident populations, including resident songbird populations, and (2) did the article examine associations between avian richness and landscape characteristics in specified

urban green space locations. These two inclusion criteria resulted in 114 articles: 45 from EBSCOhost and 69 from Web of Science. These articles were selected for full text evaluation to determine suitability with our research objectives. We further excluded articles that examined urban avian populations, but (1) did not include site-specific landscape characteristics (quantitative or qualitative); (2) did not report the number of avian species associated with individual study sites or site types; (3) did not include songbird species numbers; (4) did not report at least one significant relationship ($p < 0.05$) between green space factors and outcomes of interest; (5) were purely qualitative; and/or (6) were duplicate articles. This resulted in a final dataset of 45 articles considered in our work. Results are reported with terminology and/or phrasing of the original article and the number of times that a factor was reported is indicated in parentheses following the factor.

Community Structure

The predictors of avian abundance, composition, evenness, and species diversity can differ from those associated with richness. As we were primarily interested in identifying the attributes of the landscape that support the highest number of bird species, studies were restricted to those reporting species richness (number of species in an area). In addition, included articles examined richness within the boundaries of the urban and peri-urban zones (on the edge of urban development), including natural and semi-natural green space designated as parks, allotments, cemeteries, or woodlands but excluding green roofs, green walls, and locations identified as rural (Sahana et al., 2023).

Small Urban Green Space

To assess the extent that small urban green space supports songbird diversity, a subset of qualifying articles was extracted that (1) included quantitative landscape metrics for study sites < 2 ha and (2) listed the number of songbird species at each study site or site type. The categorization of ‘small’ green space is not standardized in the literature, and studies include areas from < 1 ha to < 10 ha or simply refer to a study site as ‘small’ without an operational definition (Carbo-Ramirez et al., 2011, Ferreira et al., 2021,

Gavrilidis et al., 2022, Zuñiga-Palacios et al., 2020). As a definitive classification of small green space remains variable, we assigned ‘small’ to areas < 2 ha. This approach is cognizant of the demand for highly coveted urban vacant areas while retaining a variety of size alternatives for urban practitioners to consider.

Each of these study inclusion criteria was considered essential to determine anthropogenic, structural, and natural factors that predict the richness of the avian community in urban green space and remain in accordance with our main objective of the study: to provide a condensed, user-friendly reference for urban practitioners interested in expanding the supportive role of urban green space, particularly small urban green space, to include opportunities to enhance HNC through songbird richness.

Results

Forty-five qualifying peer-reviewed articles conducted in 24 countries (21 temperate, 14 tropical, and 10 sub or semitropical) between 2000 and 2023 evaluated predictors of bird and/or songbird species richness (Appendix A). A total of 1666 study sites, range from < 0.1 ha to nearly 6000 ha, reported 177 associations with a wide range of predictive factors, classified in this study as structural (area, shape, age, and connectivity to other areas of interest), natural (vegetation, habitat, and water), or anthropogenic (noise level, number of pedestrians/minute, percentage impervious surface (includes structures and road cover), degree of urbanization, building factors (includes building height or density), percentage asphalt, and number of vehicles/minute)(Appendix B).

Anthropogenic Factors

Anthropogenic (37) factors accounted for 20.9% of the explanatory occurrences with bird and/or songbird richness: human factors (12), impervious surface (8), degree of urbanization (6), buildings (6), percentage asphalt (3), and number of vehicles/minute (2) (Figure 2, Appendix B). All human factors were recorded within each of the study sites. Excluding one article, all other anthropogenic factors related to percentage

of impervious surface or asphalt, degree of urbanization, buildings, and number of vehicles/minute refer to factors surrounding the study sites within a specified buffer zone (range 60 m to 5 km diameter) (Charre et al., 2017, Oliver et al., 2011). Only 8.1% of the associations with anthropogenic factors had a significant positive effect on richness, while 40.5% were negative and 51.4% were nonsignificant. Human factors included results associated with noise level (5), pedestrians/minute (5), number of off-leash dogs (1) and number of cats (1). Human factors had zero significant positive effects on richness, with pedestrian level having more negative effects (60%) compared to nonsignificant effects (40%) and noise level having fewer negative effects (40%) compared to nonsignificant effects (60%). Neither the number of off-leash dogs nor the number of cats had a significant influence on richness. Two articles reported a significant positive effect with the percentage of impervious surface or the degree of urbanization on richness. All other occurrences for degree of urbanization, number of vehicles/minute, percent impervious surface, and percent asphalt were split between negative (42.1%) and nonsignificant (47.4%) effects. Building-related factors (building height, percent buildings, and number of buildings) had a predominately negative (33.3%) or nonsignificant effect (50.0%) on richness, with a single article reporting a significant positive effect on richness (number of buildings) (Kumdet et al., 2021).

Structural Factors

Structural (66) factors accounted for 37.3% of the explanatory associations with bird and/or songbird richness: patch area (35), connectivity (19), patch shape (8), and patch age (4) (Figure 2, Appendix B). The size of green space had a significant positive effect (77.1%) on richness more often than a nonsignificant effect (22.9%). No negative effects were reported. Interestingly, connectivity was a significant positive factor in only 15.8% of occurrences compared to 84.2% of occurrences as a nonsignificant factor (no negative effects were reported). Patch shape and age had a significant positive effect on richness in 50% of occurrences, with patch shape having no significance in 50% of occurrences and patch age having a negative (25%) or nonsignificant (25%) effect in the remaining occurrences.

Natural Factors

Natural (74) factors accounted for 41.8% of the explanatory associations with bird and/or songbird richness: vegetation (60), water (9), and habitat number, composition, and diversity (5) (Figure 2, Appendix B). Vegetation factors (including number of woody trees, percentage canopy cover, and vegetation diversity) had more significant positive effects on richness (60.0%) than negative (8.3%) or nonsignificant (31.7%). Habitat heterogeneity (number, composition, and diversity) and the presence or amount of water, or waterbody shape had a significant positive effect on richness in all occurrences. Distance to water outside of the green space had a neutral (67%) or negative effect (33%). No positive effects of distance to water were reported.

Vegetation

There were 60 occurrences specific to vegetation (Figure 3, Appendix B). Excluding three articles reporting five factors (largest patch index of woodland, percentage vegetation, percentage woody species, tree abundance and shrub abundance), all vegetation factors were recorded within study sites (Aida et al., 2016, Rico-Silva et al., 2021, Xie et al., 2016). Factors related to abundance of trees, canopy cover, and percentage or presence of forest cover were reported in 48.3% (29) of occurrences and had a significant positive effect on richness in 62.1% of occurrences, negative in 10.3% of occurrences, and nonsignificant in 27.6% of occurrences (Figure 2, Appendix B). Shrubs, shrubs/grass, and woody vegetation had significant positive effects (58.3%) and nonsignificant effects (41.7%). No negative effects were reported. Grass and barren ground had 40.0% positive, 40.0% nonsignificant, and 20.0% negative effect on richness. Vegetation diversity or height had mostly positive effects on richness compared to nonsignificant (67.0% and 33.3%, respectively) and no negative effects. Non-native vegetation had equal positive (33.3%), negative (33.3%), and nonsignificant (33.3%) effects. There were four unique significant factors pertaining to tree cavities, surrounding green space, semi-natural, and managed green space (Aida et al., 2016, Hayes et al., 2020, Thompson et al., 2022, Wong et al., 2023). Each had a

significant positive effect on richness. Only one study reported that all vegetation structure factors examined were nonsignificant (Zuñiga-Palacios et al., 2020).

Small Green Spaces

Of the 45 articles reviewed, 12 provided landscape factors associated with songbird richness for small green spaces (< 2 ha) (Appendix C). Seven articles averaged 1.1 ha (< 1 ha to 1.98 ha) and contained an average of 15.0 bird species (range 5 to 53 species), including an average of 12.8 songbird species (range 3 to 35 species). Each of the seven articles reported results pertaining to different measured factors, often with minimal overlap. Area of green space had a significant positive effect on richness in all of the articles that examined green space area (Chaiyarat et al., 2019, González-Ortega et al., 2012, de la Hera 2019, Matthies et al., 2017, Melo & Piratelli, 2022, Schütz & Schulze, 2015). Closer proximity to a green space or water source had a positive effect on richness in one article (Chaiyarat et al., 2019), was nonsignificant in four articles (González-Ortega et al., 2012, Imai & Nakashizuka, 2010, Matthies et al., 2017, Melo & Piratelli, 2022), and was not examined in two articles (de la Hera et al., 2019, Schütz & Schulze, 2015). Vegetation and abundance of water had a positive effect on richness, except in one case of nonsignificance (canopy heterogeneity) (Schütz & Schulze, 2015). Anthropogenic factors had a negative effect on richness in articles that examined noise level, degree of urbanization, and/or percentage of impervious surface (González-Ortega et al., 2012, Imai & Nakashizuka, 2010, Schütz & Schulze, 2015). A negative effect on richness was found in one article that specifically examined noise associated with songbird richness and measured an average noise level of 61.4 dB at four sites < 2 ha (González-Ortega et al., 2012). The number of building related factors and off-leash dogs and cats had a nonsignificant effect on richness (Melo & Piratelli, 2022). Eighteen sites averaged 38.5% impervious surface (range from 1.8% to 94.0%). Those same sites averaged 21.7% canopy cover (range from 0.2% to 70.5%). An additional six sites averaged 37.5% tree cover (range from 2.6% to 80%). Thirty sites averaged 5.1% shrub cover (range from 0 to 45.2%) and 26 sites averaged 27.0% grass cover (0 to 74.4%).

Five of the 12 articles did not include site-specific landscape metrics but are worth noting as they provide information regarding anthropogenic and natural land cover predictors of songbird richness (Amaya-Espinel et al., 2019, Carbo-Ramirez & Zuria, 2011, Ferreira et al., 2021, Rico-Silva et al., 2021, Stagoll et al., 2012). One of the articles reported avian and songbird richness specifically at small sites by site type, (7 gardens ($\bar{x} = 0.3 \pm 0.05$ ha); 6 parks ($\bar{x} = 1.2 \pm 0.3$ ha); and 6 road strip corridors ($\bar{x} = 1.1 \pm 0.26$ ha)), reported the percentage of asphalt as 39.7 ± 1.85 , the percentage of buildings as 48.1 ± 3.77 , and the percentage of green space as 12.2 ± 2.05 (including the percentage of canopy cover as 45.4 ± 3.64) (Carbo-Ramirez & Zuria, 2011). Bird species ranged from 26 to 32 species and songbird species ranged from 21 to 27 species. The second article with an average green space size of 0.4 ± 0.05 ha for 18 study sites reported ‘10-25’ bird species at all sites (the majority of species noted as songbird species), found the percentage of asphalt as 20.2 ± 3.8 , percentage of building cover as 63.2 ± 10.1 , percentage of trees and shrubs as 10.7 ± 4.8 , and percentage of herbaceous plants as 5.4 ± 6.5 (Rico-Silva et al., 2021). The third article with area of green space ranging from 0.25 to 2.0 ha, reported a mean number of bird species (including unspecified songbird species) as 7.8 ± 2.6 species/site (Stagoll et al., 2012). Study sites (109) were described as ‘located in residential areas, containing varying sizes of native trees of the genus *Eucalyptus*, and >500 m from other parks’. The fourth article evaluated 60 sites ranging from 0.5 to 2.0 ha that were ‘vegetated by ornamental trees and grass located around and between buildings, publicly accessible, and of relatively rounded form’ (Amaya-Espinel et al., 2019). Bird species were recorded as ‘28 total species with 16 songbird species per site’. Anthropogenic factors (percentage of road cover and building density) had a negative effect on bird and/or songbird richness. Only building height was nonsignificant. Vegetation diversity had a significant positive effect on richness. No negative effects were reported with vegetation factors. Patch area had a significant positive effect and connection to a land source was nonsignificant. The fifth article evaluated 28 sites ranging from 0.1 to 0.8 ha that were described by ranges of tree richness and noise levels (Ferreira et al., 2021). Bird species averaged 23.4 bird species and 15.0 songbird species per study site. Noise level had a significant negative effect on

richness. Tree species richness had significant positive effects on richness, but tree density and percentage of native trees were nonsignificant factors. Connection to a water source was nonsignificant.

The five articles found a significant positive effect on richness associated with height of herbaceous plants, percentage of woody vegetation, vegetation diversity, tree species richness, or the number of large native trees but tree density and percentage of native trees were nonsignificant factors. Negative or nonsignificant effects on richness from anthropogenic factors (percentage of asphalt or road cover, building density, percentage of buildings, number of pedestrians or noise level) were reported. Patch area had a significant positive effect on richness and connection to a land or water source was nonsignificant.

Discussion

The purpose of our study was to conduct a comprehensive search of peer-reviewed publications to (1) determine the anthropogenic, structural, and natural factors (qualitative or quantitative) associated with resident songbird richness in urban green space and (2) determine site-specific quantitative landscape metrics and site associated numbers of songbird species for small (< 2 ha) green spaces. Large patch area, vegetation (type, structure, and/or diversity), water (presence and/or abundance), and habitat (number, composition, and/or diversity) had predominantly positive effects on bird and/or songbird richness. Connectivity was nonsignificant in the majority of occurrences. Predictive anthropogenic factors were reported the least often with the majority of effects being negative or nonsignificant. Below, we interpret the effects of individual anthropogenic, structural, and natural factors on bird richness and the conceptual advancements these factors provide toward understanding the characteristics of urban green space, particularly small urban green space, that support songbird richness.

Anthropogenic Factors

Anthropogenic factors were associated with species richness less often than natural or structural factors and only three factors (number of buildings, percentage of impervious surface, or degree of urbanization)

had a positive effect on richness (Kumdet et al., 2021, Oliver et al., 2011, Thompson et al., 2022). In all three instances, the presence of abundant surrounding woody vegetation was largely attributed to the positive effect of anthropogenic factors on overall richness rather than any direct benefit from anthropogenic factors, as an increase in more common species was also found (Kumdet et al., 2021, Oliver et al., 2011, Thompson et al., 2022). Noise level had mixed significance on richness in the articles that examined the factor but higher intensity of sound (> 70 dB; gas-powered lawn mower ≈ 80 dB; car horn ≈ 100 dB; sirens ≈ 120 dB) for extended periods of time can damage human hearing and has been associated with reduced cognition, hypertension, stress, anxiety, and depression (van den Berg et al., 2010, Liu et al., 2019, Müller & Kropp, 2023, Uebel et al., 2022). In addition, there is evidence that higher noise levels interfere with avian communication, distribution, and reproduction (Ferreira et al., 2021, González-Ortega et al., 2012, Marzluff 2017, Perillo et al., 2017). Green spaces with noise levels < 52 dB have been associated with higher resident avian species whereas exotic avian species were more common in green spaces with higher noise levels (Arévalo et al., 2022). Avian species, such as the American Robin (*Turdus migratorius*) can make vocal adjustments in response to anthropogenic noise, but plasticity in vocal repertoire, particularly frequency characteristics, is not present in all avian species, such as the Carolina Wren (*Thryothorus ludovicianus*) or Gray Catbird (*Dumetella carolinensis*), and can interfere with attracting mates or avoiding predation (Dowling et al., 2012, Slabbekoorn, 2013). From this perspective, abating the effect of noise in urban green space is advantageous for people and songbirds. How this is accomplished will be multifaceted, whether green space area and the taxonomic structure of vegetation, water features, zoning, and/or transportation related factors are implemented to interrupt or mask noise transmission (Cicort-Lucaciu et al., 2022). For example, a noise-sensitive park might include mature native trees acting as sound barriers, natural sounds dominating the landscape (e.g., rushing water), innovative pavement types to dampen nearby vehicle noises and designated lanes to support the use of active transportation (e.g., pedestrians and bicycles). On a positive note, a wide range of anthropogenic factors were measured in the majority of articles, but few factors analyzed were found to have an effect (positive, negative, or nonsignificant) on richness.

Structural & Vegetation Factors

Large green spaces had a significant positive effect on bird and/or songbird richness in the majority of the articles that examined patch size, including studies that exclusively examined sites < 4 ha (Amaya-Espinel et al., 2019, Carbo-Ramirez & Zuria, 2011, Jasmani et al., 2017), with increments of 0.02 ha associated with an additional species being observed (Strobach et al., 2013). Yet patch size alone did not support bird richness, as several articles reported comparable or greater richness at green space locations < 2 ha (Peris & Montelongo 2014, Rico-Silva et al., 2021), < 5 ha (Thompson et al., 2022), and < 10 ha (Zuñiga-Palacios et al., 2020) when compared to larger green spaces examined. However, larger areas are more effective at reducing perimeter/area ratios and noise levels and often consist of greater vegetation and/or habitat richness, qualities important to many urban avoiding avian species (Chaiyarat et al., 2019, Garizábal-Carmona & Mancera-Rodríguez, 2012, González-Ortega et al., 2012, Matthies et al., 2017, Peris & Montelongo, 2014). In fact, vegetation factors had a significant positive effect on bird richness in the majority of articles that examined percentage of woody vegetation, abundance of trees, canopy cover, and/or forest cover, with one article reporting greater number of native mature trees increasing bird richness by over 150% and woodland-associated songbird species richness by over 300% (Schwartz et al., 2015, Stagoll et al., 2012). Incorporating different tree species with varying growth rates will likely require planning ahead, in some cases for decadal landscape transformation, and encourages the design of green space that includes a variety of supportive vegetation cover in the interim (Stagoll et al., 2012). Furthermore, the presence of trees or woody vegetation (trees and shrubs) may explain why area did not have a significant effect on bird species diversity in any article that examined the factor (de Groot et al., 2021, Huang et al., 2022, Korányi et al., 2021, Kumdet et al., 2021, Morelli et al., 2017, Rico-Silva et al., 2021). Finally, patch shape had mixed predictive value in the eight studies that evaluated the factor. However, reducing edge effects (patch perimeter to area ratio) was often cited as an important factor to support richness as well as support a broader range of uncommon or specialist species (Garizábal-Carmona & Mancera-Rodríguez, 2012, Huang et al., 2022, Jasmani et al., 2017, Peris &

Montelongo, 2014). Together, these outcomes favor the concurrent incorporation of patch area and vegetation richness, and potentially shape, in designing green space that supports bird diversity.

For humans, there are conflicting results regarding the appeal of large patch size and vegetation characteristics, with preferences for more open and mowed green space with reduced tree canopy (Felappi et al., 2020). Small, vegetatively diverse green space that includes open area could help alleviate safety concerns associated with larger green space, increase the frequency of contact with nature, and offer support to a variety of bird species (Felappi et al., 2020).

Connectivity

Connectivity is often cited as an important consideration in green space planning and wildlife conservation strategies but had a nonsignificant effect on avian richness in the majority of studies investigating the factor. This outcome occurred in studies evaluating richness and the distance of small areas to species rich large areas (Charre et al., 2013, González-Ortega et al., 2012, La Sorte et al., 2020) and in studies that exclusively examined the isolation of small green spaces and species richness (Amaya-Espinel et al., 2019, Ferreira da Silva et al., 2021). This is important information, as emphasizing the establishment of a network of green spaces may place unnecessary restrictions on municipalities concerning the placement of green space and diminish the value of more isolated locations in avian conservation (Riva & Fahrig 2022). To be clear, we are not discrediting the importance of connectivity and recognize that green space that is distributed in an equitable and accessible pattern is important for humans and terrestrial wildlife movement (Larson et al., 2021, Rigolon 2016, Schell et al., 2020). However, the results of this review indicate that when the focal animal is avian, connectivity may be a secondary concern. In fact, rethinking connectivity with avian communities in mind can jumpstart benefits to historically and perpetually under-resourced human communities that lack access to adequate green space and connections with existing green space can be maintained through vegetated corridors, such as street trees (Ferreira da Silva et al., 2021, Fernández-Juricic et al., 2000).

Small Green Space and Songbirds

Valuable information regarding site and landscape level factors supporting songbird diversity were identified across the dataset where studies focused on both small and larger green spaces, and particularly in the articles focusing on small green spaces. Large patch area had a significant positive effect on richness in the majority of articles containing small (< 2 ha) green spaces and in articles that exclusively examined small green spaces. Although size may be viewed as an essential and primary consideration to conserving songbird diversity, several articles reported comparable or greater richness at small green space locations and large green spaces may not be an achievable option in many urban areas. To that point, natural factors, particularly woody vegetation (trees and shrubs) had an overwhelmingly positive effect on songbird richness. When patch size is a restriction, green space with increased vegetation structure (herbaceous plant richness, woody vegetation, or mature trees) may be able to compensate for smaller patch sizes for many species. In addition, as results indicated that connectivity was nonsignificant in a majority of occurrences, this outcome removes another possible obstruction to green space allocation. Emphasizing vegetation structure within green spaces may be a suitable tradeoff for a lack of connectivity as well as patch size. As urban communities consider “pocket parks” and other green and creative repurposing of smaller vacant spaces, this point may help drive decisions about the types of vegetation to include. For anthropogenic factors, the absence of positive effects on richness was a recurring outcome but this category of factors was also reported the least often, indicating that natural and structural factors likely have a more significant role in supporting songbird richness. Finally, for the articles that provided site-specific landscape metrics and songbird richness, there was a wide range of factors regarding the amount of impervious surface, canopy cover, woody and herbaceous vegetation, and multiple tree related factors that supported songbirds. This outcome is encouraging, as it demonstrates that a range of effective factors can be combined to provide suitable urban habitat for songbirds.

Limitations and recommendations

This review can serve as a guide for urban practitioners interested in expanding the conventional role of urban green space to incorporate qualities to enhance HNC and songbird conservation. However, we do not claim it to be an exhaustive search of the literature (e.g., non-English, technical reports) nor a comprehensive list of evidence pertaining to songbird richness in urban green space. For example, our search criteria focused on resident songbird richness, as this criteria aligns with providing people year round bird diversity that has been associated with enhanced HNC. However, other metrics, such as abundance and/or composition, may not be supported by the same factors as richness and result in dominance by a few species or lower numbers of uncommon or guild specific species. This possibility was the rationale for including information pertaining to the environmental factors associated with species abundance, composition, evenness, and species diversity alongside richness.

Publishing site and landscape level data along with site-specific numbers of bird and/or songbird species, often collected regardless of study objectives, is key to improve and expand the accessibility of this type of research to a broader audience, particularly urban practitioners trying to manage multiple interests. In addition, our search resulted in only four articles that specifically evaluated small green space. Future research investigating the supportive conditions and compositions of small urban green spaces could result in a broad assortment of valuable applications, particularly as urban populations continue to expand and face growing challenges to human health, nature connectedness, and environmental sustainability.

Conclusions

The overwhelming appeal of songbirds, as well as their diversity and global distribution, presents a compelling opportunity to rethink urban green space design that supports people and songbirds. The conventional list of green space qualities that are often viewed as paramount to conservation must be reevaluated to develop a shortlist of factors that have known positive effects and are feasible for densely populated or under-resourced areas. To do otherwise disregards the conservation potential of small green

spaces as well as their possible role to broaden conservation awareness and support, namely by keeping people connected to nature through the spaces they share with songbirds. Although green space designs may vary, based on our findings we present several recommendations: (1) allocate green space of any feasible size; (2) incorporate a variety of native plant species, particularly tree species; (3) incorporate native habitat diversity, including open grass areas; (4) integrate water; (5) place green spaces in under-resourced areas and connect spaces through green corridors; and (6) plan for the temporal transformation of green spaces. Collectively, these recommendations have the potential to empower urban practitioners with viable options to generate design ideas that have the capacity to meet the interests of urban residents, human and avian.

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Figures

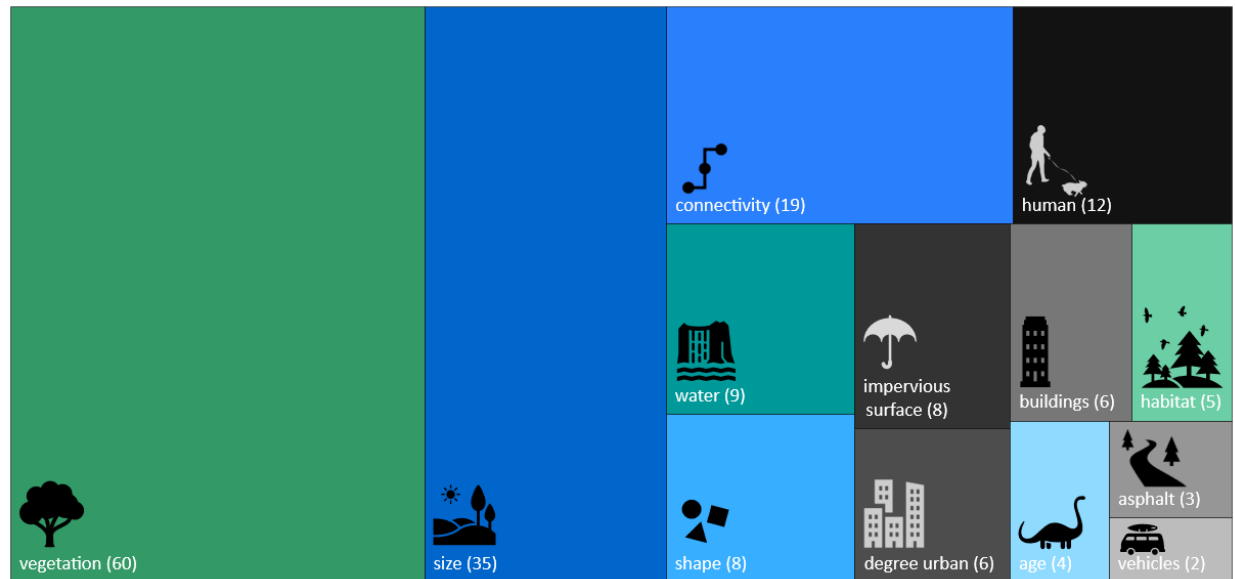


Figure 1. Number of natural (green), structural (blue), and anthropogenic (gray/black) factors associated with avian richness from the full dataset of 45 peer-reviewed articles published between 2000 to 2023.

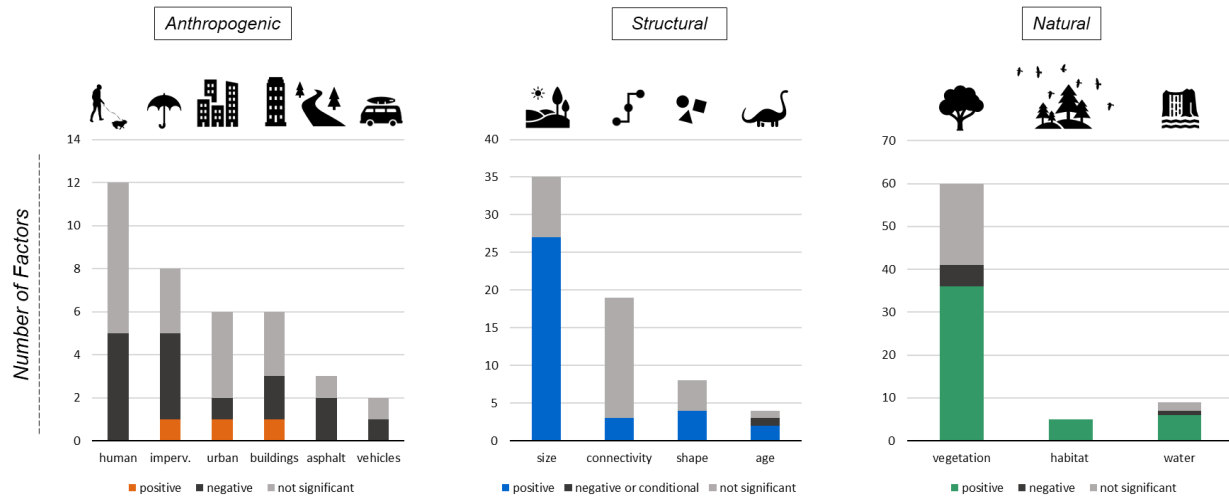


Figure 2. Type and number of anthropogenic (human factors (human), percentage impervious surface (imperv.), degree of urbanization (urban), building factors (buildings), percentage asphalt (asphalt), and number of vehicles/minute (vehicles); structural (size, connectivity, shape, and age); and natural (vegetation, habitat, water) factors and the significance (positive, negative, or not significant) of each factor on bird species richness examined from the full dataset of 45 peer-reviewed articles published between 2000 and 2023.

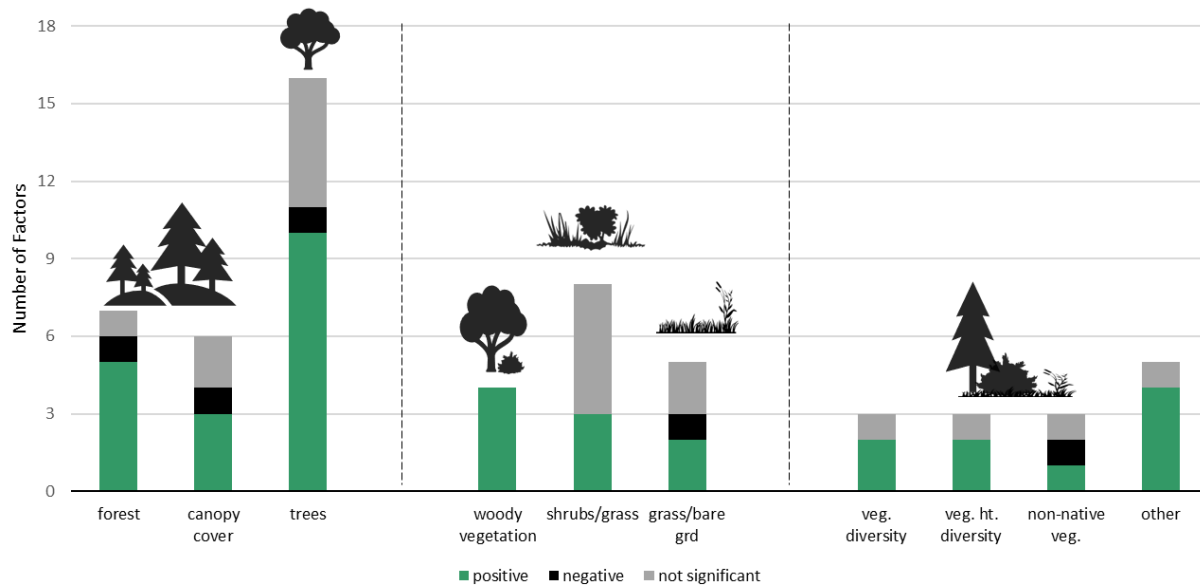


Figure 3. Type and number of vegetation factors and the significance (positive, negative, or not significant) of each factor on bird species richness examined from the full dataset of 45 peer-reviewed articles published between 2000 and 2023.

Appendices

Appendix A: Reference number, author, date of publication, and study location examining avian richness from the full dataset of 45 articles published between 2000 and 2023 in our review.

Reference Number	Author	Date of Publication	Study Location
1	Aida et al. DOI	2016	Klang Valley, Malaysia
2	Amaya-Espinel et al.	2019	Santiago, Chile
3	Bonança et al. DOI	2017	São Paulo, Brazil
4	Carbó-Ramírez & Zuria	2011	Pachuca, Mexico
5	Chaiyarat et al. DOI	2019	Bangkok, Thailand
6	Chang & Lee DOI	2016	Tainan, Taiwan
7	Charre et al.	2013	Mexico City, Mexico
8	Dale DOI	2018	Oslo, Norway
9	Fernández-Juricic	2000	Madrid, Spain
10	Ferreira et al. DOI	2021	Rio Claro, Brazil
11	Garizábal-Carmona & Mancera-Rodríguez DOI	2021	Medellin, Columbia
12	González-Oreja et al. DOI	2012	Puebla, Mexico
13	de Groot et al.	2021	Ljubljana, Slovenia

14	Hayes et al. DOI	2020	Georgetown, Guyana
15	de la Hera	2019	Vitoria-Gasteiz, Spain
16	Huang et al.	2022	Fuzhou, China
17	Imai & Nakashizuka DOI	2010	Sendai, Japan
18	James Barth et al. DOI	2015	Queensland, Australia
19	Jasmani et al. DOI	2017	Petaling Jaya, Malaysia
20	Kaushik et al. DOI	2022	Dehradun, India
21	Khera et al. DOI	2009	Delhi, India
22	Kontsiotis et al. DOI	2019	Dehradun, India
23	Korányi et al. DOI	2021	Göttingen, Germany
24	Kumdet et al.	2021	Plateau State, Nigeria
25	La Sorte et al. DOI	2020	New York City, USA
26	MacGregor-Fors et al.	2018	Veracruz, Mexico
27	Machar et al. DOI	2022	Olomouc City, Czech Republic
28	Matthies et al. DOI	2017	Hannover, Germany
29	Melo & Piratelli DOI	2022	São Paulo, Brazil
30	Morelli et al. DOI	2017	Beijing, China

31	Mühlbauer et al. DOI	2021	Munich, Germany
32	Oliver et al. DOI	2011	St Louis, USA
33	Peris & Montelongo	2014	Salamanca, Spain
34	Rico-Silva et al. DOI	2021	Florencia, Columbia
35	Sandström et al.	2006	Orebro, Sweden
36	Schütz & Schulze	2015	Vienna, Italy
37	Shih DOI	2018	Taipei City, Taiwan
38	Shwartz et al. DOI	2008	Tel Aviv, Israel
39	Stagoll et al. DOI	2012	Canberra, Australia
40	Strobach et al.	2013	Boston, USA
41	Thompson et al.	2022	Reykjavik, Iceland
42	Wong et al.	2023	Singapore
43	Xie et al. DOI	2016	Beijing, China
44	Zorzal et al.	2021	Vitoria, Brazil
45	Zuñiga-Palacios et al. DOI	2020	Pachuca, Mexico

Appendix B. Observed effects of structural, natural, and anthropogenic factors predicting overall avian richness examined from the full dataset of 45 peer-reviewed articles published between 2000 and 2023. Explanatory factors had a positive (+), negative (-), non-significant effect (NS), or conditional significance (+)(-) on richness. Shaded areas are factors that were not examined or not referenced in the significant results presented in the articles. Information that was not provided in the articles is indicated by NP. Reference numbers correspond to reference numbers used in Table 1.

		Predictors of Community Structure					
		Structural & Natural Factors			Anthropogenic Factors		
Reference Number	Study Site Size (ha)	Green Space Area	Connectivity ¹ Shape ² Age ³	Vegetation or Water	Buildings and Road Factors	Impervious Surface or Degree of Urbanization	Human Factors
	Number of Study Sites						
1	0.06-127 80	(+)		(+) % vegetation (surrounding green space) (+) number of woody trees		(NS) degree/type of urbanization (suburban or business district)	
2	0.5-2.0 60	(+)	(NS)(1)	(+) vegetation diversity	(-) % asphalt (road cover) (-) % buildings (building density)		

					(NS) building height		
3	11.9-50 4	(+)	NS(2) NS(3)	(+) presence of water/proximity of water bodies			
4	0.1-2.0 19	(+)		(+) height of herbaceous plants	(-) % asphalt (-) %buildings		(NS) pedestrian density (NS) noise level
5	1.4-400 10	(+)	(+)(1)	(+) habitat composition			
6	0.3-52.8 54	(+)	(NS)(1)	(-) number of non- native tree species (NS) % canopy cover (NS) vegetation diversity			(-) pedestrian density
7	11.0- 1100 12	(+)	(NS)(1)	(+) foliage height diversity (NS) tree-related factors		(NS) % impervious surfaces (inside green space)	
8	0.6-98.1 93	(+)	(NS)(1)	(+) presence of native forests		(NS) degree/type of urbanization	

						(inner/ residential or outer/ near-forest buffer zone)	
9	1.0- 118.2 25	(+)	(NS)(1) (+)(3)				
10	0.1-0.77 28		(NS)(1)	(+) tree species richness (NS) tree density (NS) % native trees (NS) distance to water (surrounding green space)			(-) noise level
11	0.2- 103.7 44	(+)	(+)(2)	(-) number of introduced trees (+) % area dominated by grass and shrubs & without trees		(-) % impervious surface	
12	0.7-702 22	(+)	(NS)(1)				(-) noise level
13	<39.0- 666 39	(NS)		(NS) presence of forests		(NS) degree/type of urbanization (urban or peri- urban, i.e., inside or outside the motorway ring	

						road)	
14	NP 114			(+) type of green space -managed (e.g., parks and cemeteries)			
15	0.5- 17.01 31	(+)					
16	3.54- 34.19 9	(NS)	(+)(2)	(+) % woodland (+) waterbody shape index			
17	0-66.6 20		(NS)(1)	(+) % water (prevalence of water)		(-) degree of urbanization (200m & 1000m buffer zone)	
18	<900 95			(+) number of mature trees			
19	0.7-3.5 9	(+)	(NS)(2)	(-) % canopy cover (+) % open grass/ground (+) % native vegetation species (+) % exotic		(NS) human presence (NS) noise level	

				vegetation species			
20	0.3-224 18	(+)		(+) tree species richness (+) woody species richness		(NS) % impervious surface	
21	2.0-2135 19	(+)		(+) woody species richness (NS) density of medium-sized trees (NS) total density of woody exotic species (NS) % shrub diversity (NS) shrub density			
22	<3-1100 113			(+) presence of forests			
23	1.0-9.0 34	(NS)		(+) % tree cover (NS) % shrub cover		(NS) % impervious surface	

24	16.78-116.54 15	(NS)	(+)(3)	(+) number of shrubs (+) number of tree species (NS) grass height (NS) density of flowering/fruit plants (NS) % bare ground	(+) number of buildings (-) number of vehicles		(-) pedestrian density
25	0.10-1119.41 102	(+)	(NS)(1) (NS)(2)	(+) % tree canopy			
26	<900 6			(+) presence of forest			
27	2.9-4.2 6		(+)(1)	(-) presence of forest			
28	0.72-62.26 32	(+)	(NS)(1)	(+) number of habitat types (+) diversity of habitat types			
29	1.1-5300 25	(+)		(+) % shrub cover (+) distance to water (surrounding green space)	(NS) number of glass panes (inside site) (NS) number of vehicles (inside site)		(NS) number of off-leash dogs (NS) number of cats

30	24.82-2050.93 10	(NS)	(NS)(1)	(+) presence of large trees (+) patches of deciduous trees (+) % water			
31	0.09-6.71 103	(+)	(NS)(1)	(+) % grass cover (+) density of trees (+) number of mature trees (NS) % shrub cover			(-) mean number of people
32	15.0-5923 20	(+)	(+)(1)			(+) % impervious surface	
33	0.2-5.95 20	(+)	(NS)(1)	(+) % tree cover			
34	0.12-2.47 18	(NS)		(+) % woody vegetation cover (area surrounding green space) (NS) tree abundance (area surrounding green space) (NS) shrub abundance (area surrounding	(NS) % buildings (building cover) (NS) % asphalt (paved surfaces)		

				green space)			
35	96.1-810.40 8					(-) % impervious surface (urban gradient)	
36	0.7-34.5 36	(+)		(NS) canopy diversity		(-) % impervious surface (sealed areas)	
37	4.0-547 30	(+)	(NS)(1) (NS)(2)	(+) habitat diversity (+) % water		(NS) degree of urbanization (NDVI, NDBI, & distance to nearest green space)	
38	262 1			(+) % woody plant species richness (-) % lawn cover (-) distance to water (surrounding green space)			
39	0.25-2.0 109			(+) number of large native trees			
40	0.01-210 30	(+)	(NS)(1)	(+) number of tree cavities			
41	0.5-40.93 15	(NS)	(+)(2) (+)(-)(3)			(+) degree of urbanization (suburban or central)	
42	NP 64	(+)	(+)(2)	(+)			

				%semi-natural vegetation (+) presence of freshwater bodies			
43	2.27- 22.04 29	(+)		(NS) foliage height diversity (+) largest patch index of woodland (surrounding green space)		(-) % impervious surface	
44	3.12- 227.2 7	(+)	(NS)(1)	(+) habitat diversity			(NS) noise level
45	0.2-4.11 17	(NS)		(NS) any vegetation structure variables			

Appendix C. The number of sites, number of avian and songbird species, study objectives, factors measured, observed effects, and author comments and recommendations for seventeen articles from the full dataset of 45 peer-reviewed articles published between 2000 and 2023 that evaluated small green spaces < 2 ha. Reference numbers labeled (a) are the articles that provided quantitative site-specific landscape factors and (b) are the articles that provided quantitative site-specific landscape factors and site-specific songbird species numbers. NP= information that was not provided. There may be additional factors measured but not analyzed or listed due to correlation with other factors. Reference numbers correspond to reference numbers used in Table 1.

Reference Number	Number of Sites < 2 ha total sites	Study Objectives	Factors Measured	Observed Effects	Author Comments and Recommendations
	Number of Species avian songbird				
4	19 19	analyze how green space characteristics, those of the adjacent landscape, and human disturbance variables affect bird species richness, abundance, and community composition (during summer and winter)	area (ha); perimeter (m); tree and ground cover (%); tree and shrub species richness; tree, shrub, and herbaceous plant height (m); buildings (%); asphalt (%); area covered by green space (%); distance to the closest area covered by native vegetation; distance to the	Green space area was the most important variable that positively influenced bird species richness, for both the summer and the winter communities. Summer bird species richness was lower in places that had a greater percentage of area covered by buildings in the adjacent	(1) greenspaces should have the largest possible area and contain a complex vegetative cover to support resident and migratory birds (2) the landscape matrix around green spaces should maximize the amount of vegetative cover and connectivity between sites, taking advantage of well-designed road strip corridors
	26-32 21-27				

			closest greenspace; distance to the closest main road; number of pedestrians and vehicles; and noise level (dB)	landscape. Generalist and opportunistic species were favored by urbanization.	(3) small green spaces could function as steppingstones which could be temporarily used by different species while moving through urban landscapes
5 ^b	1 10	evaluate the relationships between bird diversity, park size, distance to the nearest main park, and habitat compositions	area (ha); human population density (people/km ²); average building density (%); average building height (m); distance to the nearest mainland urban park (km ²); and trees, wetland and grassland (%)	Large areas had the highest overall species richness (migratory and resident). Parks closer to mainland parks had more overall species richness than isolated parks. More resident species in small parks. More migratory species in large parks. Species richness was positively correlated with grasslands and wetlands and negatively correlated with increasing buildings.	(1) maintain and expand large parks in the city to increase biodiversity and complexity of the urban ecosystem by increasing grassland and reduce buildings in the park areas (2) plant more trees and increase wetland in surrounding park areas, along with controlling human population, building density and height
	16 14				
9 ^a	4 25	assess the influence of fragment age, size and isolation on bird	area (ha); age; grass cover (%), shrub cover (%), coniferous cover (%),	Richness was significant in old parks (>75 yrs old) but not significant in	(1) connection through street trees may explain the nonsignificance of connectivity
	6-8 5-7				

		community composition patterns and the role of local and regional factors on community structure	deciduous cover (%), number of shrub and tree species, shrub and tree height, and the number of stems; distance to and between parks and large main park (m)	young parks (<25 yrs old). Park age accounted for 46% of richness variance and size explained 16% of richness variance. Age & size were the main factors influencing richness and composition.	(2) park age is a significant indicator for habitat complexity, with older parks having higher vegetative heterogeneity.
10 ^a	28 28	assess how noise, vegetation aspects, distance from a major habitat patch and from water are related to species composition, species richness, total abundance and feeding guilds	area (ha); distance from the border of large green space and from water bodies; tree species richness, proportion of native tree species, tree density; and noise level (dB)	noise level was negatively related to bird species richness, composition, total abundance, and abundance of granivorous species. Tree species richness presented positive relationships with bird species richness, composition, and total abundance.	(1) negative effects of noise can be offset by increasing tree species' richness
	9-36 7-23				
11 ^a	33 44	evaluate the effects of site-specific features such as size and shape of green spaces, land cover, and	area (ha); perimeter/area ratio; trees (%); grass-shrubs (%); impervious surfaces (%); species richness	Bird species richness increased towards larger and more regular-shaped urban green	(1) decrease the proportion of introduced (young) trees (2) reduce edge effects
	14-40 NP				

		vegetation on bird species richness	and abundance of trees and understory; tree basal area, canopy coverage (%), and average height (m) of introduced, regional, and local trees	spaces (squared or rounded), with less percentage of impervious surfaces and more of grass–shrubs, and less influence of introduced trees in habitat structure (i.e., less crown coverage, basal area, and average height). Richness also increased when richness or abundance of native understory vegetation (of local or regional origin) increased, but introduced tree dominance had the most significant effect on bird species richness.	(3) promote a higher prevalence of native understory vegetation
12 ^b	4 22	study the nested subset pattern of songbird assemblages	area (ha); distance from large green space (km); tree nestedness; and background noise level (dB)	Size of green space was the most explanatory factor with noise the second most explanatory. The effect of noise was more noticeable in open, sub-open, & non-forest habitats. Rare	(1) maintain a minimum area of suitable patch (2) control noise pollution
	9-14 9-14				

				species could be found only in the most species-rich sites, whereas widely distributed species could be found in most sites.	
15 ^b	15 31	evaluate environmental seasonality and park features on species composition, diversity and nestedness of the breeding and wintering avian communities	area (ha); shape (ha/km); grass cover (%); shrub cover (%); tree density (no/ha); mean tree height (m); mean tree trunk diameter (cm); tree diversity; and mean noise level (dB)	Avian diversity was significantly greater during breeding than during the winter period, although the most diverse parks during breeding were also the most diverse during winter. Most of the among-park variation in diversity was explained by park size, while tree density had a marginal contribution that was only significant during winter. Seasonality affected distribution but not diversity or nestedness.	(1) favor the existence of a few relatively large parks (over 10 ha) instead of many small ones to maintain a diverse urban avifauna all year round
	16 15				
17 ^b	11-20	evaluate ecological traits associated with avian communities and the	area (ha); tree canopy (%); shrubs (%); grass (%); ground surface paved with	The avian community tended to be dominated by a few species and lower numbers	(1) increase shrubs (2) urban avian community dominated by a few species or
	5-12 3-10				

		environmental factors important in changing the structure of avian communities	asphalt (%), open area (%); artificial structures (%); degree of isolation; urbanization; visibility (%); and water (%)	of uncommon species. The overall species richness decreased in areas categorized as urban vegetation, those surrounded by urban areas, and at the sites with many artificial structures. Species richness was positively influenced by the prevalence of water. All study parks and green spaces exhibited similar levels of the isolation index.	lower numbers of uncommon species
19 ^a	7 9	assess the effect of park characteristics related to vegetation richness and structure and human-related factors on bird communities	area (ha); shape (perimeter/area ratio); canopy cover (%); open grass/ground (%); noise level (dB); native and exotic vegetation species; canopy size (m); tree height (m); shrub height (m); surrounding land use; proximity to main road (m); tree diameter (cm); and	The percentage of canopy covers (negative relation) and park area (positive relation) are the best predictors of bird species richness in small urban parks. Human activities and park surroundings have a marginal effect on the presence of bird species in small	(1) small parks have the capacity to maintain overall urban biodiversity, ecosystem services and ecological connectivity (2) newly established small urban parks should have a planting design and composition that provide habitats and foraging area for birds (3) the right proportion of
	7-16 NP				

			accessibility by humans	parks.	vegetated area and open lawn should be considered within the parks to create habitat complexity
28 ^b	12 32	examine determinants of species-area effects, distance effects, and the effects of habitat structure on total, native, and endangered species richness for vascular plants, birds, and mammals	area (ha); shape (perimeter/area ratio); distance to urban edge and nearest green space (m); number of habitat types; green space (%); and diversity of habitat types	Patch area in combination with habitat heterogeneity was most important for bird richness (total, native, and endangered).	(1) conserve large green spaces that include a high diversity of habitats
	14-23 13-20				
29 ^b	5 25	test which biotic (i.e., vegetation characteristics and human and pet disturbances) and abiotic variables (i.e., area size, number of vehicles, and glass panes) influence functional diversity indices of dietary guilds, migrants, residents, and total bird community	area (ha); herbaceous cover (%); herbaceous height (cm); shrub height (cm), cover (%), and morpho-richness; tree height (m), cover (%), abundance; distance to water (m); number of glass panes; number of pedestrians; number of vehicles; and number of homeless and/or off-leash dogs and cats	Large-sized areas of urban green spaces and shrub cover are the main characteristics that drive bird richness and functional richness of all bird guilds (frugivore-nectarivore, insectivore, resident, and migrant) and the total avian community.	(1) prioritize large areas with high shrub cover (2) mitigate the negative impact caused by glass panes, traffic of vehicles, and domestic animals
	22-53 13-35				
33 ^a	18 20	assess the effect	area (ha);	Park area and	(1) fewer species

	4-11 3-11	of size, degree of isolation, and habitat characteristics on the distribution of birds during the breeding season	distance of park to river (m); number of tree and shrub species; percent (%) tree, shrub, and lawn cover; bare and paved ground; and number of trees of varying diameters (cm)	tree cover accounted for 73.1% of the variation in bird richness. Some species did not seem to be related to park area but rather to other factors, such as vegetation and the degree of park isolation with respect to other areas.	observed in the smallest parks can be explained in terms of their higher edge/area ratio, resulting in fewer specialist “interior” species (2) presence of most of the species does not appear to be influenced by size but by other variables related to park characteristics and their degree of isolation
34	17 18	assess the effect of local and landscape level vegetation, building cover, and urbanization on native and exotic bird species	area (ha); tree and shrub richness and abundance; plant height (cm); paved surface (%); building cover (%); grassland cover (%); woody vegetation cover (%); and road cover (%)	At the local scale, environmental factors did not have a significant effect on bird richness. At the landscape scale, native bird richness and abundance were positively related to woody vegetation cover. Exotic birds were positively influenced by variables associated with urbanization.	(1) increase the taxonomic and structural complexity of native vegetation within green spaces to improve habitat quality (2) prevent the proliferation of exotic bird populations
	10-25 NP				
36	8 36	effect of park size, canopy heterogeneity within the park, and the	area (ha); natural green space (%); manmade green space (%);	Species richness increased with increasing park size and	(1) bird assemblages of parks embedded in an urban landscape matrix with a high
	7-12 6-10				

		proportion of sealed area surrounding each park	sealed areas (%); and forest/tree-covered areas (%)	decreased with increased percentage of sealed areas.	permeability for forest birds most likely provide an increased ecosystem function and promote and maintain high diversity and ecosystem function
39	109 109	role of large native trees	area (ha); number and diameter of trees (cm)	large trees had a consistent, strong, and positive relationship with bird diversity and as trees became larger in size, their positive effect on bird diversity increased.	(1) proactively plan for large trees and implement tree preservation policies that recognize biodiversity values (2) the addition of five trees >100 cm increased species richness by 157%, average abundance by 91%, probability of breeding by 158%, and woodland species richness by 301%
	7.8±2.6 NP				
40 ^a	12 30	assess the value of small-scale green space initiatives relative to large green space for biodiversity	area (ha); bare soil (%); building cover (%); impervious surface (%); lawn cover (%); canopy cover (%); green space cover (%); basal area; average tree height (m); and trees with cavities (%)	The main factor associated with species richness was the patch size of green space and to a lesser extent, tree cavities.	(1) small increases of a few hundred square meters were associated with an increase in bird richness. (2) an additional 150m ² in green space patch size accounted for one additional species being observed
	3-13 2-9				
41 ^a	7 15	assess the	area (ha); shape	Richness was	(1) park size was

	3-5 NP	relationship between bird diversity and small (<5 ha) and large (7-41 ha) green space attributes within urban sprawl (central or suburban)	(perimeter/area ratio); age; urban context (central or suburban)	higher in the city center and in intermediate (40-60 yrs old) and older (>60) urban green space compared to young (<40) suburban green space. Richness in intermediate and older green space was not significantly different. Polygon shaped parks were best for community structure, excluding evenness.	not relevant to richness, demonstrating that small green space should not be disregarded in urban planning
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