Shared Spaces: Relationships Between Human Recreation and Avian Conservation in Urban Greenspaces

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Abstract

Shared Spaces: Relationships Between Human Recreation and Avian Conservation in Urban Greenspaces

Chloe Cull

Urban greenspaces are spaces are often intended for the use of people and wildlife; however, balancing the dual priorities and needs of people and wildlife from these spaces can be challenging. This thesis aimed to assess how urban greenspaces with varying levels of human activity are supporting bird nest success. It also aimed to assess differences in bird communities close and far from recreational trails, and differences between urban greenspaces with different management styles. We conducted a field study in the summer of 2023 to collect data on bird diversity and nest survival on the island of Montreal. Through this work, we found that human activity did not significantly influence bird nest survival. We also found that bird communities further from trails in informal urban greenspaces were the most diverse; however, we did not find a relationship between the number of people using trails and bird diversity. This work provides land and urban greenspace managers with integrated science advice to help them support access to nature for people while maintaining existing avian biodiversity.

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Land Acknowledgement

This research was conducted on the Island of Montreal, which is located on the unceded Indigenous lands of the Mohawk and Haudenosaunee People. The Kanien'kehá:ka Nation is recognized as the custodians of these lands and waters. Tiohtià:ke/Montréal is historically known as a gathering place for many First Nations. Today, it is home to a diverse population of Indigenous and other peoples.

For more information, please consult Concordia's land acknowledgement with history and resources:

https://www.concordia.ca/indigenous/resources/territorial-acknowledgement.html

1. General Introduction

Urban greenspaces provide important services to people such as temperature regulation, pollution mitigation, and places to recreate (Aram et al. 2019, Dadvand et al. 2015). In cities, urban greenspaces are some of the only recreational areas where people can access nature and wildlife. Interactions with nature are known to improve mental health by reducing stress and decreasing feelings of depression and anxiety (Jimenez et al. 2021). For example, one study revealed that mental health in people encountering birds as part of their everyday life was significantly better than people that do not encounter birds. These improvements in mental health were also observed in people with diagnosed depression, which globally affects an estimated 350 million people. Bird watching could be a natural intervention to improve mental health in people with and without depression (Hammoud et al. 2022). Furthermore, spending time in nature can improve immune function, reduce high blood pressure, and improve pulmonary and cardiac function (Oh et al. 2017). A review found consensus for decreased quantity and quality of opportunities for people to experience nature, likely linked to modern habits and urbanization (Bratman et al. 2019). To ensure that people gain the benefits of recreating in nature, they must have the spaces in which to do so. There is thus a need to manage and protect our urban greenspaces (Keeler et al. 2019, van den Bosch & Sang 2017, Haase et al. 2014).

Bird watching in particular is an important and popular method of connecting with nature in urban areas and is accessible to people of all ages. Unfortunately, bird populations are facing decline due to habitat degradation and loss, among other factors (Birds Canada 2024). As cities expand, forest and natural habitat is lost to development. Collectively, North America has lost over 2.9 billion breeding birds since 1970 (Rosenberg et al. 2019). Not only is this concerning for their role in connecting people to nature, but the decline of birds can have significant ecological consequences (Şekercioğlu et al. 2004). Birds carry out functions such as pest control, pollination, nutrient cycling, and seed dispersal. Furthermore, birds serve as indicators of environmental health, as they are widespread and sensitive to changes in their ecosystem and in lower trophic levels. Urbanization is a significant and growing contributor to habitat loss (Mcdonald et al. 2023), but the protection and management of urban greenspaces can help mitigate the ecological consequences of bird population decline.

Urban greenspaces are valuable to both migratory bird species and year-round residents. Some migratory birds will stopover in urban greenspaces to replenish fat stores before further migration North (Poirier et al. 2024). Others can be drawn into cities inadvertently from light pollution (Van Doren et al. 2017), as light can interfere with birds' visual cues from stars and landmarks and confuse them (Rebke et al. 2019). Urban greenspaces are spaces where migrant and resident bird species can seek refuge, find areas to raise young, and forage (Prihandi & Nurvianto 2022).

To increase the benefits people and wildlife receive from nature, there is a rising number of urban greening initiatives in Canada, at both local and national scales. In Montreal, the Grand Parc de l'Ouest and the Grand Parc de l'Est plans are two examples of municipal government efforts to increase green area. These plans aim to create a network of greenspace across the island of Montreal by protecting existing nature parks and woodland, forests, marshes, and farmland that connect these existing parks (City of Montreal 2024). In particular, the Grand Parc de l'Ouest has the potential to be Canada's largest municipal park, at over 3100 hectares of land (City of Montreal 2024). As an example of a federal greening initiative, Parks Canada has developed the National Urban Parks Plan. This plan seeks to designate existing urban greenspaces as new National parks, thereby benefitting from similar protection and management to existing traditional National parks. Funding for the creation of six of these parks by 2025 was announced in 2021 (Parks Canada 2023). These strategies are indicative of the recent interest in preserving and managing urban greenspaces for birds and other wildlife, in addition to promoting human recreation.

While urban greenspaces are meant to support both human and bird health, historically, human activity has had negative impacts on urban birds (Fernández-Juricic & Jokimäki 2001). For example, literature has suggested that human recreation in both wild and urban greenspaces can reduce bird density and richness (Bötsch et al. 2017, Bötsch et al. 2018). However, some research suggests that people may not influence direct measures of bird wellbeing. One study showed a reduction in nest predation near recreational areas and posited that the presence of humans resulted in a reduction of known nest predators in the area (Miller & Hobbs 2000; Miller & Hobbs 2002). Another study in a national park in Spain found that during times of increased human activity, there was an increase in bird species richness and Simpson diversity (Pérez-González et al. 2024). The impact of human activity on birds may be more nuanced than previously understood.

In the following two chapters of my thesis, I investigated the impact of human activity on avian nesting success, diversity, and community structure. I also looked at differences in avian communities between formally managed and informally managed urban greenspaces. Both chapters seek to find a balance between human recreation and bird success and diversity within our urban greenspaces. Specifically, I asked:

1. Does human activity in urban greenspaces influence nest survival of four species of open-cup shrub nesting birds in Montreal?

2. Does human activity influence bird species richness, diversity and community composition in urban greenspaces and are there differences between informally and formally managed urban greenspaces?

In the first chapter of my thesis, I assessed whether human activity influences the survival of nesting birds in urban greenspaces. Reproduction is a critical part of a bird's life cycle as ensures the survival of the species and allows them to maintain populations and genetic diversity As we plan future urban greenspaces and management plans, it is important to think about bird nest success and investigate the potential influence humans may have on breeding outcomes. I conducted a nest survival study in urban greenspaces of varying levels of human activity and assessed how human activity, quantified by indices from anonymous cellphone use data, would influence nest survival.

Building on this work in my second chapter, I looked at the relationship between human use and bird diversity and community composition within and across urban green spaces. Within greenspaces, I assessed whether trail presence and the average number of trail users influenced bird diversity and species richness. I also explored the differences between bird communities close and far from trails. Across greenspaces, I assessed whether informal vs. formal greenspace management (at the park level) influenced bird diversity and composition. Overall, I seek to provide an account of the impact of human activity on bird reproduction and diversity in urban greenspaces. The results of my two thesis chapters serve to inform urban park planners and managers on how to best manage trails within urban greenspaces for birds and people.

Chapter 1

Title: Human Recreational Activity Does Not Influence Open Cup Avian Nest Survival in Urban Greenspaces

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Statement of Ethics Compliance

All details of animal monitoring were approved by Concordia University's Animal Care Facility (Protocol no. 30017925) and by The Canadian Wildlife Service (Permit no. SC-98).

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Abstract

The breeding period of birds is a critical and sensitive period. Understanding how human use of urban greenspaces affects nest survival can help us assess how our urban greenspaces are doing to support breeding bird populations in cities and support science-based management of urban greenspaces that benefit both people and nature. We conducted a nest survival field study between April and August of 2023 in multiple greenspaces in Montreal, Quebec, Canada, the country's second-largest city. We asked whether human presence (distance to trails and amount of human activity) influences the nest survival of four common open-cup nesting bird species. We also asked if variables traditionally associated with nest survival, vegetation concealment and seasonality, would influence nest survival. Our analyses surprisingly revealed no significant influence of human activity, vegetation concealment, and time of year on nest survival for our target species. We found for nests that did fail, nests established during the earlier part of the nesting period failed faster. Within the limitations of our study system, our findings suggest that human presence is not negatively impacting the nesting success for our target bird species using urban greenspaces. Our study provides integrated science advice to land managers so they can support opportunities for people to connect with nature without causing trade-offs with biodiversity conservation.

1. Introduction

Natural areas in cities are increasingly recognized for their value in providing support for wildlife and services for people. Birds often take refuge in city parks and forests, hereafter referred to as "urban greenspaces", which are defined as delineated patches of land containing natural components (trees, shrubs, grasses, gardens) (De Haas et al. 2021). For example, in Montreal, researchers found a higher abundance and diversity of shrub-nesting birds in parks compared to residential areas (Rousseau et al. 2015), implying that these are important spaces for avian conservation (Buron et al. 2022). Parks also have more opportunities for coordinated efforts to improve habitat quality and diversity for birds. In contrast, residential spaces like backyards and gardens are more difficult to manage at a large scale, as individual property owners have varied preferences for vegetation and may choose ornamental, non-native plants that do not support biodiversity as well as native plants do (Threlfall et al. 2017). Urban greenspaces provide wildlife, including birds, with shelter, areas to raise young, and food, which is particularly important in cities where green cover is low (Vasquez & Wood 2022).

In urban settings, birds are widespread and known to be biodiversity indicators (Fraixedas et al. 2020). They often stop in urban greenspaces along their migration routes to rest and replenish fat stores (Rodewald & Matthews 2005; Seewagen et al. 2010), while others are drawn in by artificial light pollution (McLaren et al. 2018). Urban greenspaces can be attractive to open cup shrub-nesting bird species specifically, as cities often have many of their preferred shrubby edge habitats (Kurucz et al. 2021). These species have lower rates of nest survival in comparison to species that use other nesting strategies (Ospina et al. 2018). Their nests are often and easily accessed by mesopredators, which are common in cities in the absence of sensitive apex predator species (Morosinotto et al. 2012). Cities present many general dangers to birds, including building and window collisions, and novel predators (Van Doren et al. 2021; López-Flores et al. 2009). Furthermore, the fragmented nature of urban habitats poses challenges to birds as it can limit their movement and increases vulnerability to predation and competition (Marzluff 2001). These challenges underscore the need for long-term avian monitoring in urban spaces and the need to implement conservation solutions, which could include improving the management of urban greenspaces to support birds.

Responsibility for protecting and managing urban greenspaces is shared between federal or provincial initiatives and local municipal governance. In Canada, for example, federal initiatives such as the National Urban Parks initiative, the Growing Canada's Community Canopies initiative, and the Nature Smart Climate Solution Fund provide funding and/or guidance to promote the conservation, restoration, and management of urban nature. (Parks Canada 2023; Natural Resources Canada 2024; Environment and Climate Change Canada 2024). The establishment, protection, and management of urban greenspaces is particularly important for biodiversity in southern Canada, as this region is heavily developed, but also contains the majority of the country's species at risk. Furthermore, southern Canada has experienced low conservation responses relative to the threats facing biodiversity in these regions (Kraus & Hebb 2020).

In addition to protecting biodiversity, urban greenspaces facilitate human-nature interactions, with urban birds representing some of the most accessible wildlife to people. Interactions with nature have been shown to reduce the frequency of violence, mortality and heart rate, while improving attention span and the frequency of physical activity (Kondo et al. 2018). Additionally, human-bird interactions specifically help to reduce symptoms of anxiety, paranoia, and depression (Stobbe et al. 2022). A recent study found a positive relationship between urban bird diversity and self-reported good mental health, indicating that cities with greater biodiversity may enhance overall mental wellbeing (Buxton et al. 2024). Birds provide people with important cultural services, such as promoting feelings of relaxation and a strong connection to nature through activities such as birdwatching or bird feeding (Cox & Gaston 2016). These positive interactions provide incentive to protect and maintain our urban greenspaces.

While people receive mainly positive effects from birds, studies have reported that human presence in urban greenspaces can impact the diversity and abundance of bird species (Bötsch et al. 2018; Jokimäki 1999; Kangas et al. 2010; Lepczyk et al. 2008; Van der Zande et al. 1984). Some studies have suggested that urbanization and human presence are negatively correlated with bird species richness (Peña et al. 2022; Bötsch et al. 2018). A recent publication showed that most bird species cannot tolerate a high level of human pressure, with only 22% of over 6000 global species of birds being more tolerant (Marjakangas et al. 2024). Yet, there is a lack of consensus on how more direct measurements of bird population well-being, might be impacted by human disturbance (Chamberlain et al. 2009; Vincze et al. 2017). A strong example of a direct measurement is nest success, as the breeding period represents a critical and vulnerable period in a bird's life and allows for the survival of a species (Forslund & Pärt 1995).

Research in more natural areas has suggested that human presence and recreation have negative consequences on avian nest success, but evidence and consensus of this in urban greenspaces is lacking. Human disturbance had a significantly negative effect on nest success in seabirds in a nature park in Scotland (Beale & Monaghan 2004). Another study on blue tits (*Cyanistes caeruleu*) in experimentally placed nest boxes in a forest 60 kilometres outside of Madrid found that nestlings hatched on holidays, linked to an increase in recreation and human gatherings, were associated with impaired development (Remacha et al. 2016). Nests closer to roadways and human development are also more likely to be abandoned by the cavity-nesting American kestrel (*Falco sparverius*) (Strasser & Heath 2013). Waterfowl are reported to spend less time at their nests due to human disturbance, thereby increasing the chance of nest predation (Stien & Ims 2015). Predation is globally known to be the primary source of nest mortality (Ricklefs 1969). Mesopredator populations, including common nest predators such as crows and raccoons, often explode in urban environments, as these spaces favour conditions that increase mesopredator survival and reproduction (Prugh et al. 2009; Kövér et al. 2015, Prange & Gehrt 2004).

Conversely, a study in a suburban area of Colorado found that experimentally placed nests closer to trails incurred less predation, likely because human presence and recreation decreased known predators of shrub and low-nesting bird species (Miller & Hobbs 2000; Miller & Hobbs 2002). This is known as the "human shield" hypothesis, which proposes that in regions with higher human activity, human presence acts as a buffer against the impacts of predation on prey species, effectively shielding these animals from their predators and increasing survival (Berger 2007, Gámez & Harris 2021; Pérez-González et al. 2024). Another study on Northern cardinals (*Cardinalis cardinalis*) in Ohio publicly owned parks (including some in highly urbanized areas) found that human recreation did not have an apparent effect on nest survival, and that height was the mediator of human disturbance and likelihood of flushing (when birds leave their nest in response to disturbance) (Smith-Castro & Rodewald 2010b). They believed that nests where birds flushed their nests at further distances from humans, compared to those where birds flushed when humans were closer, would experience more predation because their nests are unoccupied for longer (Smith-Castro & Rodewald 2010b). Evidence that human disturbance both does and does not impact nest success highlights the need for clarity on the subject, especially as cities expand and the number of people using urban greenspaces increases.

The overall aim of our work is to assess whether human presence in urban greenspaces influences the nest survival of common species of open-cup shrub nesting birds on the island of Montreal. We also sought to understand how aspects of the vegetation in the nest patch and seasonality might influence nest survival, as these are often included in traditional nest survival studies and are known to be important predictors of nest survival (Davis 2005; Ringelman 2019). For nests that failed, we also investigated whether these variables were significant predictors of the total number of active days that a nest experiences—defined as the number of days from nest inception (first day of building) to nest failure. We did this by conducting a nest survival study across three sites, measuring vegetation variables at the nest patch, quantifying human activity using anonymous cellphone data (Filazzola et al. 2022), and distances of nests to trails, and conducting Cox proportional hazards modelling.

We predict that nesting survival would rise with greater distances from trails and lower rates of human activity, given birds' vulnerability to disturbances posed by trail users, such as loud noises and dogs (Steven et al. 2011), which could increase flushing and signal predators to the location of the nest (Martin et al., 2000) or cause parental abandonment (Beale & Monaghan 2004; Boyd, n.d.; Strasser & Heath 2013). Additionally, we predict that nests higher from the ground, that have more vegetative concealment and shrubby vegetation would increase nest survival and the number of active days a nest experiences. We anticipated this as ground predators common in urban forests may face more difficulty finding and accessing nests (Martin 1993; Seibold et al. 2013; Ringelman & Skaggs 2019) and that nests would be more shaded from the sun, which is crucial for regulating temperatures for healthy nestling development

(Corregidor-Castro & Jones 2021). We expected that nests would experience higher rates of success and more active days with the progression of time through the season, as there is more dense foliage later in the season to conceal and shade nests and a lower likelihood of cold weather events.

2. Methods

2.1 *Study Sites*

The Island of Montreal is in the St. Lawrence Lowlands of Southern Quebec and contains Canada's second largest city. The Island of Montreal covers an area of 498.29 km2 with an average human density population of 4022.3 people / km2 (Government of Canada 2022). The area hosts various habitats such as woodlands, wetlands, brown-lands and shoreline habitats amongst a developed, urban landscape, allowing for approximately 145 bird species to nest each year (Québec Breeding Bird Atlas – n.d.). We conducted our study in three urban greenspaces on the primarily residential and industrial west side of the Island of Montreal: Bois-de-Liesse Nature Park, Technoparc, and Stoneycroft Wildlife Area—selected to span a gradient of human activity (Appendix A). While the parks differ in total size, their vegetation composition is relatively similar and all contain similar dense shrubs, which attract our target bird species.

Bois-de-Liesse is a high visitation park managed by the city of Montreal that is used by cyclists, runners, and dog-walkers, as well as for recreational activities such as picnics and children's day camps. Technoparc is a large greenspace that includes both newly acquired city land (yet to be managed for recreation) and privately owned areas. The area is informally managed by a non-profit organization and is primarily used by birders and nature photographers. Stoneycroft Wildlife Area is a private research area with no public access that is owned by McGill University and hosts a small field station that is active 6 months each year. Our nest searching efforts in all three greenspaces were focused along both small footpaths and larger, more heavily trafficked trails.

2.2 *Study Species*

We studied four target species that commonly nest in all our study sites: American robins (*Turdus migratorius*), gray catbirds (*Dumetella carolinensis*), Northern cardinals (*Cardinalis cardinalis*), and yellow warblers (*Setophaga petechia*). These species are generalist open cup nesters and thus have likely comparable survival and predation rates (Billerman et al. 2022; Leston & Rodewald 2006). Despite their status of "least concern", they are still vulnerable to threats posed by human influence and a changing climate (Lindenmayer et al. 2011). Focusing on managing for common species could thus serve as a strategy to indirectly support and protect at-risk species, particularly those with similar nesting and reproductive behaviours. These common species are also more likely to be known and recognized by the general public, which helps facilitate people's interactions with nature.

2.3 *Nest Monitoring*

We initiated nest searching at dawn, the period of peak avian vocalization and activity (Southworth 1969) and ended at 14:00 between April 26th and August 4th, 2023. Searching was conducted at one site per day rotating through each of the three sites. We did not search for nests on days with heavy rainfall or other inclement weather, such as thunderstorms or days with extreme heat warnings, when birds are known to be less active (Rosamond et al. 2020). Nest searching methods included both territory mapping (Smith et al. 2009) as well as opportunistic observations of target species. Behavioural cues used in finding nests included observing individuals carrying nesting material, vocalizing, or feeding young (Martin & Geupel 1993). During territorial mapping we marked the location of adult birds on a physical map each time we were in that area and approximated the extent of individual territory (Jablonski et al. 2010). We also noted the location of male birds vocalizing, as this often indicates that they were at the edge of a territory (Stoddard et al. 1991).

Once found, we recorded nest geographic coordinates in decimal degrees using a Garmin GPS (Extrexx 22X). We also collected data on weather conditions, the time the nest was found, the species to which the nest belonged, the nest substrate or tree species, and the presence of potential nest predators that could be seen or heard within a 10m radius of the nest (Purcell & Verner 1999; DeGregorio et al. 2016)

We monitored nests every three to five days, following previously established nest monitoring methods (Bailey et al. 2019). Unlike searching, we conducted nest monitoring in a variety of weather, including light rain. In some cases, nests could not be monitored by direct observation at eye level, and we used binoculars and/or an elevated endoscopic camera. We noted the presence of an adult incubating eggs or brooding nestlings, and the nest was presumed to be active. At each nest monitored, we collected the following data: time, date, weather, information on the status of adult birds (if present), eggs (if present), young (if present), condition of the nest (whether it was unfinished, fully constructed, flattened with fecal matter, or removed), whether predators could be observed or heard in a 10m radius of the nest, and any other noteworthy information (Bailey et al., 2019). In some cases, we observed instances of active predation on nests, and we took note of this. If a nest had been removed from where it had once been located, we noted the condition and location of the disturbed nest. We defined nest success as when at least one nestling successfully fledges the nest. We included nest abandonment, nest predation, and nest removal as nest failures.

2.4 *Vegetation Surveys*

We surveyed vegetation at three spatial scales: the nest tree or shrub (henceforth "nest tree"), a 1 m radius nest patch, and a 5 m radius nest patch. We conducted these surveys typically within five days (but 10 surveys were conducted within 5-12 days) of the nest failure or success date to capture vegetation characteristics of the nest patch as accurately as possible. For each nest tree, we recorded the diameter at breast height (DBH), species, height, nest height, vegetative complexity (see Appendix B), and canopy cover above the nest using digital image analysis (see Appendix B). To estimate nest concealment, we used checkerboards (three by three alternately black-and-white squares) of three sizes to accommodate differently sized nests, adapted from Nudds' method of estimating vegetative cover of deer (Nudds 1977, see Appendix B). For the 1 m radius vegetation survey we identified all woody stems in a 1 m radius around the nest tree to species level and tallied the number of stems based on size classes (< 1 cm, 1-3 cm, 3-6 cm, and 6-9 cm DBH). In the 5m radius vegetation survey we identified each tree greater than 5cm to species and measured their DBH. Lastly, we measured the distance of each nest to the nearest trail.

2.5 *Human Activity Indices*

To investigate the human impact of nest survival, we obtained human activity indices of our three sites by using ©MapBox Movement data (www.mapbox.com/movement-data). These data were recorded from 2020 to 2022, and while they did not correspond to our study year, we assumed that the average activity in this timeframe would reflect the human activity present at our sites in 2023. The activity indices were obtained from anonymized cellphone location data within 10 m x 10 m plots per two-hour window (following Filazzola et al. 2022). We subsequently overlaid these human activity indices with our nest GPS points through spatial analysis using R version 4.3.2 (R Core Team 2023), using the stars, sf, stringr, and dplyr packages (Pebesma & Bivand 2023; Pebesma 2018, Wickham 2023; Wickham et al. 2023) to extract mean activity indices within a 20 m radius of each nest location.

2.6 *Nest Survival Analysis*

We used program RMark (Laake 2013) to estimate daily survival rates (DSR) of each of our target species and used the DSR to the power of the average nesting period for each species to calculate species-specific modelled nest success (Jehle et al. 2004). We considered the average nesting period to be from the start of nest building to when the young fledge the nest. For American robins, the average nesting period is 35 days, for gray catbirds it is 32, for Northern cardinals it is 30, and for yellow warblers it is 31 (Billerman et al., 2022). To visualize survival over time for each of our target species, we plotted Kaplan-Meier curves using ggsurvfit, ggplot2, and magrittr packages (Sjöberg et al, 2024; Wickham 2016; Bache & Wickham 2022) in R 4.3.2 (R Core Team 2023). These curves display the probability of the nest surviving each day through the nesting period.

To assess the effects of distance to trail, human activity, vegetation variables, and seasonality on nest survival, we used Cox proportional hazard modelling (Cox 1972). This modelling approach is used when testing the effects of various covariates on the duration until nest failure while accounting for censoring, and time-varying factors (Nur et al. 2004; Roper 2003; Heisey et al. 2007; Liebezeit et al. 2009). Nest successes were our censored events, and were assigned values of “0”, whereas nest failures were assigned as “1”.

Preceding our model building, we checked our variables of interest for collinearity. We established a cutoff for collinearity of 0.7, consistent with studies in ecology. We calculated

Pearson correlation coefficients and then visualized the correlations using the corrplot() function in R Studio and checked for any significant correlation (Wei & Simko 2021; R Core Team 2023). We also ensured that our models met the assumptions associated with Cox proportional hazards modelling. The fundamental assumption for Cox proportional hazards modelling is that the hazard of the event of interest occurring is constant over time. We assessed this assumption using the cox.zph() function from the R survival package, visually assessing plots of the residuals (Therneau 2024).

We built five models (Table 1) based on our hypotheses, aiming to identify variables (Table 2) that may impact nest survival of our target species. We included site and species as random effects variables in all models to account for the fact that our studied sampling locations were nested within sites and that the species may respond differently. Our chosen explanatory variables were regressed against the number of days the nests survived. This generated hazard ratios for nest failures over time. Hazard ratios indicate the probability that an event of interest will occur, in our case, these events were nest failures. For our seasonality model, we chose to use the day of year when each nest was initiated, as we included nests that failed before egg laying.

Table 1. Our built models with their explanatory variables used in Cox proportional hazards modelling of avian nest survival in Montreal urban forests. The response variable for all models was the time to nest failure. Random effects of site and species are included.

Model Name	Hypothesis	Explanatories
Human Impact	The proximity of nests to trails and the average human activity around nests strongly influences nest survival.	Distance to Trail + Human Activity Indices + (1|Species) + (1|Site)
Vegetation	The vegetative cover, the height, and the density of stems surrounding nests strongly influences nest survival	Vegetation Concealment + Nest Height + # Small Stems/Ha + (1|Species) + (1|Site)
Seasonality	Seasonality, quantified by the day of year when nest building was first initiated, strongly influences nest survival	Initiation Date + (1|Species) + (1|Site)
Global		Distance to Trail (m) + Human Activity Indices + Vegetation Concealment + Nest Height + # Small Stems/Ha + Initiation Date + (1|Species) + (1|Site)
Null		(1|Species) + (1|Site)

We fit models using the coxme() function from the Coxme (Therneau 2012) and survival (Therneau 2024) packages in RStudio 4.3.2 (R Core Team 2023). We used the corrected Akaike's information criterion (AICc), the widely used maximum-likelihood estimator, to assess the most parsimonious and predictive model (Table 4) (Lebreton et al. 1992).

2.7 *Number of Active Days Analyses*

For nests that failed, we used a multivariate linear regression model to assess the impacts of human presence variables (distance to trail, human activity index, and site), seasonality (day of year) and concealment variables (coverage, canopy cover, vertical complexity, density of surrounding vegetation). Analysis was done with packages lme4 (Bates et al. 2015) and lmerTest

(Kuznetsova et al. 2017), and visualization was done with ggplot2 (Wickham 2016). Our resulting mixed model is the following:

Active days ~ concealment + canopy cover + vertical complexity + 1m vegetation density + distance to trail + human activity + day of year failed + (1|site) + (1|species)

3. Results

3.1 *Nest survival of target species*

We found and monitored 93 nests of our target species across three urban sites until failure or success. A nest was considered successful if at least one nestling successfully fledged. Four nests were removed from the analysis as they were determined to be outside site boundaries. An additional two nests were removed as we could not access them for proper monitoring, so their fates were unknown. This resulted in a final sample size of 87 nests (Appendix C & D). For all four target species and across all three sites, we found an overall apparent nest success rate of 24.1%. American robins had the highest modelled nest survival estimate, followed by yellow warblers, gray catbirds, and Northern cardinals had the lowest modelled nest survival estimate (Table 3).

Table 2. Summary statistics for variables measured and used in this study of bird nest survival (American robins, gray catbirds, Northern cardinals, and yellow warblers) in Montreal, Canada.

Variable	Range	Median	Mean (+/- SD)
Distance to Trail (m)	0.10 – 110.00	5.20	15.63 (+/- 22.46)
Vegetative Concealment	0.00 – 6.00	2.19	2.22 (+/- 1.30)
Human Activity	4.16×10^{-4} – 0.05	4.53×10^{-3}	0.01 (+/- 0.01)
Initiation Date (DOY)	1.00 – 58.00	34.50	32.17 (+/- 14.67)
Canopy Cover	0.06 – 45.53	1.84	6.22 (+/- 11.53)
Vegetation Density (1m from nest)	0.00 – 3.18×10^5	1.59×10^4	2.66×10^4 (+/- 4.81×10^4)
Vertical Complexity	1.00 – 3.00	2.00	2.09 (+/- 0.71)

Table 3. Daily survival rates estimated, standard errors (SE) and the percentage of successful nests for American robins (n = 32), gray catbirds (n = 11), Northern cardinals (n = 23), and yellow warblers (n = 23) using the RMARK program.

Species	DSR	SE	Modelled Nest Success
American robins	0.94	0.01	11.5%
Gray catbirds	0.89	0.04	2.4%
Northern cardinals	0.82	0.05	0.03%
Yellow warblers	0.90	0.03	3.8%

Kaplan-Meier survival estimate curves show the probability something will survive through time. We observed steep decreases in nest survival probabilities during the first half of the nesting period, and more graduate declines in the second half of the period (Figure 1). These patterns were consistent across all four target species.

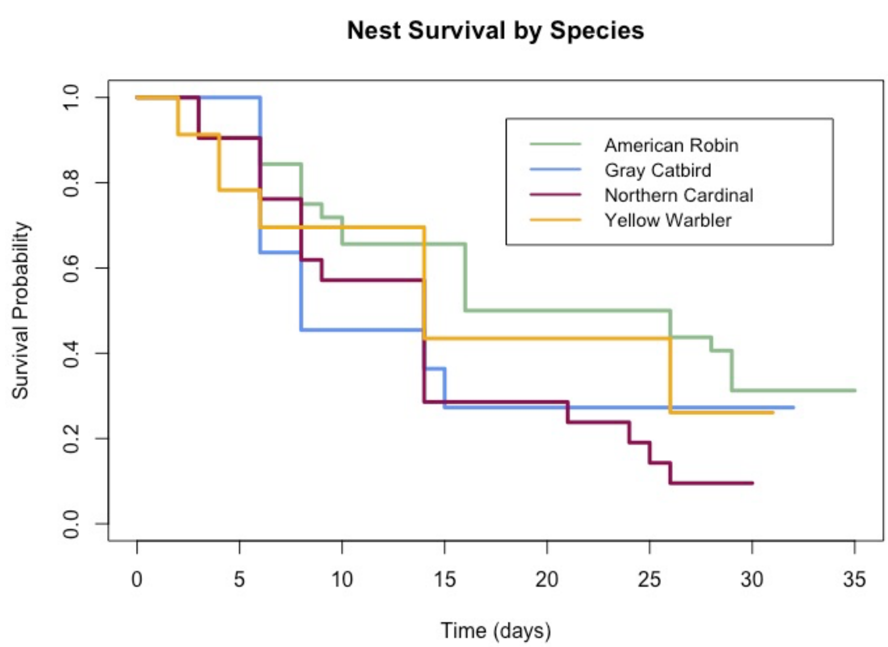

Figure 1. Kaplan-Meier survival curve displaying the survival probability of our four target species: American robins, gray catbirds, Northern cardinals, and yellow warblers across three urban forested sites in Montreal over time.

We built our Cox proportional hazard models and then ranked their fit based on AICc, providing us with measurements of how well our hypothesized models fit our nest survival data (Table 4). None of our models differed enough to classify any one of them as more or less parsimonious than others (Appendix E & F).

Table 4. Results from candidate models predicting nest survival of American robins, gray catbirds, Northern cardinals, and yellow warblers in three urban forests of Montreal. Each model is named based on its predictors. The number of parameters (k), the corrected delta AIC (AICc), and the fitted Log-Likelihood are reported for each model.

Model	Variables	*k*	ΔAICc	loglik
Seasonality	Nest Initiation date	3	0	-225.86
Null	N/A	2	0.2	-226.75
Human Influence	Distance of nest from trail + Mean human activity index	4	3.6	-226.65
Vegetation	Number of small stems/hectare + nest height + vegetation concealment	5	5.3	-226.38
Global	Number of small stems/hectare + nest height + vegetation concealment + distance of nest from trail + mean human activity indices + calendar date	8	9	-225.37

3.2 *Determinates of number of active days in failed nests*

Human presence (distance to trail) and concealment (concealment, canopy cover, vertical complexity, and vegetative density) did not have significant effects on the number of active days. These effects were similar across site (random effect variance 0.00). Seasonality (day of year) was the only explanatory variable to significantly predict the number of active days (β: -0.09, 95% CI: 0.24 – 0.76) prior to a nest failing, with nests that were active earlier in the season failing faster (i.e., less active days before failure).

Discussion

We asked whether the presence of humans, nest patch vegetation, and seasonality in urban greenspaces with varying degrees of human activity on the Island of Montreal predicted the nest survival of four common species of open-cup nesting passerines. For nests that failed, we explored whether these same variables predicted the number of active days nests had before failure. Surprisingly, we found that none of the chosen predictors, including human activity and distance to trails, significantly explained variations in nest success, despite varying values of the predictors across nests and sites. Through linear mixed modelling, seasonality was the best predictor of a nest's number of active days before failure. Nests that were active earlier in our study period failed within fewer days whereas nests that were active later in our study period were active for a longer period of time. These urban greenspaces were thus found to accommodate human use without compromising nest success.

Studies looking at modelled nest survival of various bird species in urban landscapes have found varying results. One study in Costa Rica found that survival in the clay-coloured thrush (*Turdus grayi*) was reduced in urban environments due to the presence of brightly coloured artificial materials in their nests that attracted predators to their nests (Corrales-Moya et al. 2023). Another study of shrub nesting birds in Hungary found that modelled nest survival was higher in urban areas compared to rural areas, but it was looking at artificially built nests (Kurucz et al. 2021). Another in the northeastern US investigated modelled nest survival through a lens of predation and included three of four of the target species we used: gray catbirds, northern cardinals, and American robins. They found modelled nest survival of American robins and gray catbirds to be higher in urban areas compared to rural areas, but they did not specifically incorporate human activity in their modelling, instead looking at a gradient of urbanization (Ryder et al. 2010).

Our four target species had low rates of modelled nest survival compared to previous studies of these species in both urban and wild greenspaces. Studies in residential and urban areas found that American robin nests had modelled nest survival rates between 1 and 42 %, depending on the presence of predators (Yen et al., 1996, Malpass et al. 2016). In more forested, natural sites, American robins have been found to have modelled nest success of 43 % (Duguay et al. 2001). Gray catbirds are modelled to have nest survival around 40 – 50 % in both urban areas and more forested habitats (Peak et al. 2004; Piergallini & Yahner 2001; Ryder et al. 2010). Modelled nest survival for yellow warblers in natural forest settings is reported to be around 30 – 50 % (Humple & Burnett 2010; Briske 1995), but can be as low as 10 % in urban or suburban areas (Strusis-Timmer 2009). Cardinals have been found to have lower rates of modelled nest survival in both natural forests (15 %) and urban forests (15-25 %) (Filliater et al. 1994; Smith-Castro & Rodewald 2010a; Billerman et al. 2022). Our survival rates were much lower than most of these modelled survival rates (Table 3), which could be showing these sites are not high-quality habitat for these species in general.

Contrary to our prediction that nests exposed to higher human activity would experience higher rates of abandonment or predation, we did not find a significant effect of human presence on predicted nest survival. There are a couple of alternative explanations that may explain this finding. Firstly, wildlife in urban spaces may become more tolerant of human presence as time progresses. For example, recent research has found that birds in urban spaces have been less fearful of humans following the COVID-19 pandemic (Diamant et al. 2023). Our target species are also known to be common in urban spaces, meaning that they likely have higher tolerances to human presence and activity. Secondly, a hypothesis known as the "human shield hypothesis" has been proposed in which we may observe an increase in wildlife population abundances due to a decrease in predators (Geffroy et al. 2015; Møller 2012; Valcarcel and Fernández-Juricic 2009). Recent literature has suggested that human presence is positively related to an increase in bird songs and vocalizations, and authors posited that the human shield hypothesis could be the driver (Pérez-González et al. 2024). Perhaps a reduction in predation and habituation to city life could explain the lack of sensitivity to human disturbance we found.

In contrast to previous studies that suggest nest patch vegetation is influential in nest survival, it was not a significant predictor of nest survival in our study area. Perhaps there are vegetative drivers at play that we did not measure. For example, the amount of suitable nest habitat area within a greenspace, or the amount of green land cover surrounding each of our sites. Nest survival in ground-nesting species has been shown to increase with an increase in suitable nest habitat for multiple species (Webb et al. 2012; Simonsen & Fontaine 2016), with the amount of greenspace in the matrix around sites also increasing rates of nest success (Simonsen & Fontaine 2016).

While seasonality was not a significant predictor of nest survival, our seasonality model performed marginally better than the others, indicating that seasonality may influence nest survival in our study area. We found that our target species nesting in urban greenspaces are more likely to experience nest failure earlier in the season and most nests are likely to fail before the fifteenth day of the nesting period, regardless of site (Figure 1). We can also observe that for our four target species, nest failure rates were steepest in the first two weeks of the nesting period, which correspond to nest building, egg laying and early incubation periods (Figure 1). These periods are when nests are most vulnerable. Birds are more likely to abandon nests before their nestlings hatch – at which point they have invested a lot of energy into their nesting attempt and are less likely to abandon (Verboven & Tinbergen 2002). Furthermore, the incubation period is when nest predation events are known to be most common (Roper & Goldstein 1997; Farnsworth & Simons 1999).

Birds attempting to nest early in the season encounter several challenges that could explain our results. Key hazards to their survival earlier in the nesting season are lower temperatures, decreased food availability, and shorter days (Dunn 2004; Germain et al. 2015; Nager 2006). Producing and incubating eggs is an extremely costly task for the parents, and maintaining an optimal temperature for both their survival and proper embryo development is more difficult in the colder temperatures of the early nesting season (D'Alba et al. 2009; Kim & Monaghan 2006; Nager 2006). Additionally, birds learn from past nesting attempts and can even acquire knowledge on how to best build nests from more experienced adults (Guillette et al. 2016). And lastly, earlier in the nesting season the vegetation is just starting to leaf out, so nests will have less concealment from predators and are easier to find (Ringelman & Skaggs 2019). These factors likely contributed to the lower number of active days experienced by early-season failures and to seasonality being the best predictor of overall nest survival.

A few limitations may have influenced our results. While the study sites varied widely in their access, management, and levels of human activities, they were all larger, more 'natural' greenspaces. Future research could include areas with even greater human activity, as human influence might become more influential in such areas. There may be a threshold of tolerance or a point at which higher rates of human activity become harmful to nest survival. We also (for logistical reasons) targeted four species that were known to commonly nest in these areas, and as such may be species predisposed to be adaptive to human presence. Other rarer species may indeed be more sensitive to disturbance than the target species of this study, as it was recently shown that 78 % of bird species do not tolerate high human-dominant environments (Marjakangas et al. 2024).

Within the context of the study's caveats, generally our findings suggest that human activity and the presence of trails used for human recreation are not negatively impacting the nesting success for our target bird species using urban greenspaces. This may tentatively suggest that urban greenspaces can provide recreational activity and connection to nature for people without additional negative effects for common nesting birds. Land managers, such as municipal governments, have a great need for such integrated science advice that meets their desire to understand multiple goals of managing urban greenspaces. Future research that continues to improve our understanding of synergies and trade-offs between connecting people with natural spaces and human-wildlife interactions is useful in guiding both place-based management and general best practices and policies.

Chapter 2

Title: Proximity to trails in urban greenspaces related to variation in avian communities and diversity

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Statement of Ethics Compliance

All details of animal monitoring were approved by Concordia University's Animal Care Facility (Protocol no. 30017925) and by The Canadian Wildlife Service (Permit no. SC-98).

Keywords: Recreational trail-use, avian diversity, urban ecology

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Abstract

We conducted a field study on bird communities in May through early August 2023 in four urban greenspaces in Montreal, Quebec, the second largest city in Canada. We asked if there was a relationship between the presence of trails and human activity (quantified by the number of trail users per hour) and avian species richness and diversity in urban greenspaces, and whether bird communities close to (< 25 m) and far from (> 25 m) trails differed. We also explored if patterns of bird diversity and composition differed between informal and formal urban greenspaces (management status). We anticipated bird communities far from trails in informal urban greenspaces would be the most diverse and rich in species. Using generalized linear models, paired t-tests, and ordinations, we found no evidence to support a significant relationship between three of our predictor variables (human activity, stem density, greenspace management status) and avian species richness or diversity. However, we did find significant positive relationships between the proximity to trails (< 25 m. vs > 25 m) and both avian species richness and diversity. We also compared bird communities close and far from trails in informal and formal urban greenspaces, and found that in informal urban greenspaces, communities close and far from trails are more similar than in formal urban greenspaces. Our results suggest that bird communities are shaped more by the structural presence of trails rather than the number of people using them, within our study system. Possible management outcomes from this work are two-fold: (1) recognizing that trail presence in forested greenspaces provides a novel habitat structure (e.g., shrubby edges) that leads to unique species assemblages and (2) that high traffic but low-density trail network in greenspaces would allow for human recreation as well as limit disturbance to more sensitive, inner forest species in these areas.

1. Introduction

Urban greenspaces in cities aim to conserve declining biodiversity and allow people to connect with nature and wildlife, often difficult to access in cities. Urban greenspaces may include forest fragments, parks, and other natural spaces in cities that provide services to humans and benefits to wildlife (Taylor & Hochuli 2017, Semeraro et al. 2021). Spending time in urban greenspaces can contribute to human health and mental well-being, for example by reducing heart rate and stress, and improving attention span (Kondo et al. 2018, Hedblom et al. 2019). Urban greenspaces also contribute to biodiversity conservation, providing both transient and resident wildlife species with resources such as areas to raise young, shelter, and food (Aronson et al. 2017, Threlfall et al. 2017). As a highly vagile group, birds are often supported by urban greenspaces throughout their annual cycle. As such, avian diversity and richness are often used as indicators of habitat quality (Sandström et al. 2006, Peris & Montelongo 2014, Nielsen et al. 2014). Birds are well known to make use of urban greenspaces both during their breeding and non-breeding periods (Leveau et al. 2022, Chyb et al. 2021). Migratory birds use urban greenspaces as stopover sites along their migration routes where they critically serve to replenish energy stores (Schmaljohann et al. 2022, Tryjanowski et al. 2013, Poirier et al. 2023). As urban greenspaces are valuable to humans and birds, it is important to implement management strategies that support both.

The presence of people in urban greenspaces has been found to impact both the diversity and abundance of birds (Bötsch et al. 2018; Jokimäki 1999; Kangas et al. 2010; Lepczyk et al. 2008; Van der Zande et al. 1984). For example, some studies have shown a negative correlation between bird species richness, bird density, and human presence (Peña et al. 2022; Bötsch et al. 2018). Human activity and nature-based recreation can impair nest survival and nestling development (Beale & Monaghan 2004, Remacha et al. 2016). For instance, a study on seabirds in an oceanside park found a significant negative effect of the number of park trail users on nest success (Beale & Monaghan 2004). Birds can also display behavioural changes in response to nature-based recreation, including a significant reduction in foraging time (Thomas et al. 2003). However, not all studies find a negative impact, some indicate that the relationship between human recreation and birds is more nuanced. For example, one study found no evidence to suggest that human activity is a predictor of urban nest survival (Chapter 1). Another paper found an increase in the diversity of bird vocalizations during a peak period of tourism in a national park, and surprisingly no negative association between the presence of people and bioacoustics indices of biodiversity (Pérez-González et al. 2024). Further research is needed to better understand the impact of human activity on bird diversity.

While many studies focus on impacts on richness and abundance, human presence and recreation can also influence bird community composition. Some bird species tolerate human presence and recreation better than others. One study found that 22 % of over six thousand global bird species can tolerate highly urbanized areas (Marjakangas et al. 2024). Smaller bird species with broad dietary and habitat niches, larger clutch sizes and longevity, greater dispersal abilities, lower elevational limits, and less territorial are more likely to have higher human tolerance (Neate-Clegg et al. 2023, Samia et al. 2015). Some examples include Northern cardinals (*Cardinalis cardinalis*), often found in high densities in urban forests (Leston & Rodewald 2006), European blackbirds (*Turdus merula*), more often found in urban settings than suburban or rural areas (Kurucz et al. 2021), and house finches (*Haemorhous mexicanus*), known to be adaptable to urban environments and take advantage of resources from humans (Issakson 2018). On the other hand, many species do not tolerate highly urbanized areas. Some examples are various species of woodpeckers (Myczko et al. 2014), wood thrushes (Heide et al. 2023), and Canada warblers (Wilson et al. 2018). It is important to consider greenspace management strategies that can help better support all bird species and provide them with suitable habitat.

The management and design of urban greenspaces can be an important factor in both bird species richness and the amount of contact between humans and birds. Urban greenspaces can be classified in many ways, and one method is to categorize them based on management status. 'Formal' urban greenspaces are publicly accessible, officially designated for recreational use, and can be managed for variable goals. For example, city parks are considered formal greenspaces (Taylor & Hochuli 2017, Feltynowski et al. 2018). They are often landscaped for aesthetic purposes and typically include large networks of trails that are well-maintained (Bedimo-Rung 2005, Monz et al. 2013, Seaman et al. 2010, Kabisch et al. 2013, Jim & Chen 2006, Chiesura 2004). Formal greenspaces will often have large open spaces of mowed lawns and exotic vegetation planted based on aesthetic preferences, and these characteristics are associated with low native wildlife diversity (Watson et al. 2019, Hostetler & Main 2010). However, when well-planned for biodiversity conservation, formal urban greenspaces can both support a large diversity of birds and meet park users' aesthetic preferences (Vasquez & Wood 2022, Tribot et al. 2018, Vasquez & Wood 2022, Nielsen et al. 2014). For example, city nature parks are formally managed greenspaces, and they are planned with shared goals of recreation and conserving nature. Features of urban greenspaces that help to support birds include a large total area (Chamberlain et al. 2007, Huang et al. 2022, Callaghan et al. 2018), a high diversity of ground vegetation (Luther et al. 2008, Huang et al. 2014), and diverse vegetation structure (Xie et al. 2016). There is a need for studies that contrast and compare bird diversity and community composition in informal and formal urban greenspaces, as this would help urban greenspace managers make decisions on the level of management to best support a high diversity of birds.

While most studies assessing urban biodiversity consider formal greenspace, 'informal' greenspaces play an underappreciated role in both biodiversity conservation and recreation. Informal urban greenspaces encompass a variety of green cover types, including fragmented woodlands, abandoned lots, brownfields, and areas of spontaneous vegetation (Biernacka et al. 2023, Rupprecht & Byrne 2014, Kattwinkel et al. 2011). There are many descriptions and definitions of informal greenspaces (Biernacka et al. 2023, Rupprecht & Byrne 2014), and here, we define them as sites with limited management for recreation or official designation (Kim et al. 2018, Watson et al. 2023, Rupprecht & Byrne 2014). Informal greenspaces can support local people and their needs, as they are dynamic and used for many purposes—including recreation, urban agriculture, physical exercise, and social interactions (Rupprecht & Byrne 2014). They also have the potential to reduce historic unequal distribution of green cover in cities (Sikorska et al.2020). Areas in cities home to low-income and equity-deserving communities often have few parks, whereas wealthier and primarily white areas have higher access to parks and greenspace (Crouse et al. 2017, Rigolon 2016, Boone et al. 2009, Curran & Hamilton 2009). Leaving existing undeveloped spaces and lots to 're-wild' in areas where green cover is low could start to address historic injustice (Rupprecht & Byrne 2017, Sikorska et al.2020).

Formal and informal greenspaces differ in their management, physical structure, and access. Most often, there are park regulations that park-users must adhere to when entering a park; including prohibition of hunting or poaching, staying on the trail, keeping dogs leashed, and properly disposing of garbage (Parks Canada 2022). In addition to designated park staff, social norms help to enforce some of these regulations. For instance, a survey revealed a strong consensus among park visitors that there is a social obligation to never litter when visiting parks (Murdock & Heywood 2002). In some instances, informal greenspaces may have regulations, but unlike formal greenspaces, there are no designated staff or official park patrols to enforce them (Burns & Schintz 2000). This lack of formal governance has made some people wary of these spaces, and there are reported concerns of crime, safety, and littering or garbage dumping in informal greenspaces (Farahani & Maller 2019, Rupprecht 2017). Other people enjoy the lack of regulations and naturalness of these spaces, as there is more flexibility in use, and promote a stronger sense of connection to nature (Farahani & Maller 2019, Rupprecht 2017). Comparing the structure of urban greenspaces, formal greenspaces often have large, paved or gravel trails for recreation, trail maps, and signage. Trails also exist in informal greenspaces, but these can be smaller and underdeveloped (Watson et al. 2023). Trails might be maintained by community groups in some cases, but users will also create informal footpaths (Gawryszewska et al. 2024). Most studies suggest a negative influence of trails on wildlife (Steven et al. 2011, Larson et al. 2016, Westekemper et al. 2018).

Birds are well known to make use of urban greenspaces both during their breeding and non-breeding periods (Leveau et al. 2022, Chyb et al. 2021). Features of urban greenspaces that help to support birds include a large total area (Chamberlain et al. 2007, Huang et al. 2022, Callaghan et al. 2018), a high diversity of ground vegetation (Luther et al. 2008, Huang et al. 2014), and diverse vegetation structure (Xie et al. 2016). Migratory birds also use urban greenspaces as stopover sites along their migration routes where they critically serve to replenish energy stores (Schmaljohann et al. 2022, Tryjanowski et al. 2013, Poirier et al. 2023). As such, avian diversity and richness are often used as indicators of habitat quality (Sandström et al. 2006, Peris & Montelongo 2014, Nielsen et al. 2014). As urban greenspaces are valuable to humans and birds, it is important to implement management strategies that support both. Research has focused on informal and formal greenspaces separately, and very few studies have compared bird communities and diversity between the two (Rupprecht et al. 2015). One recent study in South America found that informal greenspaces support a different community of birds than urban parks. They found that informal greenspaces maintain mostly native species, including some rare species not often found in cities (Villaseñor et al. 2022). This is because informal greenspaces often include abundant and diverse shrubby vegetation and trees, and this explicitly supports urban bird diversity (Rega-Brodsky et al. 2018, Paker et al. 2014).

Other than differences in vegetation diversity and structure between formally and informally managed greenspaces, the physical structure of sites and the access it provides to people may influence the number and kind of species of birds present in these spaces. Trails create habitat fragmentation and allow novel predators, such as house cats, easier access to birds (Primack & Terry 2021, Miller & Hobbs 2000, Miller et al. 1998). A review of the impact of recreation on birds suggests that even low-impact activities, such as walking, can have repercussions on bird physiology, behaviour, and reproduction (Steven et al. 2011). However, some literature suggests that edge habitat created by trails increases bird diversity as it attracts shrub-nesting species (Miller et al. 1998). None of the studies in this review compared the impact of recreation on bird communities in informal versus formal urban greenspaces (Steven et al. 2011). This could provide insight into the management strategies needed to conserve bird diversity.

Trail presence may influence wildlife, but the distance from trails to birds in greenspaces could shape their community structure as well. A study on breeding birds in an area of land reserved for recreation and wildlife near the city of Boulder in the US, found a difference between bird communities close and far from trails, stating that habitat generalists occurred more often closer to trails (Miller et al. 1998). They suggest that the threshold of tolerance to human activity for bird species found the furthest from trails is around 75 m (Miller et al. 1998). However, they did not include a measure of human activity on trails, i.e., the number of people using the trails. A similar study in urban and natural forests found a lower density and species richness of birds close to trails in urban sites with a high level of human recreation. Furthermore, they did not detect a difference between points close and far from trails in natural forest sites with lower human recreation (Bötsch et al. 2018).

Our study aimed to assess how the presence of trails and human activity are related to bird species richness, diversity, and composition in both formally and informally managed urban greenspaces. Conducted through an observational study in Montreal, Quebec, Canada, we asked whether urban bird diversity and community composition vary with proximity to trails and whether trail user density or vegetation density influences these patterns, as well as whether results are consistent across both formal and informal urban greenspaces.

We hypothesize that informally managed urban greenspaces would have higher bird species richness and diversity compared to formally managed urban greenspaces, as recent literature suggests that these spaces are biodiversity hotspots (Sikorski et al. 2021, Villaseñor et al. 2022). We hypothesized that bird species richness and diversity are influenced most by (1) vegetative structure at sites or (2) driven by the average number of trail users at sites. We predict that bird species richness and diversity would be higher at transects that have denser, shrubby vegetation. The presence of shrubs and the diversity of vegetation structure has previously been shown to influence bird species richness in both natural and urban spaces (Yang et al. 2020, Campos-Silva & Piratelli 2021, Dagan & Izhaki 2019). We predict that bird species richness and diversity would also be higher at transects with a lower number of trail users, as humans could disturb more sensitive bird species (Bötsch et al. 2018, Kangas et al. 2010, Lepczyk et al. 2008). Lastly, we hypothesize that informally managed greenspaces would have more homogeneity between close and far bird communities, compared to formally managed greenspaces. This is because we expect that informal greenspaces would have a lower number of trail users and a higher density of vegetation. We also expect that the types of management practices that occur within formal greenspaces would not occur in informal spaces, and some of these practices could be unfavourable to sensitive bird species but more favourable to generalist species (Drapeau et al. 2009, Aszalós et al. 2020). For example, parks (formal greenspaces) tend to remove dead wood as it can pose a hazard for trail users, and dead wood is known to support a large diversity of birds, including some endangered and rare species (Bujoczek et al. 2021). In contrast, informal greenspaces often do not have intensive management that removes dead wood, thus they would support species that rely on dead wood.

2. Methods

2.1 *Study Sites*

The island of Montreal is in the St. Lawrence Lowlands of Southern Quebec, and Montreal is Canada's second-largest city. The Island of Montreal is 498.29 km^2 in area and has a population density of 4022.3 people/km^2 (Government of Canada 2022). Montreal hosts a variety of habitats, including woodlands, wetlands, and shoreline habitats. The area is home to many species of birds, and others use greenspace on the Island during migration stopovers. We conducted our field study towards the western side of the Island of Montreal in four sites: Bois-de-Liesse Nature Park, Technoparc, the Morgan Arboretum, and Stoneycroft Wildlife Area, which were selected to represent a gradient of human activity and were spatially paired based on formality of management, two formal and two informal. The parks differ in total area and are predominantly forested.

Bois-de-Liesse (formal) is a high visitation park formally managed by the city of Montreal. It is used widely by cyclists, runners, and dog walkers, as well as for recreational activities such as picnics and school day trips. The Morgan Arboretum (formal) is a large forest reserve that functions as both a recreational park and for teaching and research purposes, as it is owned and formally managed by McGill University. It is used by local dog walkers, McGill field courses, and at times used a movie location for filming. Technoparc (informal) is a large greenspace that includes newly acquired city land yet to be managed for recreation, and privately owned land prized for development. The area is informally managed by a not-for-profit organization and is used primarily by birders and nature photographers. Stoneycroft Wildlife Area (informal) is a private research area restricted to the public and is also owned by McGill University, adjacent to the Morgan Arboretum. It hosts a small field station that is active for four months per year and is managed informally by a not-for-profit. We conducted our human activity surveys and walking point count surveys along four trail stretches of 200 m at each of our four sites, including an even mix of small footpaths and larger, more heavily trafficked trails.

2.2 *Human Activity Surveys*

We assessed human activity by walking our selected trail stretches of 200 m at each site and counting each individual or group that we passed. Most surveys were conducted between 8 and 10 minutes, but the total time each survey took was recorded to account for observation effort. We counted people who passed us while walking and collected data on any high-risk behaviours to birds that people might have been engaging in, including allowing their dog(s) off-leash, walking off the trail, and yelling. We conducted surveys between May and August, conducting at least one survey per month on a weekday, and at least one survey per month on a weekend, excluding holidays. With these data, we averaged the number of trail users for each trail, which gave us a measure of human activity.

2.3 *Vegetation Surveys*

We conducted vegetation surveys at two spatial scales at each trail: Gentry surveys, also known as “narrow belt transect surveys” and quadrat surveys (Gentry 1988)(Appendix A). We conducted three quadrat surveys along each Gentry transect, one at the start of the transect, starting at the trail edge and extending into the transect, one at the 25 m point of the transect, and one at the end of the transect at 50 m (Appendix A). Our quadrat surveys were 2 m x 2 m in area and were conducted to assess vegetation density present near the trails selected in our study. Within each quadrat, we counted the number of woody stems per each unique species present and tallied the number of stems present based on size classes (< 1 cm, 1-3 cm, 3-6 cm, and 6-9 cm DBH). In total, we conducted 192 quadrat surveys.

2.4 *Breeding Bird Surveys*

To assess bird species richness and diversity, we conducted a fixed-width line-transect surveys (Franzer 1981). Our method involved walking each of our four 200 m trail segments per site for ten minutes and identifying each bird species heard or seen during this time. We followed standard breeding bird survey protocols, with all surveys occurring between sunrise and 9:00, in satisfactory weather conditions (good visibility, little to no precipitation, little to no wind), and performed by trained ornithologists (BF and AM). We counted birds present in fixed-width belts on either side of the trail in bands of 0 – 25m, 25 – 50 m, and > 50m, with birds flying by overhead recorded separately. Each transect was surveyed twice, once during the early breeding period (May) and again in the later breeding period (June), with detections from both visits being pooled and retaining the highest count of the two visits for each species.

2.5 *Statistical Analyses*

We calculated bird species richness and Shannon diversity indices for each of our recreational trails. We first filtered the data to remove all flyovers and simplified our distance bands to have a 'close' to trail dataset (0 – 25 m) as well as a 'far' to trail dataset, where we summed the 25 – 50 m and > 50 m distance bands. Then, as we aimed to compare primarily forested habitats, we removed a wetland-associated species (Red-winged Blackbird; *Agelaius phoeniceus*) that was highly vocal and present in wet margins near some of our paths). To test for differences between species richness and Shannon diversity in bird communities both far and close to trails, we used a paired t-test in R 4.3.2 (R Core Team 2023). For these two t-tests, we pooled data from both formal and informal sites. We also pooled data from close and far bird communities and conducted a t-test to test for differences between species richness and Shannon diversity in bird communities in sites with informal versus formal management status.

We used a linear modelling approach to test whether differences were influenced by vegetation structure, an interaction between the average number of trail users and distance from trails, or the greenspace type (formal vs informal). We included the interaction between the number of average people per hour and the distance from trail because we wanted to assess whether the impact of distance from trails on bird communities changed with different levels of human activity. The models were built as follows:

Shannon Diversity ~ Stem Density + Distance*Average Number of Trail Users/Hour + Management Style

Species Richness ~ Stem Density + Distance*Average Number of Trail Users/Hour + Management Style

We checked model assumptions through visual inspections of residual plots. We used a statistical significance level of $\alpha = 0.05$ to indicate strong support, and $\alpha = 0.1$ to indicate marginal support.

To further investigate these community differences, we created ordinations of species present close and far from trails using Bray-Curtis dissimilarity distances and a Non-metric Multidimensional Scaling (NMDS) approach in the vegan package of Program R (Oksanen et al., 2022). NMDS is an indirect gradient analysis approach, which produces an ordination where objects that are more similar to one another are ordinated closer together. We chose the NMDS method as our goal was to explore the relationship between the environmental/human variables and the species community grouping, as well as because the NMDS handles nonlinear and nonnormal response variables. We grouped bird communities by their distance from trails (close versus far) and created ordinations in our informal and formal urban greenspaces. We fit explanatory variables as vectors in the NMDS space: the average number of trail users per hour and the average stem density in plots near and far from the trail. The significance of these vectors was tested through permutation tests (n = 999).

3. Results

Across both informal urban greenspaces, we found a total of 41 bird species. Across the formal urban greenspaces, we found a total of 34 bird species (Appendix B). Our t-tests showed a significant positive difference between species richness ($p = < 0.001$) and Shannon diversity ($p = < 0.001$) in bird communities close and far from trails. Species richness and Shannon diversity increased further from trails. We found marginally significant differences in species richness between formally and informally managed sites ($p = 0.07$), and in Shannon diversity ($p = 0.08$) (Appendix C).

We found a statistically significant relationship between the distance from trail (close < 25 m and far > 25m) and species richness (Table 1) and Shannon diversity. None of the other variables in the linear model were statistically significant.

Table 1. Summary results from a linear model investigating the influence of management style (informal vs formal), the distance from trails (close vs far), the average number of people per hour, and the average stem densities on bird species richness in urban greenspaces of Montreal.

Predictor	**Coefficient (β)**	**Standard Error**	**t-value**	**p-value**
Management Style	0.01	0.11	0.08	0.94
Distance from Trail	0.50	0.18	2.80	< 0.01
Average Number of People / Hour	4.88×10^{-3}	0.01	0.56	0.58
Average Stem Density	-4.17×10^{-3}	0.01	-0.40	0.69
Distance from Trail: Average Number of People / Hour	-3.05×10^{-3}	0.01	-0.26	0.80

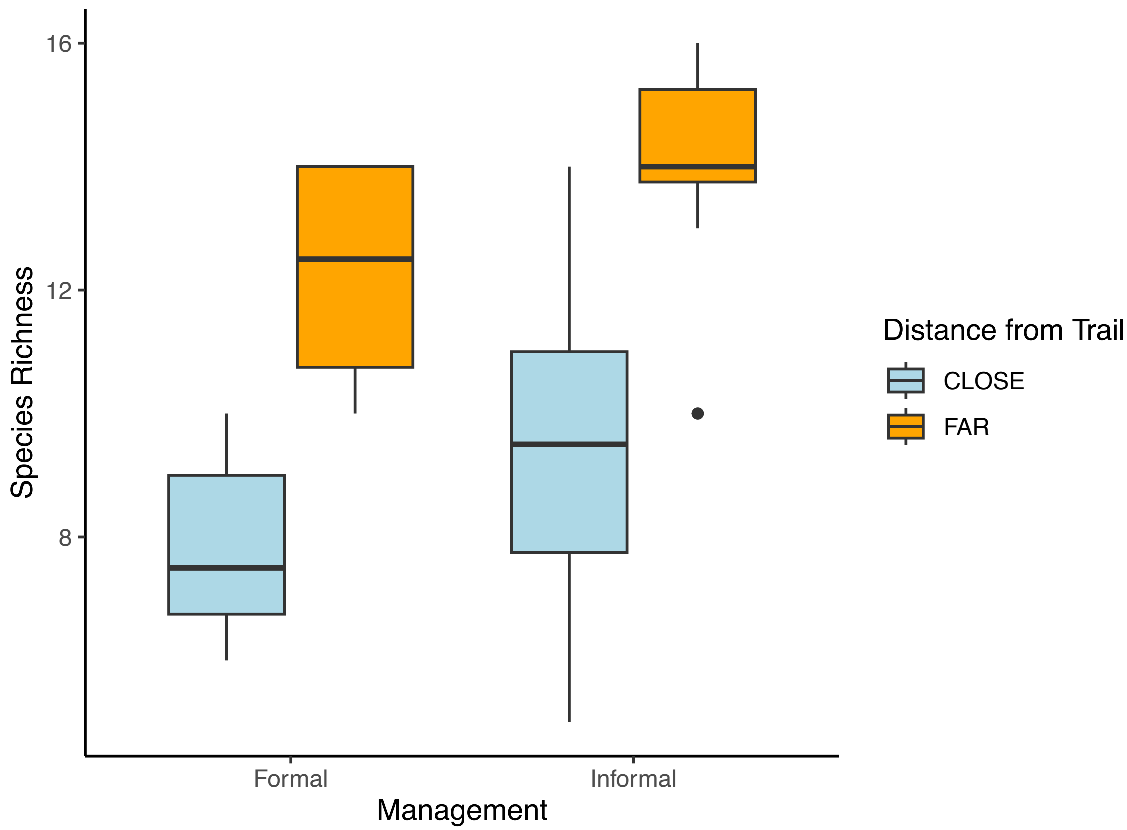

Figure 1. Bird species richness close and far from trails (coloured) between informally and formally managed urban greenspaces in Montreal.

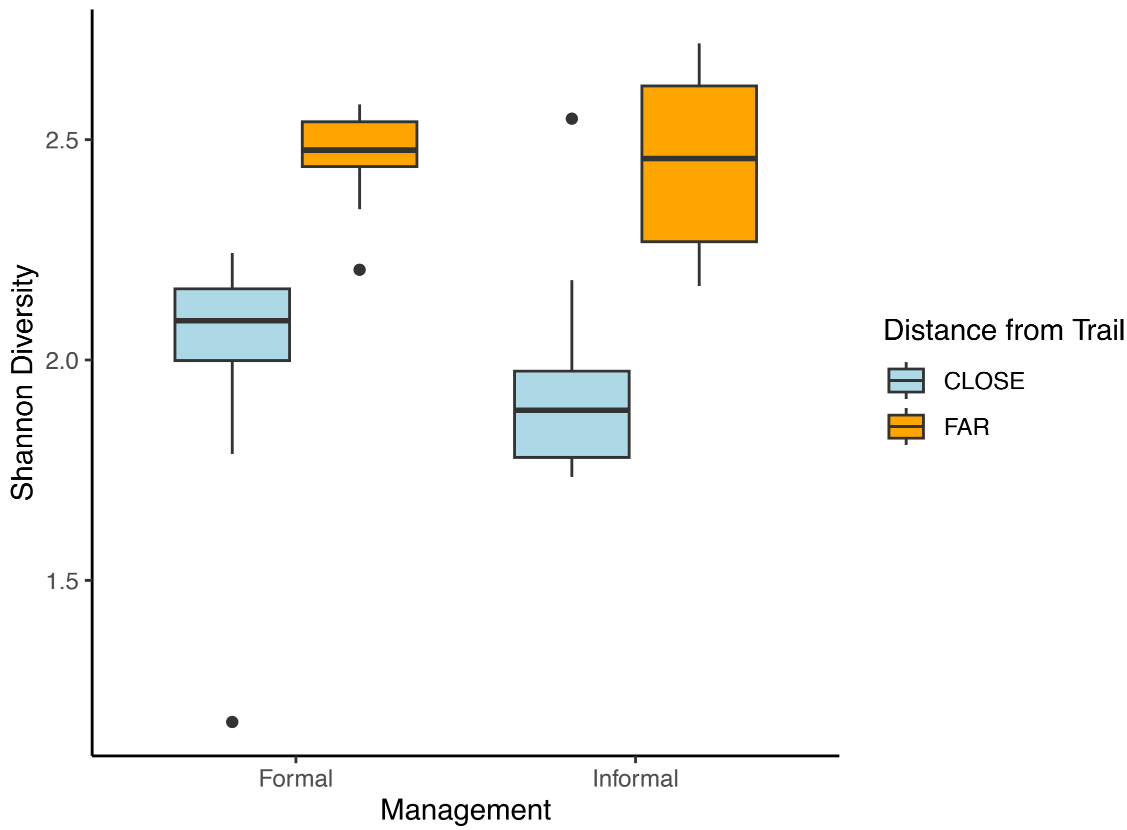

Figure 2. Bird Shannon diversity close and far from trails (coloured) between informally and formally managed urban greenspaces in Montreal.

The range in the average number of people per hour on trails in informal sites (0-19.20) was lower than in formal sites (0-25.95) (Appendix D). The average stem density in informal sites was higher (0.13-17.63) than in formal sites (0-11.63) (Appendix E). Through all human activity surveys, we recorded one instance of a dog present in informal sites, and it was off-leash. In formal sites, we recorded three instances of dogs on leash and eight instances of dogs off-leash. We also recorded four instances of people going off-trail, and all of these occurred in formal urban greenspaces.

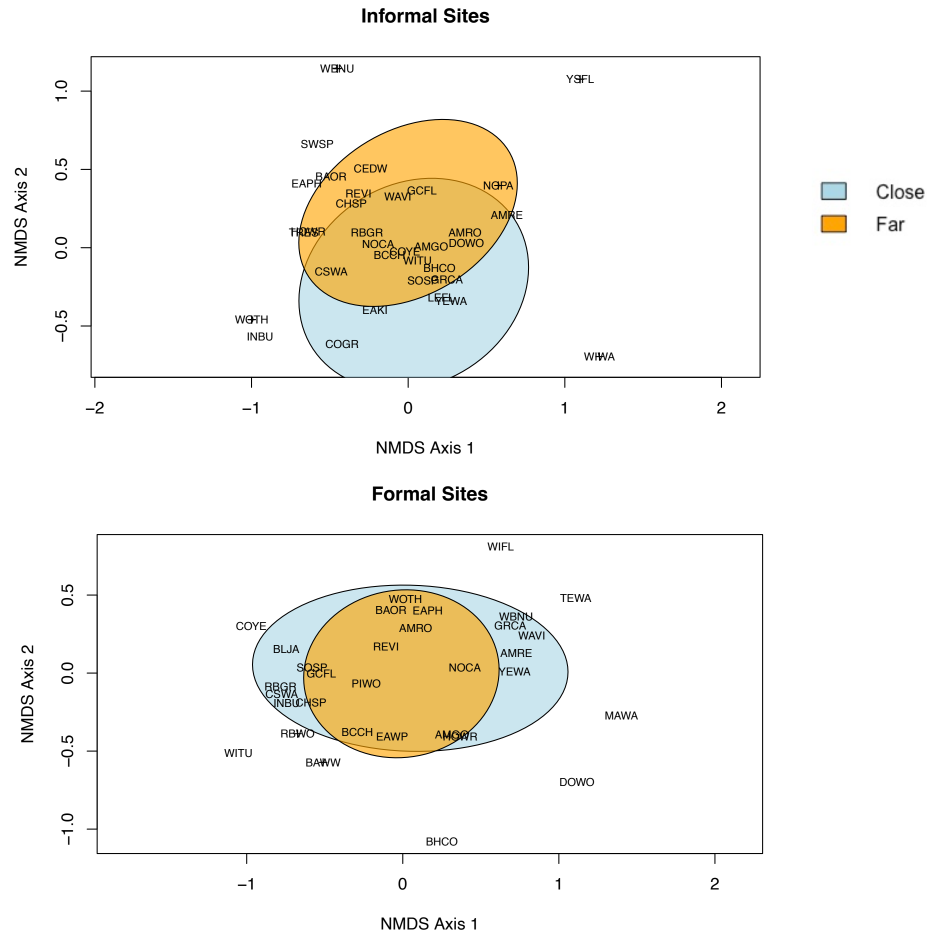

Figure 3. Non-metric Multidimensional Scaling (NMDS) ordination plots showing bird communities both far and close to trails in informal and formal urban greenspace sites in Montreal. The codes used represent different species. Stress values for formal and informal sites were 0.12 and 0.19 respectively.

We projected explanatory variables as vectors onto the NMDS ordination space. Neither of the two variables were significant. For our informal sites, stem density had a p-value of 0.80, and the average number of people per hour had a p-value of 0.24. For our formal sites, stem density had a p-value of 0.10, and the average number of people per hour had a p-value of 0.28.

4. Discussion

We asked if distance from trails, management style (formal vs informal), human activity, and/or vegetation density are related to bird species richness, diversity, and community composition in Montreal urban greenspaces. We found a significant relationship with proximity to trails, where species richness and Shannon diversity are higher > 25 m from trails compared to adjacent to trails (< 25 m). There was no significant relationship between management style and Shannon diversity or species richness from the linear models, based on the transect-level data. However, we did find that overall, there were more bird species present across the informal greenspaces compared to the formal greenspaces (42 vs 34 species) when the transect-level data was consolidated to the site-level (Figures 1 & 2). We found a marginally significant relationship based on t-tests to support this. Lastly, we did not find a significant relationship between human activity or vegetation density and both Shannon diversity and species richness at the transect-level. This suggests that in our study, the presence of trails more so than the number of people on those trails, is related to changes in bird diversity in urban greenspaces.

Our finding that proximity to trails is significantly related to diversity and species richness aligns with previous work and supports the idea that protecting and maintaining areas free of trails and potential human disturbance is beneficial for bird conservation. A study in two forested sites < 2 km from cities with high levels of recreational trail use found that bird species richness was significantly related to trail proximity. Bird communities near the trail (50 m from the trail) exhibited a 4 % decrease in species richness compared to bird communities further from trails, at 120 m (Bötsch et al. 2018). Although our distances were different than in this study, we too observed a decrease in both species richness and Shannon diversity closer to recreational trails (Figures 1 & 2). We suspect that this could be partly due to the presence of people on trails, as was the case in a previous study looking at bird species richness at points close (50 m) and far (120 m) from recreational trails (Bötsch et al. 2018). They concluded that it was the mere presence of humans on trails that explains the lower species richness close to trails; however, they did not measure human use or activity directly, and instead compared two highly used greenspace sites and two low-use recreational sites (Bötsch et al. 2018). We also expected that some aspects of vegetation would drive differences in Shannon diversity and species richness, as sites with higher vegetative complexity and density have been previously found to support a more diverse community of birds (Remeš et al. 2022, Yang et al. 2020, Xu et al. 2022, Campos-Silva & Piratelli 2021, Dagan & Izhaki 2019).

While bird species richness and Shannon diversity were significantly different between communities close and far from recreational trails, unexpectedly, neither woody stem density nor the average number of trail users were statistically significant in our models. As such, we did not find evidence to support our hypotheses that either vegetation density or human activity on trails would explain bird diversity or species richness. Our findings suggest that the number of trail users may not be harmful to bird communities, within the numbers present in our study system (Appendix E). It should be noted that we only included four urban greenspaces in our study, and they were not located in downtown Montreal. Had we included more intensively urbanized sites, we might have observed different patterns. Similar to our findings, a study in urban parks in China did not find a significant effect of the number of trail users on bird diversity. They suggest their finding could be due to abundant shrubby vegetation at their sites, which makes it more difficult for birds to see people, thereby reducing human-induced disturbance (Xu et al. 2022).

Our sites did have an abundance of shrubby vegetation close to trails, and vegetation density was much higher close to trails compared to points further from trails (Appendix D). A dense vegetative buffer along recreational trails could potentially mediate the impacts of human activity on birds. However, we did not find a significant relationship between woody vegetation density and bird diversity and species richness. It is possible that the number of woody stems we measured did not correspond with high vegetative concealment, and MacArthur & MacArthur argue that it is the density of *foliage* specifically that influences bird diversity (1961). The density of stems does not always correspond to the density of foliage. For example, in mature forests, taller trees with extensive canopies will shade smaller vegetation, and these smaller vegetation may allocate more resources into growing taller to compete for light instead of investing energy into leaf biomass (Zhang et al. 2012). As our sites all have some mature forest areas, this could be possible for some of our transects. Furthermore, it could be the complexity of vegetation that significantly influences bird species richness and Shannon diversity. Habitats with many layers of vegetation provide birds with more resources and can accommodate birds with varying needs (Moudrý et al. 2021, Davison et al. 2023). We did not measure vegetative complexity, but perhaps this would have influenced bird species richness and diversity.

The relationship between management (formal vs informal) and bird species richness and Shannon diversity was not significant from our models, as it considered transect level diversity. We also split species richness and diversity by close vs far, rather than looking at the species richness and diversity close and far combined. The liner model was measuring alpha diversity as it was analyzing the diversity within each transect and assessing how management status affects it at that level. Alpha diversity is diversity on a local level, such as diversity within a defined plot, or in our case, diversity within a transect (Andermann et al. 2022, Whittaker 1960). However, there are clear differences in both species richness and Shannon diversity in Figures 1 and 2 that were not captured by the linear model, and t-tests revealed marginal significance. This suggests that there are differences in beta and gamma diversity, looking at differences in species composition between transects with different management statues, and the overall diversity across all four sites. Beta diversity refers to the diversity that differentiates between communities, so in our case this would be diversity between all transects within a site. Lastly, gamma diversity is defined as the overall species diversity across all communities within a specific area and is a broader level of diversity. In our study, gamma diversity is looking at the informal sites as a whole, and formal sites as a whole (Berthon et al. 2021, Whittaker 1960).

We did anticipate that informal urban greenspaces might be higher in species richness and diversity, as these 'wilder' spaces have been found to harbour high levels of bird diversity (Villaseñor et al. 2022, Zuñiga-Palacios et al. 2020). Informal urban greenspaces are capable of supporting bird species known to be rare in cities as a result of their abundant shrubby vegetation (Villaseñor et al. 2022, Rega-Brodsky et al. 2018, Paker et al. 2014). Greenspaces with more intensive management practices, like formal parks, still have potential to host high levels of bird species richness and diversity, under the right conditions (Korányi et al. 2021). For example, older and larger formally managed parks can support a high diversity of birds in cities (Callaghan et al. 2018, Thompson et al. 2022). Even so, informal urban greenspaces still present novel habitat of high biodiversity value.

We found that communities close (< 25 m) and far (> 25 m) from trails in formal urban greenspaces were more distinct than in informal (Figure 3). Formal sites are more likely to have a clear separation between edge and interior forest habitat which would drive this separation, and the species observed in our ordinations reflect this. For example, in formal urban greenspaces, we see that shrub loving species are always found < 25 m from trails. These species include yellow warblers (*Setophaga petechia*), gray catbirds (*Dumetella carolinensis*), indigo buntings

(*Passerina cyanea*), and chestnut-sided warblers (*Setophaga pensylvanica*), all of whom are known to favour forest edge habitat (The Cornell Lab 2019). Several of these species are also bright and colourful, so finding them in edge habitat near trails provides people the opportunity to spot and enjoy avian wildlife. In formal sites, we also see a clear community of interior forest species found > 25 m from trails. The wood thrush (*Hylocichla mustelina*), red-eyed vireo (*Vireo olivaceus*), pileated woodpecker (*Dryocopus pileatus*), great crested flycatcher (*Myiarchus crinitus*), Eastern wood peewee (*Contopus virens*) are all characteristic of interior forest habitat (The Cornell Lab 2019). Additionally, the wood thrush and Eastern wood pee-wee are two species at-risk that are protected under Canada's Species at Risk Act (2002/2024).

In informal urban greenspaces, we see most of the same species found in formal sites, but we observe more overlap between bird communities > 25 m and < 25 m from trails, and a higher number of unique species (Figure 3). Species such as the American goldfinch (*Spinus tristis*), the chestnut-sided warbler, and the gray catbird, known as shrub-loving edge species, were found in both close (< 25 m) and far (> 25 m) bird communities. Forest interior species are also both found closer and further from trails, including the great-crested flycatcher, the downy woodpecker (*Picoides pubescens*), and the warbling vireo (*Vireo gilvus*). We also see unique species in informal urban greenspaces, including the least flycatcher (*Empidonax minimus*), the tree swallow (*Tachycineta bicolor*), Northern parula (*Setophaga americana*), and the Eastern kingbird (*Tyrannus tyrannus*). We suspect this is because informal urban greenspaces are less intensively managed, and often have a larger mosaic of habitat types throughout than formal urban greenspaces, which have more distinction between habitat types. Furthermore, formal greenspaces often removed dead wood, as it can pose a hazard to trail-users and is less aesthetically pleasing to some (Fröhlich & Ciach 2020). In informal greenspaces, dead wood removal is less common, and a higher amount of dead wood can help support many species that rely on it to provide nesting space and foraging opportunities (Bujoczek et al. 2021). For example, woodpeckers favour large dead trees for cavity nesting (Gutzat & Dormann 2018).

Some species are found in close and far distances from trails in both informal and formal urban greenspaces. These species include the Northern cardinal (*Cardinalis cardinalis*), the American goldfinch, the American robin (*Turdus migratorius*), the great-crested flycatcher, and black-capped chickadees (*Poecile atricapillus*). These are all common, native, generalist species, so it is not surprising to find them across all proximities and management statuses of urban greenspace. Generalist species are among the most tolerant to urban areas (Callaghan et al. 2019), and they can fill ecological roles needed in urban greenspaces. Furthermore, common bird species are more recognizable by people, and this recognizability can contribute to a sense of place and connection to nature. People who can identify and appreciate their local bird species are also more likely to support conservation efforts and value biodiversity (Cox & Gaston 2015). Common native species should not be overlooked for their value to ecosystems and people and can be supported by our urban greenspaces.

Informal urban greenspaces host a higher diversity of birds and a mosaic of habitat, and if they are brought into formal management status, it is important to preserve the diversity they contain. It is important to leave some protected area in urban greenspaces with ample distance from trails and human activity. This will help support bird species that are more sensitive to people or require vegetation that is characteristic of interior forests. A review on the impact of distance to trails and recreation on wildlife (mainly birds and ungulates in wild settings, although a few studies were urban) found that the median threshold distance to human recreation and tolerance was between 40 – 111.5 m and suggested that greenspace managers maintain a minimum distance of 250 m between any two trails (Dertien et al. 2021). Our study provides further evidence that these spaces without human activity are important for a diversity of birds, including some at-risk species.

Our study also found that within the levels of human activity seen (Appendix E), the relationship between trails and bird diversity appears to be more about the structure of trails than the number of people using trails. Trail edges should be valued for the unique habitat they provide to bird species. Shrubby, dense native vegetation that occurs at trail edges might not be aesthetically valued, but it should not be cleared or removed, as it accommodates shrub nesting and foraging species that might not otherwise occur in urban greenspaces. Encouraging the growth of native shrubs is important and are more likely to support a higher diversity of urban birds (Berthon et al. 2021) Based on our findings, planning less dense, larger trails might present the best-case scenario for birds and people. Urban greenspaces can be planned and managed thoughtfully to both give people access to nature and provide birds with unique and required habitat.

General Conclusions

In my work, I investigated bird nest survival in three urban greenspaces across a gradient of human activity in Montreal to determine the relationship between recreational trail use and nest success. I also investigated the relationship between recreational trail use and bird diversity and species richness in four Montreal urban greenspaces of two different management statues – informal and formal. The results from both chapters indicate that human activity in Montreal urban greenspaces may not have a strong relationship to bird nest survival and diversity, which is a potential synergy between human recreation and bird conservation.

In my first chapter, I found a total of 93 nests over the field season from four species: American robins, Northern cardinals, yellow warblers, and gray catbirds. Through mixed modelling, I found that although human activity was not a significant factor, seasonality most strongly influences bird nest success. I further investigated this by isolating the nests that had failed in our study and found that nests established earlier in the season failed faster. Human activity was also not a significant factor in the number of days a nest is active for. I speculated that the various behaviours people engage in in urban greenspaces, including letting one's dog off leash and venturing off trail to create informal trail networks, might better predict nest survival. It is also possible that my target species are more adapted to life in the city and have developed a degree of resiliency that I did not account for (Diamant et al. 2023). Perhaps I would have observed more of an influence of human activity had I included sites that were in Montreal's urban core. Furthermore, there could be a relationship where humans are deterring these birds' usual predators and reducing predation (Geffroy et al. 2015; Møller 2012; Valcarcel and Fernández-Juricic 2009, Pérez-González et al. 2024). Although I did not test for any of these possibilities, my work shows that there are other factors at play, and it could be a complex web of variables that predict nest survival outcomes.

My second chapter focused on the relationship between human activity, quantified here by the average number of trail users per hour, and the diversity and community composition of bird communities in Montreal urban greenspaces. I looked at greenspaces with two different management statuses: formal and informal. This is one way of categorizing urban greenspaces and considers the level of official management in place. I found 34 bird species in formal sites and 41 bird species in informal sites. Through linear modelling, I did not find a significant relationship between the average number of recreational trail users and diversity or species richness. Interestingly, there was a significant relationship between both diversity and species richness and proximity to trail, with diversity and richness was higher further (> 25 m) from trails. I did not find a significant relationship between diversity and richness and management status; however, the linear model was considering only transect-level differences – which I explained in my work as being our alpha level diversity. There is a clear difference in the site-level diversity, both beta and gamma diversity as outlined in my manuscript, when comparing informal and formal urban greenspaces together.

My results provide information on how to plan trails in a way that maximizes benefits to humans and birds, which is highly relevant to greenspace managers. Within similar study systems, we may not need to be concerned about the use of recreational trails on nest survival. Furthermore, the significant difference in bird communities close (< 25 m) and further (>25 m) from trails suggests that urban greenspaces should be planned to keep some protected areas far from trails to conserve bird species that are more sensitive to human activity or prefer interior forest habitat. I recommend a low density of high-traffic trails to greenspace managers. I also suggest that planting and maintaining native shrubby vegetation adjacent to trails is an important act to conserve bird diversity within an urban greenspace. Shrubby edges provide novel habitat that maintains species favouring woodland edges, that might not otherwise be present in urban greenspaces. As there were still many bird species present close to trails, including some brightly colored species that are easy to recognize, this provides an opportunity for people to connect with nature. Birds contribute to a healthy, diverse ecosystem, and they also bring joy and a higher sense of mental wellbeing to people. As such, it is important to continue research similar to what I have presented. For example, investigating the impact of human recreational activity on birds in downtown cores would be a key next step; are the patterns I observed consistent? Furthermore, investigating specific behaviours in urban greenspaces to determine if these may have a greater impact on birds would be another step toward better understanding these complex relationships. It key that we continue to seek areas of synergy between managing urban greenspaces for birds and for people.

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General Conclusions: References

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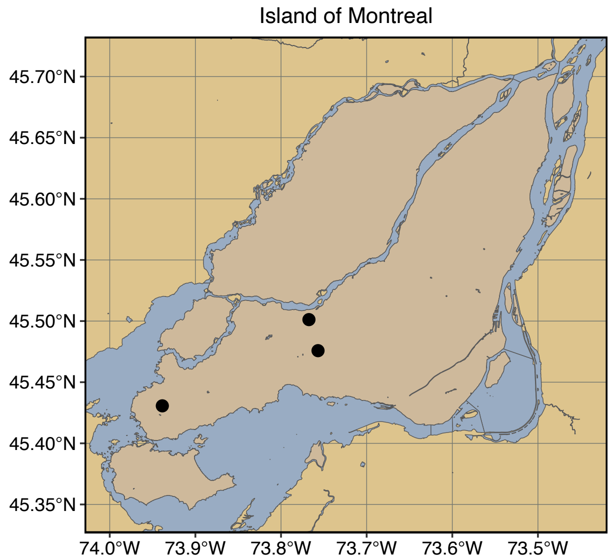
Appendix – Chapter 1



Appendix A. Map of study sites on the Island of Montreal, QC. The leftmost point is Stoneycroft Research Area, the top right point is Bois-de-Liesses Nature Park, and the point below it is the Technoparc.

Appendix B. *Various vegetation survey methods.*

For vegetation complexity considered three layers: understory, midstory, and canopy. We defined understory as any vegetation below hip level, midstory was anything above 6 feet tall, and the canopy layer was consistent with typical definitions of canopy in forestry (Dueser & Shugart Jr. 1978, Canadian Forest Service 2008). We scaled vegetation complexity from 1-3 based on the number of layers present (e.g., a nest patch with an understory and a canopy layer would be coded to have a vegetative complexity of 2).

We took canopy cover photos above each nest that could be reached for a photograph by hand, roughly 1 inch above the nest at a 180° angle. The same person took all photos for consistency. We conducted digital image analysis (Xiong et al. 2019) in ImageJ (Schneider et al. 2012) using an extension called Hemispherical_2.0 to generate canopy cover values (Beckschäfer 2015).

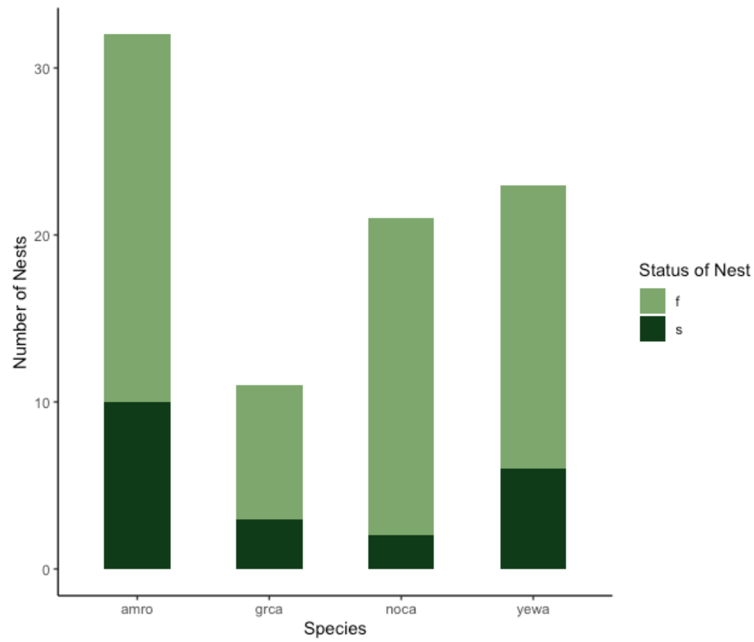
For our vegetative concealment measurements, we used checkerboards of alternating black and white squares. The same observer estimated the number of checkerboard squares that were visible in all four cardinal directions of the nest by standing 3 m from the nest. We took an average concealment value for each nest from these four measurements.

Appendix C. All nests found in the study, their location, species, and failure (F) or success (S).

Nest Number	Site	Species	Fate
2	Technoparc	Northern cardinal	F
3	Bois-de-Liesse	Northern cardinal	F
5	Technoparc	American robin	F
7	Technoparc	American robin	F
8	Technoparc	American robin	F
9	Technoparc	American robin	F
11	Bois-de-Liesse	Northern cardinal	F
12	Technoparc	Northern cardinal	S
13	Technoparc	American robin	F
15	Technoparc	American robin	S
16	Technoparc	Northern cardinal	F
17	Technoparc	Northern cardinal	F
18	Technoparc	Northern cardinal	F
20	Technoparc	American robin	F
21	Bois-de-Liesse	Northern cardinal	S
22	Bois-de-Liesse	Northern cardinal	F
24	Bois-de-Liesse	Northern cardinal	F
25	Stoneycroft	American robin	S
26	Stoneycroft	Northern cardinal	F
27	Technoparc	American robin	F
28	Technoparc	American robin	F
29	Technoparc	American robin	F
30	Technoparc	American robin	F
32	Bois-de-Liesse	American robin	S
33	Bois-de-Liesse	American robin	S
34	Bois-de-Liesse	Northern cardinal	F
36	Bois-de-Liesse	Northern cardinal	F
37	Bois-de-Liesse	Northern cardinal	F
38	Technoparc	American robin	S
39	Technoparc	American robin	F
42	Technoparc	American robin	F
43	Technoparc	American robin	S
44	Bois-de-Liesse	American robin	F
45	Bois-de-Liesse	Northern cardinal	F
47	Stoneycroft	American robin	F
48	Stoneycroft	Yellow warbler	F
50	Technoparc	Northern cardinal	F
52	Bois-de-Liesse	American robin	F
53	Bois-de-Liesse	Gray catbird	F
54	Bois-de-Liesse	Northern cardinal	F
55	Bois-de-Liesse	Gray catbird	F
56	Bois-de-Liesse	Yellow warbler	F
57	Bois-de-Liesse	American robin	F
58	Bois-de-Liesse	Gray catbird	F
60	Stoneycroft	Gray catbird	F

Appendix C. Continued

Nest Number	Site	Species	Fate
61	Technoparc	American robin	S
62	Technoparc	Yellow warbler	S
63	Technoparc	Yellow warbler	S
64	Technoparc	American robin	F
65	Technoparc	American robin	S
66	Technoparc	Yellow warbler	F
67	Bois-de-Liesse	Northern cardinal	F
68	Stoneycroft	American robin	F
69	Technoparc	Yellow warbler	F
70	Technoparc	Yellow warbler	F
71	Technoparc	Yellow warbler	F
72	Technoparc	Yellow warbler	F
73	Technoparc	Gray catbird	S
74	Bois-de-Liesse	Gray catbird	F
75	Stoneycroft	Yellow warbler	F
76	Stoneycroft	Yellow warbler	S
77	Technoparc	Gray catbird	S
78	Technoparc	American robin	F
79	Technoparc	Yellow warbler	F
81	Technoparc	American robin	S
82	Bois-de-Liesse	Yellow warbler	F
83	Bois-de-Liesse	Gray catbird	F
84	Bois-de-Liesse	Gray catbird	F
85	Bois-de-Liesse	Yellow warbler	F
86	Bois-de-Liesse	Gray catbird	F
87	Bois-de-Liesse	Yellow warbler	F
88	Technoparc	Yellow warbler	S
89	Stoneycroft	Northern cardinal	F
91	Stoneycroft	Yellow warbler	F
92	Stoneycroft	Yellow warbler	F
96	Stoneycroft	Yellow warbler	F
97	Stoneycroft	Yellow warbler	S



Appendix D. The total number of nests found for each of four target species from a nest survival study conducted in the spring and summer of 2023 at Bois-de-Liesse Nature Park, Technoparc's Parc-des-Sources, and the Stoneycroft Research Area in Montreal. From left to right: American robins (n = 32), gray catbirds (n = 11), Northern cardinals (n = 21), and yellow warblers (n = 23). The pale green at the top of the bars shows the number of nests that failed, and the dark green below indicates the number of successful nests.

Appendix E. Candidate models with the two lowest corrected delta AICcs (excluding the Null model) predicting nest survival of American robins, gray catbirds, Northern cardinals, and yellow warblers in three urban forests of Montreal are reported, along with their coefficients, exponential coefficients (hazard ratios), standard errors, 95% confidence intervals, z-values and p-values. A hazard ratio > 1 indicates an increase in hazard and a lower probability of survival, while a hazard ratio < 1 indicates an increasing probability of survival.

Model and Variables	Coefficient	Exp	SE	95% CI	Wald z	Wald p
Seasonality						
Initiation Date	0.01	1.01	0.01	[-0.01, 0.03]	1.4	0.16
Human Influence						
Distance of nest from trail	0.05	1.05	0.22	[-0.38, 2.46]	0.22	0.83
Mean human activity	6.86	952.07	12.43	[-17.51, 31.23]	0.5	0.58

Appendix F. Random Effects Variables for Top Models

For our Cox proportional hazards Seasonality model, the random effect variable of "species" accounted for 0.04 of the observed variance, and the random effect variable of "site" accounted for 0.01 of the observed variance. The random effect variable of species accounted for 0.03 of the variance observed, and the random effect of site accounted for 0.02 of the variance observed for our human influence model.

Appendix – Chapter 2

Appendix A: Gentry transects

Along each of our 200 m trails, we conducted Gentry transects at each 50 m interval, alternating between the left and right sides of the trail. This yielded a total of 4 transects per trail, and 16 transects per field site. Our Gentry transects were 2 m in width and 50 m in length, extending perpendicularly from the trail, pictured below, In this 100 m^2 area, we identified each woody stem that was greater than 5 cm at diameter breast height (DBH) to the species level and measured their exact DBH. We also conducted quadrat surveys along each gentry transect pictured below.

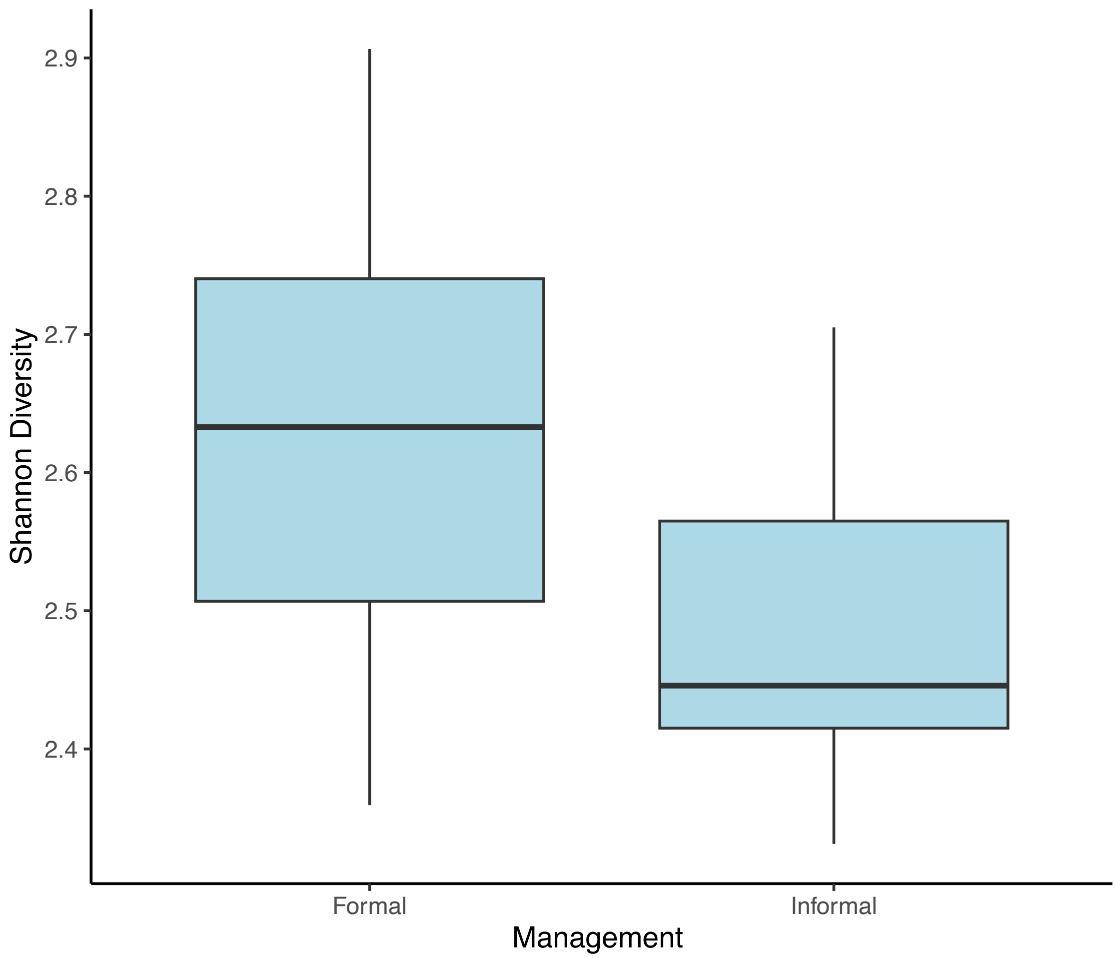
Appendix A. Example of gentry transect vegetation surveys extending from a trail at a field site in Montreal, Canada. Shows the three quadrat surveys conducted for small woody stems at the start, the middle, and the end of the gentry transect. Gentry transects were 50 m in length extending perpendicularly from 200 m trails.

Appendix B. All bird species recorded at informal and formal Montreal urban greenspaces. Informal sites were the Technoparc and Stoneycroft Research area, formal sites were Bois-de-Liesse and the Morgan Arboretum. Both scientific and common names included below.

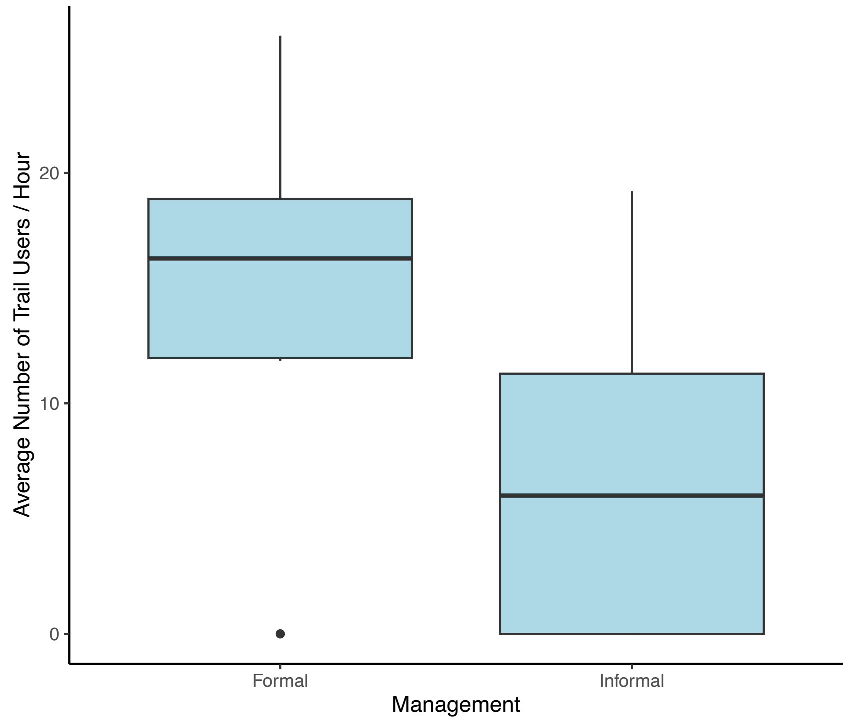
Informal Urban Greenspaces	**Formal Urban Greenspaces**
American goldfinch (*Spinus tristis*)	American crow (*Corvus brachyrhynchos*)
American redstart (*Setophaga ruticilla*)	American goldfinch (*Spinus tristis*)
American robin (*Turdus migratorius*)	American redstart (*Setophaga ruticilla*)
Baltimore oriole (*Icterus galbula*)	American robin (*Turdus migratorius*)
Black-capped chickadee (*Poecile atricapillus*)	Baltimore oriole (*Icterus galbula*)
Brown-headed cowbird (*Molothrus ater*)	Black-and-white warbler (*Mniotilta varia*)
Blue jay (*Cyanocitta cristata*)	Black-capped chickadee (*Poecile atricapillus*)
Black-throated green warbler (*Setophaga virens*)	Brown-headed cowbird (*Molothrus ater*)
Cedar waxwing (*Bombycilla cedrorum*)	Blue jay (*Cyanocitta cristata*)
Chipping sparrow (*Spizella passerine*)	Chipping sparrow (*Spizella passerine*)
Common grackle (*Quiscalus quiscula*)	Common yellowthroat (*Geothlypis trichas*)
Common raven (*Corvus corax*)	Chestnut-sided warbler (*Setophaga pensylvanica*)
Common yellowthroat (*Geothlypis trichas*)	Downy woodpecker (*Picoides pubescens*)
Chestnut-sided warbler (*Setophaga pensylvanica*)	Eastern phoebe (*Sayornis phoebe*)
Downy woodpecker (*Picoides pubescens*)	Eastern wood-peewee (*Contopus virens*)
Eastern kingbird (*Tyrannus tyrannus*)	Great crested flycatcher (*Myiarchus crinitus*)
Eastern phoebe (*Sayornis phoebe*)	Gray catbird (*Dumetella carolinensis*)
Great crested flycatcher (*Myiarchus crinitus*)	House wren (*Troglodytes aedon*)

Informal Urban Greenspaces	Formal Urban Greenspaces
Gray catbird (*Dumetella carolinensis*)	Indigo bunting (*Passerina cyanea*)
House wren (*Troglodytes aedon*)	Magnolia warbler (*Setophaga magnolia*)
Indigo bunting (*Passerina cyanea*)	Northern cardinal (*Cardinalis cardinalis*)
Killdeer (*Charadrius vociferus*)	Ovenbird (*Seiurus aurocapilla*)
Least flycatcher (*Empidonax minimus*)	Pileated woodpecker (*Dryocopus pileatus*)
Magnolia warbler (*Setophaga magnolia*)	Rose-breasted grosbeak (*Pheucticus ludovicianus*)
Northern cardinal (*Cardinalis cardinalis*)	Red-bellied woodpecker (Melanerpes carolinus)
Northern harrier (*Circus hudsonius*)	Red-eyed vireo (*Vireo olivaceus*)
Northern parula (*Setophaga americana*)	Song sparrow (*Melospiza melodia*)
Northern waterthrush (*Parkesia noveboracensis*)	Tennessee warbler (*Leiothlypis peregrina*)
Pileated woodpecker (*Dryocopus pileatus*)	Warbling vireo (*Vireo gilvus*)
Rose-breasted grosbeak (*Pheucticus ludovicianus*)	White-breasted nuthatch (*Sitta carolinensis*)
Red-eyed vireo (*Vireo olivaceus*)	Willow flycatcher (*Empidonax traillii*)
Song sparrow (*Melospiza melodia*)	Wild turkey (*Meleagris gallopavo*)
Swamp sparrow (*Melospiza georgiana*)	Wood thrush (*Hylocichla mustelina*)
Tree swallow (*Tachycineta bicolor*)	Yellow warbler (*Setophaga petechia*)
Warbling vireo (*Vireo gilvus*)	
White-breasted nuthatch (*Sitta carolinensis*)	
Wild turkey (*Meleagris gallopavo*)	
Wilson’s warbler (*Cardellina pusilla*)	
Wood thrush (*Hylocichla mustelina*)	
Yellow warbler (*Setophaga petechia*)	

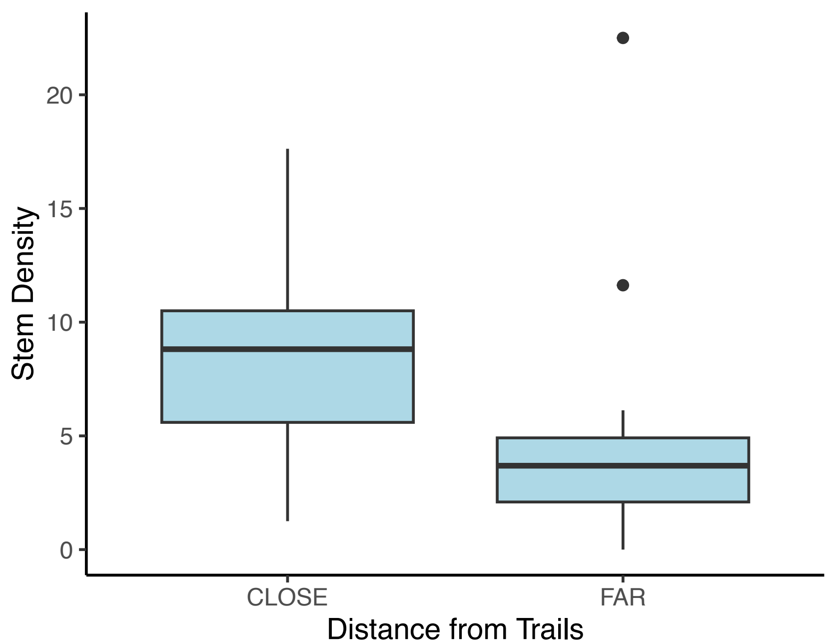
Informal Urban Greenspaces
Northern flicker (*Colaptes auratus*)



Appendix C. Shannon diversity in both formal and informal urban greenspaces in Montreal. Formal greenspaces are the Morgan Arboretum and Bois-de-Liesse and informal greenspaces are the Stoneycroft Research Area and the Technoparc.



Appendix D. Range of average human activity, measured by the average number of trail users per hour, in informal and formal urban greenspaces.



Appendix E. Average density of woody stems close and far from trails in informal and formal urban greenspaces combined.