Reframing Biodiversity Conservation: A Study of Urban Green Spaces in Seattle

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Abstract

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The continued acceleration of urbanization and land conversion for agriculture threatens global biodiversity. Various conservation plans, such as the 30X30 initiative, have been proposed for biodiversity conservation. To reach these ambitious targets, policymakers and conservationists will likely need to expand the scope of lands considered for biodiversity protection. Urban landscapes present an opportunity for the conservation of many species despite the diversity of challenges these environments pose to wildlife. The increasingly shrinking amount of land available for reserves means that a broader set of landscapes, including urban, suburban, and peri-urban, as well as a wider variety of land-use types, from urban parks to agriculture to recreational areas, should be included in discussions of biodiversity conservation. Some research has already begun to explore whether urban green patches, such as community gardens, farms, and vacant lots, can be of use to wildlife.

This study built on this research by exploring multi-functional urban green spaces in Seattle comprising forest areas and adjacent garden/farm areas. It explored whether these types of green spaces provide habitat for a diversity of wildlife species, specifically mammals and birds, and whether differences in species diversity existed between interior forest areas and garden/farm edges. Camera traps were located at three sites along transects spanning the distance between interior forest areas and garden/farm edges, and calculated species diversity at each of the transect locations using the Shannon and Simpson's Diversity Indices. Across the 66-day observation period, the camera traps yielded images of 16 bird species and 8 mammal species, with no apparent differences in diversity between forest-positioned cameras and garden/farm edge-positioned cameras. Of the sites surveyed, the park with the smallest forest area and largest agricultural area had the highest diversity according to the indices calculated. This study adds to the growing body of data supporting the use of urban landscapes in discussions of biodiversity conservation and is one of the first studies to explore the potential value of urban agricultural and green spaces in the conservation of mammals in urban environments.

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Introduction

The pace of global biodiversity decline is ever-increasing (Millenium Ecosystem Assessment 2005, World Wildlife Fund 2020). Wildlife populations decreased approximately 68% between 1970 and 2020, and the rate of extinction is approximately 1,000 to 10,000 higher than the natural rate, causing many to characterize the modern-day as the earth's sixth mass extinction event (World Wildlife Fund 2020). Furthermore, urbanization and land conversion for agriculture – the two leading causes of biodiversity loss – are expected to accelerate in the coming decades and current projections are that 70% of humans will live in cities by 2050 (United Nations 2014). Currently, one-third of our planet's land area is used for agriculture, and although large cities make up less than 1% of earth's land area, one million acres in the United States are becoming urbanized each year (Angel et al. 2011, Marzluff 2014), United Nations 2014). At the same time, only about 15% of global land area is currently protected for conservation (IUCN 2016), and 12% is in highly protected status and managed for biodiversity preservation in the United States (Protected Planet 2020). This amount of land area set aside for conservation is not considered sufficient for the restoration and revival of species diversity needed to produce sustainable and resilient global ecosystems (Clancy et al. 2020, Dimitrakopoulos and Jones 2021).

Scholars have proposed various ideas for biodiversity conservation, from E.O. Wilson's half-earth hypothesis to the current Biden administration's 30x30 plan that aims to protect 30% of the United States' public lands by 2030 (Wilson 2016, U.S. Department of the Interior 2021). However, in order to approach these ambitious targets, policymakers and conservationists will need to not only expand the reach of protected lands but also broaden the definition of what lands can be managed for biodiversity protection.

Many practitioners from various fields have already begun to broaden traditional ideas of what lands can be considered suitable for biodiversity conservation and have called into question classical ideas that nature must be remote, pristine, and untouched by humans. Despite strongly held popular conceptions of nature as something found only in remote areas away from humans, ecologists, biologists, wildlife scientists, social scientists, and others have begun to shift their understanding of nature as a human-free space and reframe it as an arena where both humans and non-humans can co-exist (Guerry et al. 2015, Marris 2016, Holl 2020, Vining et al. 2022). This transforms former ideas of urban areas as being separated from nature and not as landscapes with potential to support a diversity of wildlife species when planned in ways that promote their habitat needs (Ferguson et al. 2001, Cristol and Rodewald 2005, Baker and Harris 2007, Marzluff 2014, Lin et al. 2015, Soanes and Lentini 2019).

The lack of new lands that can be set aside primarily for conservation has stimulated research to begin to address how urban green spaces and untraditional landscapes can benefit both humans and wildlife in conservation projects (Goddard et al. 2010, Lin et al. 2015, Dorst et al. 2019, Van Helden et al. 2020). Diverse assemblages of wildlife, from predators to herbivores to invertebrates, have been observed in urban green spaces, with some studies showing equal or even higher species diversity for some taxa in urbanized green areas than in rural areas and reserves (Marzluff 2014, Hall et al. 2017, Hagen et al. 2017). Urban green spaces have been documented as pollinator havens, as nesting and migratory stopover sites for birds, and as refugia for a variety of threatened and endangered species (Olive 2014, Sivakoff et al. 2018, Freshkills Park 2019, Soanes and Lentini 2019). In addition, policymakers are increasingly understanding the value of cities in biodiversity conservation and have adopted “smart growth” and “green design” plans that promote the coexistence of humans and wildlife in cities (Olive 2014, C40 Cities 2022).

As a result of this new understanding of the conservation value of urban environments, there is burgeoning interest in various types of green space as potential forms of habitat. For example, recently, a growing number of researchers have explored the potential benefits provided by urban farms and gardens as a form of green space for wildlife. Some studies have identified these areas as potential biodiversity hotspots for plant life, invertebrates, birds, and even mammals, while others have pointed to the role of these green spaces in providing connectivity to other larger habitats, such as parks and urban forests (Goddard et al. 2010, Marzluff and Marzluff 2016, Clucas et al. 2018, Van Helden et al. 2020). In the urban environment where green space is scarce, farms and gardens, particularly those that incorporate trees, native vegetation, and other “wildlife-friendly” practices in the margins, may provide safe havens for wildlife seeking refuge from urbanization (Baker and Harris 2007, Clucas et al. 2018, Sivakoff et al. 2018, Van Helden et al. 2020). For many species, human-managed landscapes, such as farms and gardens, may even provide disproportionate benefits for their size due their ample sources of readily available food such as fruit trees, seeds, nectar-providing plants, and supplemental feeders (Baker and Harris 2007, Marzluff 2014).

However, from the perspective of wildlife, urban green spaces, such as gardens, farms, and parks, are often situated among an uninhabitable landscape matrix and may not provide the conditions for many fauna to thrive even if resources are present (Lepczyk et al. 2017). Unlike traditional wildlife habitats in more remote areas, urban parks and green spaces are often found within a biodiversity-poor, human-dominated landscape matrix involving barriers of the built environment like roads, buildings, and parking lots, and the extent to which urban green areas can provide habitat when situated among these anthropogenic structures is highly variable (Lepczyk et al. 2017). In addition to the inhospitable areas surrounding urban green spaces, the interior landscape of urban green spaces often consists of a mosaic of land uses, from recreation to paved trails, many of which are designed more for human use than for wildlife. Even if there are forest areas, wetlands, or other natural areas situated within an urban green space, the structure, composition, and size of these patches may not be suitable for many types of wildlife. In particular, native species that rely on old-growth forests and other similar ecosystems may be unable to survive on the limited resources and ecologically simplified landscapes within urban green areas.

Expanding conservation into urban green spaces will require understanding how types of green spaces are or are not suitable for supporting native wildlife populations and what landscapes contribute to conserving species with complex life histories (e.g., Grand et al. 2017). Urban green spaces are very different from the natural forests found beyond a city border by having more edge environments and dominance of early successional species. Franklin and Forman (1987) showed that forest fragmentation increases significantly when forest area is reduced by about 50%, reducing natural forests' resilience. This is an issue in urban landscapes suggesting that native interior forest area does not exist and most of the area is composed of edge environments. Despite these issues, there is evidence of species using urban green spaces. This is an important research area to determine if urban greenspaces can provide suitable wildlife habitat for native wildlife species.

This research explored the following questions:

[1] Do multifunctional urban greenspaces, such as forest and garden/farm areas, provide habitat for a diversity of native wildlife species, specifically mammals and birds;
[2] Do some components of urban green spaces provide more suitable habitat for wildlife than others, e.g., is there a difference in species diversity between interior forest areas and garden/farm edges; and
[3] Do park management restoration approaches impact native species diversity between sites.

To answer these questions, this study used camera traps to capture images of mammals and birds in spatial arrangements that allowed a comparison of diversity between common camera location categories, calculated using the Shannon and Simpson's Diversity Indices. With a better understanding of species composition within these multifunctional green spaces and how wildlife are distributed across them, this study aimed to improve our knowledge of leveraging urban green space for biodiversity conservation.

Methods

Study Area

During the winter and early spring of 2022, a pilot study was conducted on small mammal and bird community composition within three large green spaces in Seattle, Washington: Colman Park, Jackson Park/Thornton Creek Natural Area, and Rainier Beach Urban Farm and Wetlands (RBUFW). Seattle is an ideal location to explore the suitability of green spaces for conservation since it ranks in the top 50 (46th) for the amount of green space per capita compared to other American cities (The Humanitarian Data Exchange 2018). In addition, Seattle was ranked 9th in the nation for best Park Score by the Trust For Public Land, which incorporates access to parks, total park acreage, and investment in park infrastructure and restoration into its scoring system (Trust for Public Land 2022). In addition, 28% of Seattle's land is under canopy cover, 94% of residents live within a 10-minute walk of a park, and about 1,011 hectares of its total land area is forested (Seattle Office of Sustainability & Environment). Seattle is in King County, which is home to approximately 70 species of mammals, about 58 of which are small or medium-sized terrestrial species such as insectivores, bats, lagomorphs, and rodents, and around 221 bird species, according to the county's 2008 Biodiversity Report (King County 2008). Finally, in terms of urbanization, Seattle has an estimated 733,919 total residents and 7,250 residents per square mile(US Census 2021, Ballotpedia 2022). This makes Seattle the 18th most populated city and the 9th most densely populated large city in the U.S. (U.S. Census 2021, Ballotpedia 2022).

Many of Seattle's green spaces are under active management and restoration plans designed by the Green Seattle Partnership (GSP), a Seattle Parks and Recreation Department partner organization focused on urban ecological restoration (Green Seattle Partnership 2017). Currently, GSP is carrying out ecological restoration in over 50% of the city's 2,500 acres of forested land (Green Seattle Partnership 2017). Among GSP's broad list of goals is to improve wildlife habitat, reduce erosion, create cleaner air and water, and reduce stormwater and climate change impacts (Green Seattle Partnership 2017). Since its conception, GSP has engaged thousands of Forest Stewards and other volunteers in park maintenance and restoration work

(Green Seattle Partnership 2017). Each of the sites chosen in this study is currently under GSP restoration plans.

Permission to conduct this research was sought from site managers, Green Seattle Partnership/Seattle Parks and Recreation, and the Seattle Department of Neighborhoods.

Site Selection

Using the Seattle Department of Neighborhoods Community P-Patch Garden Map, each site selected had a community garden or farm directly adjacent to a forested area (Seattle Department of Neighborhoods) (Figure 1). This provided interior forest areas and forest/garden or forest/farm edges for each site selected for this study. Although no site contained community gardens/farms and adjacent forest areas of the same exact size, the three sites selected met the following criteria:

- Contained a public forested area(s) adjacent to a community garden or urban farm,
- Contained an unfragmented forested area(s) of substantial size, comprising at least half of the total park site,
- Contained overall canopy cover percentage within 10% of the other sites selected,
- Located in a different geographical area of the city from all other sites to explore the environmental variability of green space and avoid overlapping sites within the surrounding landscape matrix.

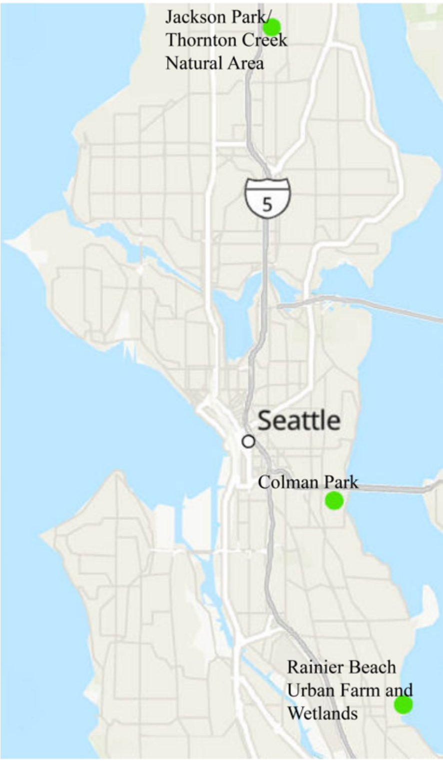

Figure 1. Map of the study locations. Source: Esri, NASA, NGA, USGS, City of Seattle, King County, WA State Parks GIS, Esri Canada, Esri, HERE, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS

Sites not only varied in size but also in habitat characteristics, structure, and proximity to anthropogenic structures in the urban landscape. Controlling for these factors is very difficult in the urban environment, where environmental variability is high. This study assessed and recorded the various characteristics of each park using geospatial data from i-Tree Canopy and by gathering plant species data from the Green Seattle Partnership Reference Map (2022) (Table 1). Management at each of the sites was broadly defined by the level of integration of forests and natural habitats with the agricultural areas. In Colman Park and Jackson Park, the community garden areas were surrounded by forest areas but were not integrated into their management plans. At Rainier Beach Urban Farm and Wetlands, site managers take a holistic approach to food production and natural ecosystems by incorporating native vegetation and wildlife habitats throughout the site.

Table 1. Characteristics and sampling dates of the three study sites.

Site	**Colman Park**	**Jackson Park/Thornton Creek Natural Area**	**Rainier Beach Urban Farm and Wetlands/Pritchard Woods**
Location	Central	North	South
Sampling dates (2022)	January 15th – 25th and January 30th – February 9th	February 18th-28th and March 4th – 14th	March 31st – April 10th and April 13th – 23rd
Forest area	16.8 acres	12.02 acres	8.2 acres
Garden/farm area	0.40 acres	0.45 acres	1.70 acres
Canopy cover	81.87%	84.8%	75.50%
Common forest species	*Arbutus menziesii (*Pacific madrone), *Pseudotsuga menziesii (*Douglas fir*),* *Gaultheria shallon* (Salal), *Holodiscus discolor* (Ocean spray), *Polystichum monitum* (Western sword fern)	*Alnus rubra* (Red Alder), *Pseudotsuga menziesii* (Douglas fir), *Tsuga heterophylla* (Western hemlock), *Rubus spectabilis* (Salmonberry), *Carex obnupta* (Slough sedge), *Lysichiton americanus* (Skunk cabbage)	*Cornus sericea* (Red-osier dogwood), *Fraxinus latifolia* (Oregon ash), *Alnus rubra* (Red alder) *Spiraea douglasii* (Rose spirea), *Carex obnupta* (Slough sedge)
Common garden/farm edge species	*Thuja plicata* (Western redcedar), *Oemleria cerasiformis* (Indian plum), *Corylus cornuta* (Beaked hazelnut), *Pseudotsuga menziesii* (Douglas fir), *Gaultheria shallon* (Salal)	*Tsuga heterophylla* (Western hemlock), *Acer macrophyllum* (Bigleaf maple)	*Salix lucida* (Pacific willow), *Carex obnupta* (Slough sedge), *Lysichiton americanum* (Skunk cabbage)
Integration of forest with garden/farm	Not integrated	Not integrated	Integrated urban farm and native ecosystems, holistic management
Restoration status	Active	Active	Active

South Seattle

Rainier Beach Urban Farm and Wetlands (RBUFW) is located in the Seattle's Rainier Beach neighborhood, located in the Southeast region of the city. To the north, RBUFW is bordered by the adjacent Pritchard Woods, a riparian forested area that borders Pritchard Island Beach on Lake Washington. RBUFW/Pritchard Woods comprises approximately 8.20 acres of forest area and 1.7 acres of agricultural production, including an orchard, children's garden, production field, and apiary.

Originally, the area that is now RBUFW was a productive slough inhabited for millennia by the Duwamish Tribe (Tilth Alliance 2021). In the 1850s, colonialists claimed the area, logged its old-growth forests, and dredged its streams for conversion to agriculture (Tilth Alliance 2021) In 1917, the construction of the Lake Washington Ship Canal across the city caused the level of Lake Washington to drop by 9 feet, which drained the slough (Tilth Alliance 2021). In 1935, the City acquired this land and operated it as a plant nursery until 2009. Finally, in 2010, the City closed down the nursery and held public meetings to gather community input for a new vision of the site (Tilth Alliance 2021). In 2010, a conceptual plan was established for RBUFW to be a sustainable urban farm that provided healthy food, educational opportunities, and environmental benefits to the Rainier Beach community (Tilth Alliance 2021). Over the past 12 years, the RBUFW has become Seattle's largest urban farm, involving mixed forest, wetland and food production areas. Site managers incorporate native vegetation and elements of natural ecosystems into food production areas, creating a diverse landscape of varied ecological niches (Leach 2014). Tilth Alliance currently manages operations of the site and runs educational programs for the public in partnership with Friends of Rainier Beach Urban Farm and Wetlands and other community partners (Tilth Alliance 2022).

Ecologically, RBUFW is currently under restoration by the GSP, Tilth Alliance, and Friends of Rainier Beach Urban Farm and Wetlands (Figure 2). During the early years of the park's development (approximately 2010-2014), the wetland channels had become overgrown with invasive vegetation, such as Reed Canary Grass (*Phalaris arundinacea*) and Field Bindweed (*Convolvulus arvensis*) (Leach 2014). A restoration plan was developed whose goals included planting native species, restoring wildlife habitat, attenuating flooding and enhancing water quality flowing to Lake Washington, and increasing access to nutritious food and educational opportunities for the public (Leach 2014) (Figure 3). In the years since, site managers and volunteers have undertaken significant removal of invasive wetland plants and have planted a stand of Pacific Willow trees along both sides of the wetland channels to prevent the return of invasive species (Leach 2014). Much of this work has occurred with volunteer assistance from a variety of community groups, including the East African Elders Program (Tilth Alliance 2022).

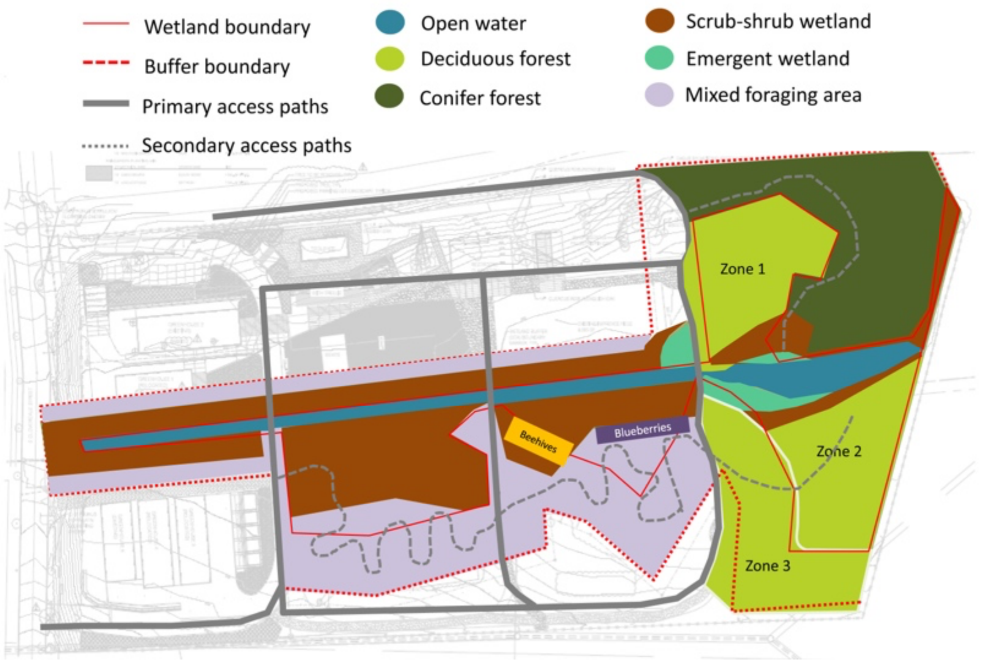

Figure 2. Map of ecosystems at RBUFW. Source: Tilth Alliance 2022

Figure 3. Map of restoration in RBUFW and Pritchard Woods. Source: Green Seattle Partnership Reference Map 2022

Central Seattle

Colman Park is located in Seattle's Mount Baker neighborhood along the eastern edge of the city on Lake Washington. John and Frederick Olmsted originally created the plan for the park in 1910. It comprises approximately 16.80 acres of forest area, a 0.4-acre community garden, numerous trails, and a beachfront area along the lake.

Currently, Colman Park is under restoration by the GSP in partnership with non-profits Friends of Colman Park and Friends of Seattle's Olmsted Parks (Friends of Colman Park 2022). The restoration plan aims to restore the vegetative health of the park through invasive species removal and removal of Bigleaf Maples that have crowded out other vegetation (Colman Park Vegetation Management Plan 2018). These areas will be revegetated with a variety of native trees, shrubs, and groundcover plants (Colman Park Vegetation Management Plan 2018). The planting palette includes approximately 26 species of native plants, including Oregon Grape (*Mahonia nervosa*), Salal (*Gaultheria shallon*), Cascara (*Rhamnus purshiana*), Pacific Dogwood (*Cornus nuttallii*), and Douglas Fir (*Pseudotsuga menziesii*) (Colman Park Vegetation Management Plan 2018).

In addition to restoring vegetative health, the restoration plan focuses on restoring access to the park's western edge, which borders a predominantly African American community in the Mount Baker neighborhood of Seattle. This area of the park was fenced off from the community in the 1970s, blocking the former entrance and excluding access to the park, all while becoming overgrown and unwelcoming (Colman Park Vegetation Management Plan 2018) (Figure 4). The restoration plan aims to re-establish a more welcoming, accessible entrance to the park for the community (Colman Park Vegetation Management Plan 2018).

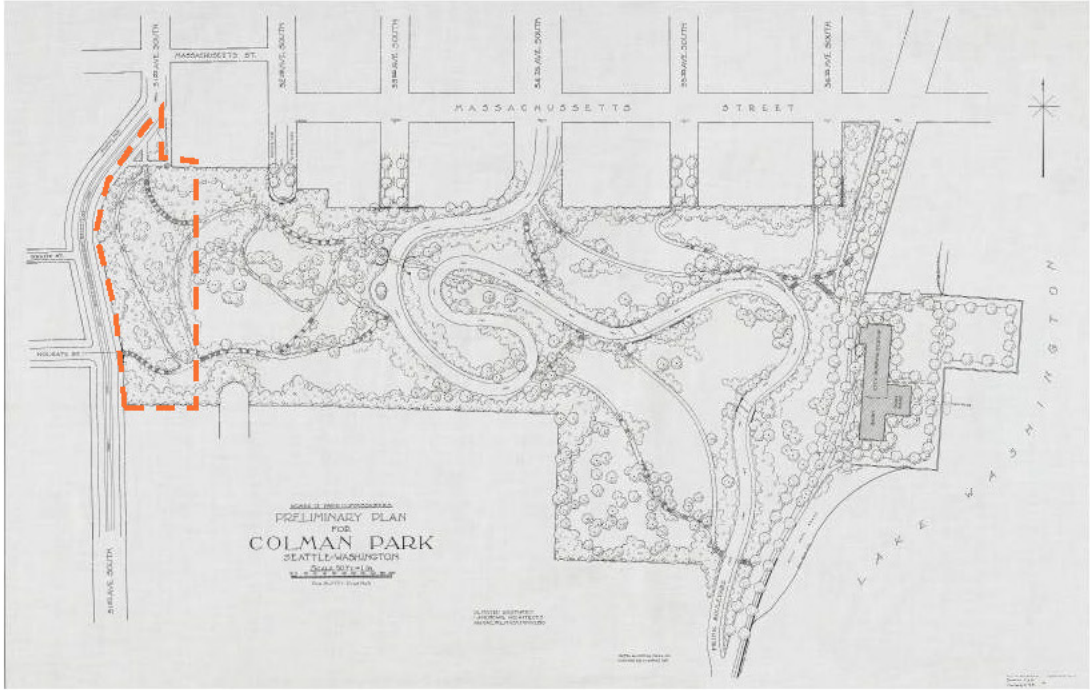

Figure 4. This map shows one key area of the GSP's current restoration plan, focusing on re-establishing community access to the park's western edge. Source: Colman Park Vegetation Management Plan 2018.

Figure 5. Map of restoration in Colman Park. Source: Green Seattle Partnership Reference Map 2022

Jackson Park/Thornton Creek Natural Area is located in Seattle’s Pinehurst neighborhood along the northern border of the city. Jackson Park comprises a golf course, a 0.45 acre P-Patch Community Garden, a wooded evergreen forest, and a 2.2 mile trail through the forest and along the edge of the golf course. The adjacent Thornton Creek Natural Area includes a riparian forested area flanking a portion of the creek, part of a larger watershed that runs 15 miles long through multiple city neighborhoods.

Jackson Park/Thornton Creek Natural Area is currently under restoration by the GSP in partnership with Thornton Creek Alliance (TCA) and Muckleshoot Indian Tribe (Thornton Creek Alliance 2022). The GSP’s restoration work involves invasive species removal, native species planting and establishment, and long-term stewardship and maintenance (Green Seattle Partnership Reference Map). The TCA’s main goals include controlling excessive stream flows, reducing pollution and improving water quality, improving degraded habitat along the creek’s banks, and public education (Thornton Creek Alliance 2022). Specific projects include an urban reforestation campaign, a grant-supported noxious weed knockout effort, citizen science water quality monitoring, and trash cleanup efforts (Thornton Creek Alliance 2022). TCA has listed sightings of a variety of wildlife in the watershed, including Bald Eagles, Great Blue Herons, Wood Ducks, Beavers, Coyotes, Raccoons, and Opossums (Thornton Creek Alliance 2022).

Figure 6. Map of restoration in Jackson Park/Thornton Creek Natural Area. Source: Green Seattle Partnership Reference Map 2022

Sampling

In each park, six camera traps were used to monitor 12 different sampling locations over a 22 day period. Thus, the total study period was 66 days. No cameras are allowed to be set up within the city's community gardens or agricultural zones due to a no-surveillance policy within the Seattle Department of Neighborhoods. This policy prohibits photography/videography within any of its community gardens.

For the first 11 days of each 22-day sampling period, three of the six cameras were placed along a transect going from the forest interior towards a garden or farm edge. The other three cameras were placed along a transect within the interior of a forested area. In this study, the garden-edge-to-forest transect was called the "Garden Transect" and the interior forest transect as the "Forest Transect". Within the Garden Transect, camera locations were given one of three labels: “GTE” for Garden Transect Edge, “GTSF” for Garden Transect Semi-forested, and “GTF” for Garden Transect Forested. Within the Forest Transect, camera locations were labeled simply as “FT” for Forest Transect because there was no gradient of land-use types within this transect. The garden transect allowed us to examine whether there were differences in species diversity along a gradient going from the garden/farm edge out toward the interior of the adjacent forest. The forest transect data allowed us to compile data solely from the interior forest areas to compare to this garden-to-forest gradient.

After the first 11 days of each study period, the cameras were moved to new locations to expand the monitoring of each site’s spatial variance and to monitor a greater coverage of each site’s area. Three of the six cameras were moved into an interior forest area, which were labeled as the “Forest Cluster”, or FC. The other three cameras were also moved and placed around the garden/farm area edges, which were labeled the “Garden Edge Cluster”, or GEC. Both sets of cameras remained in these “clusters” for an additional 11 days. No cameras were stolen or damaged during this study.

In sum, at each study site, there was one 11-day period with cameras placed in a transect formation, either within a forest area or going from forest to garden/farm edge, and one 11-day period with cameras placed in a cluster within a forested area and a cluster around the edges of the garden/farm. This sampling design gave us 12 locations sampled at each site, totaling 36 camera locations across the duration of the study. Cameras were set up in Colman Park from January 15th – January 25th, 2022 (transect sample) and January 30th - February 9th, 2022 (cluster sample), in Jackson Park/Thornton Creek Natural Area from February 18th – February 28th, 2022 (transect sample) and March 4th – March 14th, 2022 (cluster sample), and in Rainier Beach Urban

Farm and Wetlands from March 31st – April 10th, 2022 (transect sample) and April 13th – 23rd, 2022 (cluster sample).

Figure 7. Colman Park Sampling Map. Blue points depict the Garden Transect and Forest Transect camera locations. Orange points represent the cluster sample camera locations. Polygon shaded in green depicts the P-Patch community garden area. Source: ESRI Community Maps Contributors, City of Seattle, King County, WA State Parks GIS © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, Esri, USDA Farm Service Agency

Figure 8. Jackson Park/Thornton Creek Natural Area Sampling Map. Blue points depict the Garden Transect and Forest Transect camera locations. Orange points represent the cluster sample camera locations. Polygon shaded in green depicts the P-Patch community garden area. Source: ESRI Community Maps Contributors, City of Seattle, King County, WA State Parks GIS © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, Esri, USDA Farm Service Agency

Figure 9. Rainier Beach Urban Farm and Wetlands Sampling Map. Blue points depict the Garden Transect and Forest Transect camera locations. Orange points represent the cluster sample camera locations. Polygons shaded in green depict the urban farm food production areas. Source: ESRI Community Maps Contributors, City of Seattle, King County, WA State Parks GIS © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, US Census Bureau, USDA, Esri, USDA Farm Service Agency

Following methods used by Vilette et al. (2017), cameras (Bushnell Trophy Cam E3 Model) were strapped to trees using CAMLOCKBOX security boxes and locking cables and were positioned approximately 15-25 cm from the ground. In all observation periods, cameras within each sampling regime were placed 30-50 meters from each other (Vilette et al. 2017).

Camera locations were selected on maps of each site that fit the sampling regimes described above (transect or cluster), and when at the sites, traveled to the coordinates selected. Once at a coordinate, the closest tree was selected that was of sufficient size and diameter to support a camera. Thus, there was some minor variability between points selected on the map and locations sampled in actuality. Cameras were programmed to take images when movement was detected with a 10-second delay between triggers so as to minimize superfluous photographs of vegetation movement. Cameras were set to Auto mode, which allows the camera to determine the best motion sensitivity settings in accordance with the air temperature.

Although some studies, particularly those focused on small, fast-moving animals, have utilized video monitoring for improved identification, recent research comparing video footage to photographs found that both methods yielded similar identification success rates for small mammals (Glen et al. 2013). Given this research and the fact that video footage requires greater processing time and computer storage, this study chose to have cameras take photographs rather than videos. In addition, although food baits are often used in studies involving small animals, particularly mammals, baits were not used in this study due to restrictions from Seattle Parks and Recreation and also for concerns over altering feeding patterns and introducing biases. Finally, although other methods, such as point counts and passive acoustic monitoring, are typically used for bird observation, recent studies have pointed to the utility and efficacy of camera traps for gathering data on bird populations (Zhang et al. 2017, Cloyed et al. 2018, Puffer et al. 2021).

All images of humans were deleted before photo analysis took place. Mammals were identified by comparing images to the Burke Museum Mammals of Washington Guide, and birds were identified by comparing images to those from the Cornell Lab of Ornithology Birds of the World database (Burke Museum 2013, Cornell Lab of Ornithology). The University of Washington Ecosystem Fund provided funding for buying the cameras

Statistical Analysis

Three diversity indices were calculated for each camera, camera location type, and site. The first, the Shannon Index, takes into account the number of species present and their relative abundance and assumes a large sample size in which all species are represented (Sohier 2022). The Shannon Index formula takes the proportion of a specific species to the entire community, multiplies it by the natural logarithm of this proportion, and sums this multiplied value for every species in the community.

$$H = -\Sigma p_i * ln(p_i)$$

where H = the index value

$p_i = n/N$, or proportion of the community made up of species i, where n = counts of a specific species in the community and N = total counts of all species in the community

Values for the Shannon Index typically range between 0 and 5, with higher values indicating greater diversity (Sohier 2022).

The second index calculated was the Simpson's Index, which also takes into account the number of species and their relative abundance (Sohier 2022). This index expresses the probability that any two individuals drawn randomly from an infinitely large sample are of the same species (Sohier 2022). The index takes that probability value and subtracts it from 1. This formula for this index is as follows:

$$D = 1 – (\Sigma n(n-1)/(N/N-1))$$

where D = the index value

n = counts of a specific species in the community and N = total counts of all species in the community

Values for the Simpson's Index range between 0 and 1, with values closer to 1 indicating higher diversity (Sohier 2022).

Finally, the third index was Menhinick's Index, which calculates the number of species divided by square root of the number of individuals in the population. This index incorporates the sample size into the species richness, whereas the previous two indices assume there is a very large sample size (Sohier 2022). The formula for this index is:

$$D_{Mn} = S/\sqrt{N}$$

where D = the index value

S = the number of species

N = the population size

Indices were calculated in R (R Core Team, 2020) using Vegan, Tidyr, Tidyverse, and Here packages (Oksanen et al. 2017, Wickham et al. 2019, Kirill Muller 2020).

Results

Species composition

The camera traps gathered 2,054 images of mammals and birds throughout the duration of the study period. We observed 24 total species, including 16 bird species and 8 mammal species (Table 2). All bird species were native, while only 3 out of 8 mammal species were native. 2 bird species identified in this study, the Varied Thrush and Pine Siskin, are listed as a "common bird in decline", and one other, the Pacific Wren, is highly sensitive to forest fragmentation (NABCI 2014, NABCI 2016). Predator species, including the Coyote and Raccoon, appeared in all three sites, an important indicator of ecosystem health.

The most highly observed animal was the Eastern Gray Squirrel, with 408 images observed. Although there were fewer mammal species, they tended to appear more ubiquitously across all three sites and all camera location types (Table 2).

Table 2. List of mammal species recorded by the cameras and their habitat needs and conservation status.

Species	Native/ Non-native status	Associated habitats	Conservation status
House Mouse *(Mus musculus)*	Non-native	Buildings, cultivated fields, any area with cover	Least concern
Black Rat (*Rattus rattus*)	Non-native	Seaports and buildings	Least concern
Norway Rat (*Rattus norvegicus*)	Non-native	Human dwellings, cultivated fields, cities	Least concern
Eastern Gray Squirrel (*Sciurus carolinensis*)	Non-native	Forests and wooded areas within cities and suburbs	Least concern
Eastern Cottontail (*Sylvilagus floridanus*)	Non-native	Meadows and open woodlands	Least concern
North American Beaver (*Castor canadensis*)	Native	Wetlands, streams, lakes, ponds	Least concern
Raccoon (*Procyon lotor*)	Native	Wooded areas, urban and suburban, often near water	Least concern
Coyote (*Canis latrans*)	Native	Open areas, woodlands, urban areas	Least concern

On the other hand, bird species appeared in more specific camera locations, and several appeared at only one out of three sites (Table 3). These differences between birds and mammals may be a possible result of the fact that the power of flight enables birds to visit fragmented urban green spaces more easily. Bound by gravity, mammals may not able to utilize urban green space resources in this way and must find locations that serve as more permanent habitat.

Table 3. List of bird species recorded by the cameras and their habitat needs and conservation status.

Species	**Native/non-native status**	**Associated habitats**	**Conservation status**
American Crow	Native	Open areas, forest edges, cultivated fields	Least concern
American Robin	Native	Woodlands, gardens, residential areas	Least concern
Bewick's Wren	Native	Open woodlands with thick, scrubby vegetation	Least concern
Black-capped Chickadee	Native	Open woods and parks, disturbed areas	Least concern
Dark-eyed Junco	Native	Forests, open woodlands, fields, parks, gardens	Least concern
Fox Sparrow	Native	Areas of thick cover, bushy woodland edges, scrubby woods	Least concern
Golden-crowned Sparrow	Native	Brush, riparian thickets, chaparral, gardens	Least concern
House Sparrow	Native	Near human habitations, cities, farm fields	Least concern
Northern Flicker	Native	Open woodlands, city parks, suburbs	Least concern
Pacific Wren	Native	Old-growth evergreen forests, mixed forests, aspen stands	Least concern
Pine Siskin	Native	Open forests, parks, suburban woodlands	Common bird in steep decline
Ruby-crowned Kinglet	Native	Spruce-fir forests, mixed woodlands, floodplain forests	Least concern
Song Sparrow	Native	Open habitats, including lake and forest edges, suburban areas	Least concern
Spotted Towhee	Native	Areas of dense shrub cover, dry thickets, forest edges	Least concern
Steller's Jay	Native	Coniferous and mixed forests, patchy landscapes	Least concern
Varied Thrush	Native	Dark, wet, old-growth forests, parks and gardens in winter	Common bird in steep decline

Differences among camera locations

Regarding camera locations, no apparent trends indicated higher or lower diversity in forest interior areas compared to garden/farm edge areas. When comparing the transect sample data (sample 1), forest-positioned cameras had a higher mean Shannon Index than cameras closer to the gardens/farms along the garden transect. However, when comparing the cluster sample data (sample 2), garden/farm edge-positioned cameras had a higher mean index than forest-positioned cameras. Furthermore, the Colman Park GEC camera had the highest Shannon and Simpson indices but was followed closely by forest-positioned cameras at RBUFW with the second and third highest indices.

When adding the Shannon Index by transect for all three sites, the GEC cameras yielded the highest results, while the garden transect forested and garden transect semi-forested cameras yielded the lowest results (Figure 10). However, it should be noted that diversity was 0 at Jackson Park in both the GTF and GTSF cameras, which greatly lowered the total when adding all three sites for those transect categories.

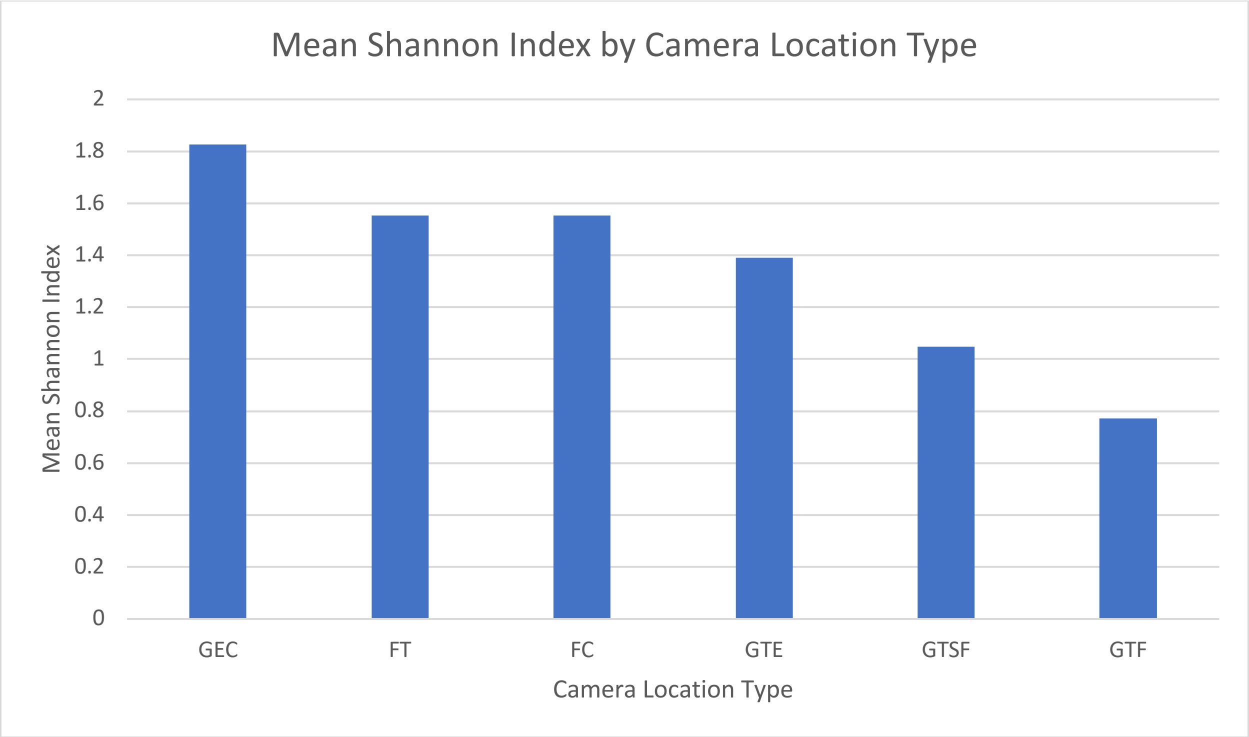

Figure 10. Mean Shannon Index by Camera Location Type (see figures 7-9 for camera locations).

Although there were no apparent differences in diversity between garden edge-positioned cameras and forest-positioned cameras, there were differences between birds and mammals with regards to camera locations. On the whole, mammals were more ubiquitous than birds across camera location types, with a mean of 4.5 camera location types averaged per species, while birds averaged 3.31 camera location types per species (Tables 4 and 5). Abbreviations: GTE – garden transect edge, GTSF – garden transect semi-forested, GTF – garden transect forested, FT – forest transect, GEC – garden edge cluster, FC – forest cluster.

Table 4. Mammal camera detection by camera location.

	GTE	**GTSF**	**GTF**	**FT**	**GEC**	**FC**
House Mouse	x	x		x	x	x
Black Rat	x	x	x	x	x	x
Norway Rat	x			x	x	x
Eastern Gray Squirrel	x	x	x	x	x	x

Eastern Cottontail	x	x	x	x	x	x
North American Beaver					x	
Raccoon			x	x	x	x
Coyote			x	x	x	x

Table 5. Bird camera detection by camera location

	GTE	**GTSF**	**GTF**	**FT**	**GEC**	**FC**
American Crow					x	x
American Robin	x	x	x	x	x	x
Bewick’s Wren		x		x	x	
Black-capped Chickadee	x		x	x	x	x
Dark-eyed Junco	x	x		x	x	
Fox Sparrow			x	x	x	x
Golden-crowned Sparrow		x	x	x		
House Sparrow				x		x
Northern Flicker			x	x	x	
Pacific Wren	x		x	x		
Pine Siskin					x	
Ruby-crowned Kinglet						x
Song Sparrow	x	x		x	x	x
Spotted Towhee	x		x	x	x	x
Steller’s Jay	x		x	x	x	
Varied Thrush	x				x	

When comparing camera location types among sites, the garden edge cameras had more consistently similar levels of diversity, according to the Shannon Indices (Figure 11). The Garden edge cluster cameras and garden transect edge cameras displayed the highest levels of similarity across all three sites, while other camera locations demonstrated greater variability across sites.

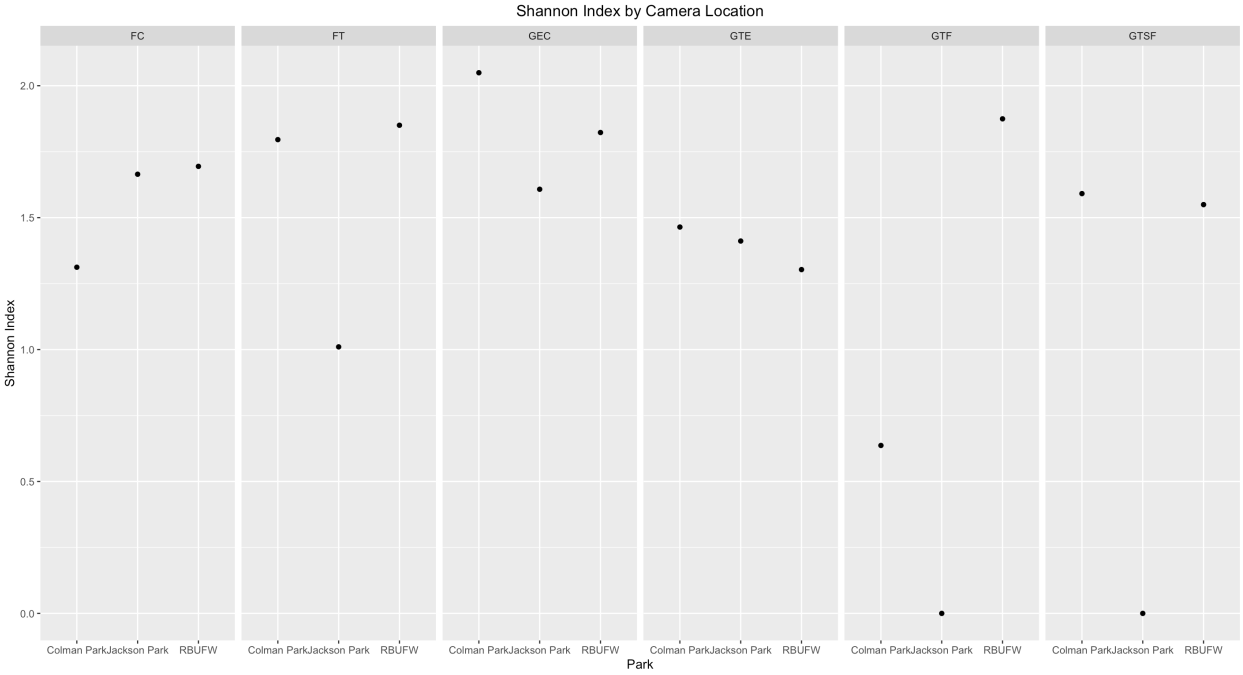

Figure 11. Shannon Index by Camera Location and Site.

Differences among sites and influence of management approach

The RBUFW/Pritchard Island Woods site had the highest diversity of the three sites, indicated by the Shannon Index, Simpson's Index, and Menhinick Index (Figures 12 and 13). Several bird species were unique to this site, and it was also the only site with all 8 mammal species. In addition to having more species, the RBUFW/Pritchard Island Woods site also had far more evenness in its data. Although Colman Park was not far behind diversity-wise, the data from that site were much more sporadic, with high variability among cameras. According to the indices calculated, Jackson Park was similarly sporadic and had lower diversity overall than either of the other sites.

As noted earlier, RBUFW/Pritchard Island Woods had the smallest forest area and largest agricultural area of the three sites. In addition, from a management perspective, site managers at

RBUFW follow a more integrated landscape design approach, in which natural ecosystem elements and native vegetation are intermixed with crop beds in some areas (Leach 2014). This contrasts with the other two sites, which have distinct forest areas fully on the outskirts of the community garden areas.

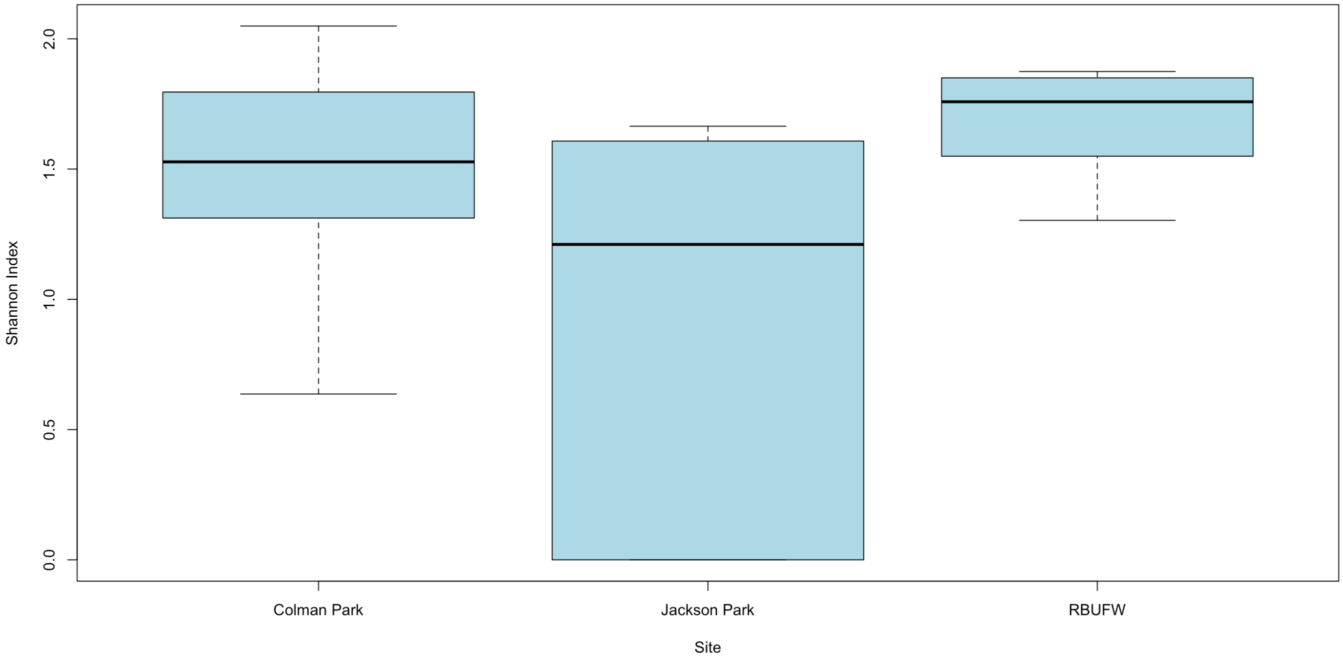

Figure 12. Shannon Index by Site.

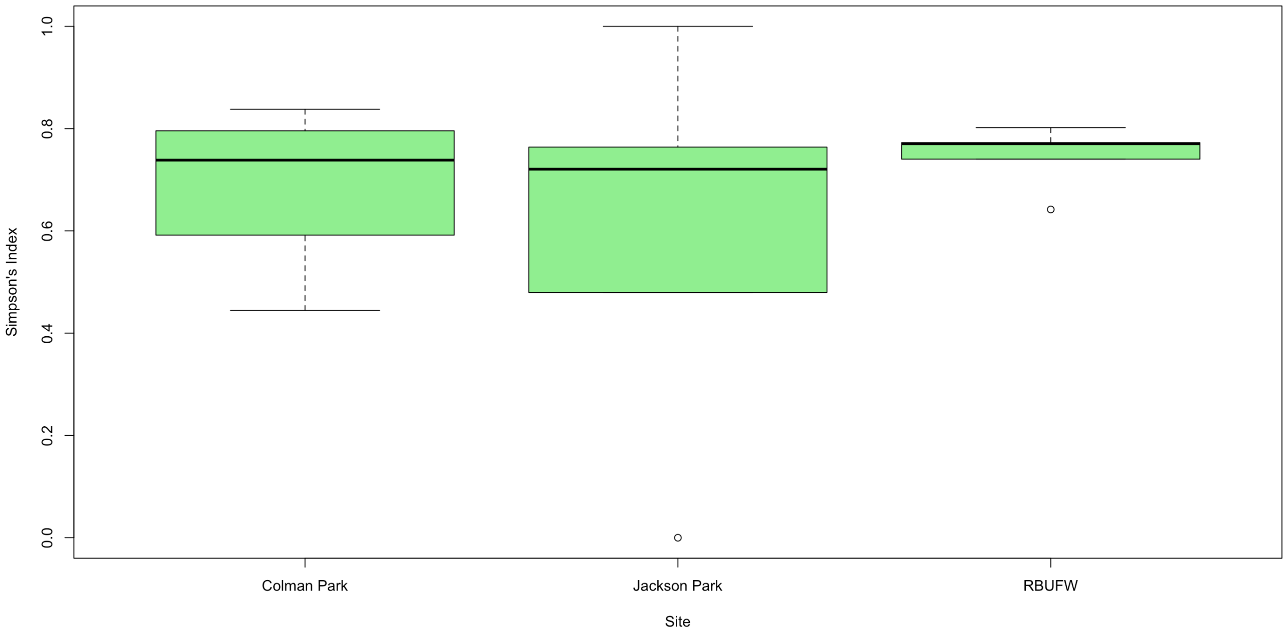

Figure 13. Simpson's Index by Site.

Discussion

This study examined whether multifunctional urban greenspaces in Seattle comprising both forests and adjacent gardens or farms could provide habitat for a diversity of native mammals and birds. Further, this study explored whether interior forest areas provided habitat for a higher diversity of species than garden/farm edge areas and whether the park management approach would impact species diversity among the sites studied. This study identified 8 mammal species and 16 bird species across all sites using camera traps, and there were no apparent differences in diversity between interior forest areas and garden/farm edge habitats. Despite its smaller forest and overall area, RBUFW, which was the only site employing an integrated management approach to food production and wildlife habitat, had the highest diversity of the three sites, as indicated by the Shannon and Simpson's Indices. These findings contradicted our expectations that a larger forest area would lead to greater species diversity and that interior forest areas would support a higher diversity of species than edge habitats. However, the results did support our hypothesis that park management approach would have an impact on species diversity.

There are multiple ways to interpret these results. The fact that there were no apparent differences in diversity between forest core areas and edge habitats could be looked at from several different angles. On one hand, the lack of difference in diversity between forest core areas and edges could indicate that there is not a significantly large enough forest core in these urban green spaces to support a variety of forest-dwelling species. In a sense, the lack of a large forest core indicates that the entire site is in close proximity to the edge and that species that cannot compete in edge habitats will not be able to survive. On the other hand, this study found three species that depend on unfragmented forests for habitat, indicating that although the forest cores are small, they serve a purpose. Finally, the fact that the garden/farm areas had levels of diversity that were similar to diversity in the forest areas may point to the utility of these agricultural areas as part of the larger landscape matrix used by urban wildlife.

There are also multiple possible ways to interpret the fact that the RBUFW site had the highest species diversity. On one hand, the RBUFW site was the only site taking a holistic approach by integrating natural ecosystems and native vegetation into its food-growing spaces, perhaps indicating that this more integrated approach is beneficial to a greater number of wildlife species. On top of this, RBUFW was the site with the smallest forest area and largest garden/farm area, a possible sign that in the urban environment, forest size has less of an impact than management approach when measuring a site's ability to support biodiversity conservation. However, with that said, our study involved a sample size of only three sites, limiting our ability to make broad conclusions about the influence of management approach and forest size on species diversity. Furthermore, the sampling period at RBUFW stretched into the spring, a time at which more birds may have been active than the winter observation periods at the other two sites. This lack of control for seasonality limits our ability to make broader conclusions about differences between sites. Finally, as mentioned earlier, environmental variability is extremely high in urban settings, limiting our ability to make broad conclusions about comparisons between sites. While we did select sites that contained some common criteria, such as a forested area adjacent to a community garden or farm, a forested area(s) comprising at least half the total site area, and canopy coverage percentage within 10% of each of the other sites, there are a number of other uncontrolled variables among these landscapes, such as presence of or proximity to water, vegetational composition and structure, presence of or proximity to roads crossing through the parks or around the perimeters, and presence/absence of other nearby green spaces and connectivity elements.

More broadly speaking, from the perspective of biodiversity conservation planning, we see several promising takeaways from this study. First, our results add to the growing body of research demonstrating the value of a broader set of landscapes for biodiversity conservation, including those located in urban environments. Even in Seattle, a very urbanized metropolis of nearly 750,000 people, comprising the 18th largest city in the United States (Ballotpedia 2022), many wildlife species are able to live among a network of urban green patches. In fact, even declining and threatened species may find refuge in the habitats of the urban environment, as demonstrated by the appearance of these species in our study and other studies that have discussed the critical role of urban green spaces in the conservation of a variety of endangered species (Freshkills Park 2019, Soanes and Lentini 2019). The fact that these threatened and declining species are appearing in green spaces situated within densely urbanized zones shows just how essential these habitats are, even if they are smaller and only faintly resemblant of the native Northwest ecosystems that once existed here.

Furthermore, this study builds on a small but growing body of research exploring the value of urban gardens and farms as part of the larger landscape matrix providing habitat for biodiversity conservation (Baker and Harris 2007, Clucas et al. 2018, Sivakoff et al. 2018, Van Helden et al. 2020). In this study, forests did not provide habitat for a higher diversity of species than garden/farm areas did, showing that the urban garden and farm areas may be an important component of the green landscape matrix depended on by urban wildlife, particularly when they are situated near forests. These findings, as well as other recent studies that have found comparable or even greater species diversity in urban agricultural areas compared to other forms of urban green space, show that urban gardens and farms should continue to be investigated for their potential to support biodiversity (Sorace 2001, Philpott et al. 2014, Clucas et al. 2018).

In addition, while many studies have examined plant and invertebrate diversity in urban gardens, few other studies have measured vertebrate diversity in urban agriculture spaces (Lin et al., 2015, Clucas et al. 2018). In fact, a 2018 literature review of studies measuring biodiversity in urban agricultural spaces found only one study that included vertebrates (Clucas et al. 2018)

This study, along with other recent research, may also challenge popular beliefs about wildlife in cities, and more broadly, what constitutes nature. Many people believe that cities are places primarily for people and hold negative opinions of wild animals in cities, particularly if they have never observed a species or lack awareness of its value (Baker 2017, Kover et al.

2022). Many people in urban areas believe that “real nature” or beneficial nature is somewhere far away in a remote area or in a national park (Haluza-Delay 2001, Vining et al. 2022). However, though they are often small and disconnected, urban green areas have shown to be important strongholds for a wide variety of species, many of which are native. Our study supports this growing body of evidence, and in doing so, challenges commonly held conceptions of cities as lifeless and devoid of biodiversity.

Building on this study, we recommend future studies take a similar approach and amplify it across many more sites and, if possible, across different cities or regions. This kind of larger-scale study would lend greater insight into the habitat selection of wildlife utilizing multifunctional urban green spaces and would provide more robust data on any differences in how wildlife use different habitat types. A longer sampling period, over multiple years rather than months, would also improve our understanding of the types of questions asked in this study. In addition, while our study utilized only one camera trap method to observe multiple taxa, future studies may consider more varied observation techniques. To more comprehensively catalogue all species present in the landscape, multiple camera heights and settings should be used. In addition, as previously mentioned, food baits are often used in studies of mammals, particularly those focused on small mammals, which are likely to attract more individuals and provide a more accurate picture of the true diversity at a site (Vilette et al. 2017). Live trapping is another option that is commonly used for small mammal monitoring, although this method causes fatalities and greater ecosystem disturbance and is thus increasingly being avoided. Finally, although camera traps have been recently tested for their efficacy in bird monitoring, other methods, such as bio-acoustic monitoring and point counts, should be considered in future urban green space studies involving bird observation (Zhang et al. 2017, Cloyed et al. 2018, Puffer et al. 2021). With all of that said, the lack of variation and precision in our sampling method may likely have resulted in a very conservative estimate of the number of mammal and bird species present in these landscapes, meaning that there may very well have been even greater levels of biodiversity than what we observed.

Conclusion

This study supports a new vision for biodiversity conservation that challenges former assumptions about what lands are available and suitable for biodiversity conservation. We argue that conservation planners need to expand the repertoire of lands considered for biodiversity protection, and that urban green spaces, including gardens, farms, and other green areas within a broader landscape matrix, should be part of this conversation. Developing more urban green spaces and more efficient use of existing green spaces should be a priority of wildlife conservation, particularly as we face unprecedented rates of species extinction and as the availability of remote lands available for reserves continues to shrink.

In order to continue to improve urban green spaces for wildlife, this study recommends both incorporating species-specific habitat features and improving the overall landscape matrix to increase connectivity between green spaces. As was demonstrated, there were 8 mammal species observed in this study, but only half were small mammals and none were native small mammals. While this may have been partly due to the limitations of the unconventional sampling method described previously, it is also important to note that many small mammals native to Washington rely on old-growth forest and large logs for shelter (West 2007). While old-growth forests take centuries to grow and would require extensive planning, incorporating logs or other similar artificial features for cover is one solution that should be implemented and tested for their ability to support more native small mammals in future studies. Furthermore, although birds do face numerous obstacles in the urban environment, such as the threat of window collisions and domestic cat predation, it is possible that flight may enable them to travel more easily across disconnected urban green spaces than mammals who have no ability to circumvent the terrestrial urban environment involving roads and other hazardous built structures. For effective native mammal conservation in these areas, the entire landscape matrix needs to be built in a more wildlife-friendly manner through the construction of strategic wildlife tunnels, corridors, and spatial planning of green space that allows for connectivity. Recent wildlife corridor projects in big cities like Los Angeles and Chicago, and neighborhood greening initiatives that create connected areas of habitat have drawn public attention in recent years and provide a promising roadmap for projects to occur in other areas (Gammon 2019, Chicago Park District 2022). Viewing the landscape as a whole and understanding all of its intricate components will be essential as conservation planners set out to achieve ambitious biodiversity targets, such as those of the 30x30 plan, in the years ahead.

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