Birds in the city:
Identifying the relationship between bird diversity and ecosystem factors in the urban agglomeration of Montreal

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Summary

Bird diversity is found to not be significantly linearly related to NDVI or climate in a quadrat analysis of the island of Montreal, suggesting that bird presence and diversity is supported by a range of environmental conditions.

Abstract

Urbanization is a driver of global biodiversity change. It displaces organisms, disrupts the functioning of ecosystems, and endows humans with a high degree of control over the natural environment in affected areas. It is therefore informative to investigate urban biodiversity and its underlying factors. Birds are a good measure of faunal diversity in urban areas because they are well represented in data from citizen science, they have managed to persist to the point of ubiquity in many cities, and they are sensitive to habitat factors. On the island of Montreal, it remains unclear how bird diversity relates to ecosystem factors such as climate and vegetation. In this project, we use citizen science-derived bird species observation data in conjunction with climate variables and normalized difference vegetation index (NDVI) to identify the relationship between bird diversity and ecosystem factors. We find no significant linear correlations at this spatial scale and discuss the limitations of citizen science as a source of biodiversity data and the process of disentangling ecological factors in complex urban environments.

1 Introduction

Urbanization is a powerful driver of biodiversity loss and redistribution across the terrestrial Earth (*Carrete and Tella*, 2011) and is a contributing factor to the current global extinction crisis. However, the consequences of urbanization on species assemblages at the local and regional scales are complex and highly dependent on the characteristics of the built environment, the native landscape, and the time scale in question. The initial expansion of urban areas and the associated dramatic change in land use displaces native flora and fauna. Through land-use modifications, the use of non-porous pavement, heating effects, chemical and light pollution, and other effects of high human population density, habitats are fragmented or lost, ecological processes are compromised, and remaining patches of intact ecosystems are degraded. Such changes favor the survival and invasion of tame species (more tolerant of human disturbance) (*Carrete and Tella*, 2011; *Marques et al.*, 2020) and the extirpation of other, more sensitive species. As a consequence of urban expansion, humans exercise a high degree of control over aspects of the urban ecosystem, particularly plant assemblages, configuration of green areas, and soil chemistry. The distribution of faunal biomass and diversity in the urban landscape is often assumed to arise from these controllable factors, but is not as predictable or manageable (*Faeth et al.*, 2011). The Shared Socioeconomic Pathways project that urbanization will reach between 60-92% by the end of the century (*Jiang and O'Neill*, 2017). In light of this impending global transformation, it is important to understand how biodiversity fits into the built landscape in order to inform sustainable urban planning and to focus conservation efforts (*Aronson et al.*, 2014).

The first draft of the Global Biodiversity Framework, authored by the Convention on Biological Diversity, stresses the importance of investing in biodiversity monitoring in order to improve planning, prioritization of resources, and reporting progress (*Programme*, 2021). Monitoring efforts must be spatially representative. Although much interest has been devoted to species loss on a global scale, it is local biodiversity dynamics that will likely dictate the long-term security of ecosystem services (*Newbold et al.*, 2015).

Local biodiversity distribution on the island of Montreal has been understudied. While Mimouni et al. (2018) studied zooplankton biodiversity in Montreal urban waterbodies and Morneau et al. (1999) collected bird population data in urban parks on the island, there have been no comprehensive full-island biodiversity analyses. Montreal is extremely urbanized with a pervious to impervious surface ratio of 0.21, higher than those of Toronto and Vancouver (*Kaykhosravi et al.*, 2020). The city is also an epicenter of urban sprawl across and beyond the island (*Montréal*, 2020).

This study aims to describe patterns of local bird species distribution on the island of Montreal and analyze these patterns' relationship to variation in climate and flora. In light of Montreal's generally pro-development attitude—as evidenced by city-approved real estate development in the western part of the Pierrefonds-Roxboro territory which threatens 122 bird species (*Dupras et al.*, 2016)—such studies are urgently needed to inform conservation efforts in the city.

We briefly establish the ecological importance of birds; as an overall taxon they encompass myriad trophic and ecological niches and are thus responsible for a wide range of ecosystem functions. Sekercioglu (2006) recognizes the unique role of birds as mobile links, crucial to maintaining ecosystem function, memory, and resilience. Birds act as genetic linkers via seed dispersal and pollination (*Tabur and Ayvaz*, 2010), trophic process linkers via grazing and predation (e.g., of insects) as well as via scavenging which enhances decomposition, and physical process linkers via ecosystem engineering - birds build nests and bore holes that are used by many other species (*Sekercioglu*, 2006). In addition to safeguarding the delivery of ecosystem services by contributing to ecosystem functioning, studies have proven birds can directly improve humans' quality of life, with Hepburn et al. (2021) concluding that bird diversity improves urban residents' satisfaction with where they live. Furthermore, on account of their sensitivity to environmental stressors (*Sullivan et al.*, 2009), birds can be used to track broader biodiversity change.

Birding is the cornerstone of many modern-day citizen science ventures (*Kullenberg and*

Kasperowski, 2016). Birds qualify as good candidates for community-based monitoring because they are easily observed being that they are 1) largely diurnal, 2) easily distinguishable, and 3) abundant. Moreover, they can be formally measured without ambiguity and are relevant to policy, scientifically credible, responsive to changes, and susceptible to analysis (*Bibby*, 1999). Citizen science efforts have proven invaluable to recent biodiversity monitoring efforts, particularly for birds, as a consequence of the rapid growth and accessibility of data on platforms such as eBird (*Sullivan et al.*, 2014). Scientists increasingly rely on eBird (and other citizen science initiatives) to efficiently gather and analyze large data sets across impressive temporal and spatial scales (*Chandler et al.*, 2017; *Horton et al.*, 2018; *Sorte et al.*, 2015).

As a result of the recorded positive relationship between vegetation density and species richness (*Fontana et al.*, 2011; *Sandström et al.*, 2006), we considered NDVI as a causal factor of the distribution of bird diversity. Indeed, as a proxy for greenness, NDVI has been found to be a positive predictor of bird diversity at large scales (*Ribeiro et al.*, 2019; *Oindo et al.*, 2000). Similarly, we examined annual temperature and precipitation as potential drivers of bird diversity distribution. Studies suggest that in some non-urban environments, microclimate is determinative of bird distribution (*Massimino et al.*, 2020; *Frey et al.*, 2016). While correlating a snapshot of bird diversity with temperature and precipitation within the scope of the island cannot gauge the effect of a changing climate on bird diversity, it gives insight into preferences of urban birds and may help explain the spatial network of persisting, healthy vegetation.

2 Data and Methods

Bird Data

Data on eBird are cataloged as geolocated checklists, submitted and automatically compared to a list of birds expected at that location based on regional species assemblages. When unexpected occurrences or high bird counts in a particular location are observed and submitted to eBird, the checklist is reviewed by expert volunteers before being included in the database. (*Gilfedder et al.*, 2018). Observation count, the number of individual birds seen of a particular species, is reported in every checklist. We acquired data for the island of Montreal from January 1, 2016 to December 31, 2021 via eBird's online data portal.

We filtered the data acquired from eBird per existing literature and eBird's Best Practices Tips (*eBird*, 2022). We only included checklists that had all species accounted for to remove incidental observations by birders not putting in sufficient sampling effort (*Steen et al.*, 2019). Additionally, we disregarded all checklists whose authors had travelled more than 8.1 km during data collection in order to reduce the effect of spatial imprecision (*Strimas-Mackey et al.*, 2020). Similarly, we disregarded all checklists whose observations were recorded over a period of more than 180 minutes to standardize sampling effort acro4ss checklists (*eBird*, 2022). Finally, some checklists were marked with group identifiers; these were completed by members of groups of birders working at the same time. In these cases, we included one random checklist from each group in order to avoid double-counting observations (*Callaghan et al.*, 2020).

Using RStudio, we applied our various filters (i.e., complete checklists, distance traveled, time spent, group observations) using the *stringr* package. This filtration reduced our initial dataset of 1.6 million observations to 800,000 observations.

Using Python, we rasterized an area encompassing the island of Montreal into quadrats of approximately 1 km^2. This area's extent is defined by the polygon formed from the following set of coordinates (lat, lon): [(45.386295, -73.999863), (45.386295, -73.450116), (45.730943, -73.450116), (45.730943, -73.999863)]. Because each observation from the filtered eBird data is associated with a particular latitude and longitude, we were able to assign each observation (of a defined species in a defined checklist) to the appropriate quadrat. We subsequently calculated bird abundance for all species (Figure 1), species richness (Figure 2), and Shannon diversity (Figure 3) in each quadrat.

We computed the Shannon diversity using the following equation:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i,$$

where *H'* is the Shannon diversity index, s is the number of species in the quadrat, and p_i is the is the proportion of species i individuals making up the overall community (*Nolan and Callahan*, 2006). This index is measured on a scale of 0 to 1, with values closer to 1 signifying higher diversity, or a combination of high species richness and evenness.

NDVI Data

The normalized difference vegetation index (NDVI) is calculated from remotely-sensed data with the formula:

$$NDVI = \frac{NIR - R}{NIR + R},$$

where NIR is near-infrared reflectance and and R is red visible light reflectance. NDVI values range from -1 to 1. Values close to 1 represent dense, productive vegetation; values near 0 are unvegetated surfaces composed of sand, rock, or concrete; values near -1 are water bodies (*Huang et al.*, 2020). Green vegetation reflects more NIR and absorbs more R than unhealthy vegetation or non-vegetated surfaces such as pavement or buildings (*Rhew et al.*, 2011). The Terra Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI data was acquired from NASA Earthdata as a .hdf file (*NASA*, 2020). MODIS samples reflectance every 16 days at a 250 meter spatial resolution. We used NDVI data from June 9, 2020 for the island of Montreal.

Climate Data

We downloaded monthly average temperature (°C) and monthly cumulative precipitation (mm) .tif files averaged across 1970-2000 from WorldClim (*WorldClim*) using the *geodata* package in R. The data have a spatial resolution of 30s (~1km). We additionally calculated the annual average of each variable.

Synthesis

To harmonize the different data sources, we recreated the sampling quadrats in ArcGIS Desktop (*ESRI*, 2021) using the same delineation rules as those used for sampling bird presence data. The quadrats were then converted to a grid in a locally-generated Mercator projected coordinate system, with an error of 40 m or less. We computed zonal averages of the NDVI, temperature and precipitation metrics using the quadrats as zones, thus yielding grids of NDVI and climate variables at the same resolution and extent as the grid. Areas where climatic data was not present were ignored in the calculations.

We then performed linear regressions between bird diversity metrics (abundance, species richness and Shannon diversity) and the averages of the NDVI and climate factors.

Table 1: Coefficients of determination for linear analysis.

Independent variable(s)	Dependent variable	R^2 score
NDVI	Abundance	0.0091
NDVI	Species richness	0.0741
NDVI	Shannon diversity	0.01945
Temperature	Abundance	0.0063
Temperature	Temperature	0.0753
Temperature	Shannon diversity	0.0063
Precipitation	Abundance	6.12e-5
Precipitation	Temperature	0.0112
Precipitation	Shannon diversity	0.00786
NDVI, Temp, Prec	Abundance	0.00786
NDVI, Temp, Prec	Temperature	0.1366
NDVI, Temp, Prec	Shannon diversity	-0.012

3 Results

We found no significant linear correlation between any bird diversity metric and any ecosystem factor, in isolation (univariable) and in conjunction (multiple linear regression), as outlined in Table 1 and illustrated in Figures 9, 10, 11 in the Appendix.

An R^2 score of 1 describes a perfect linear model, 0 describes a model in which the output is constant regardless of the input, and a negative value describes a model that is arbitrarily worse (i.e., no correlation to input) (*scikitlearn*, 2022). The best performing model we developed was the multivariable linear model predicting species richness with NDVI, annual average temperature, and average annual cumulative precipitation. As represented in Figure 4, the NDVI of quadrats in which birds were observed was approximately normally distributed, with a mean of 0.4285 and a standard deviation of 0.1822. Thus, 84% of the birds were observed where the NDVI was above 0.2463 ($-\sigma$). Furthermore, a portion of the birds observed where NDVI $<$ 0.2463 were in aqueous environments, diminishing the proportion of birds observed on land at locations with an NDVI $<$ 0.2463.

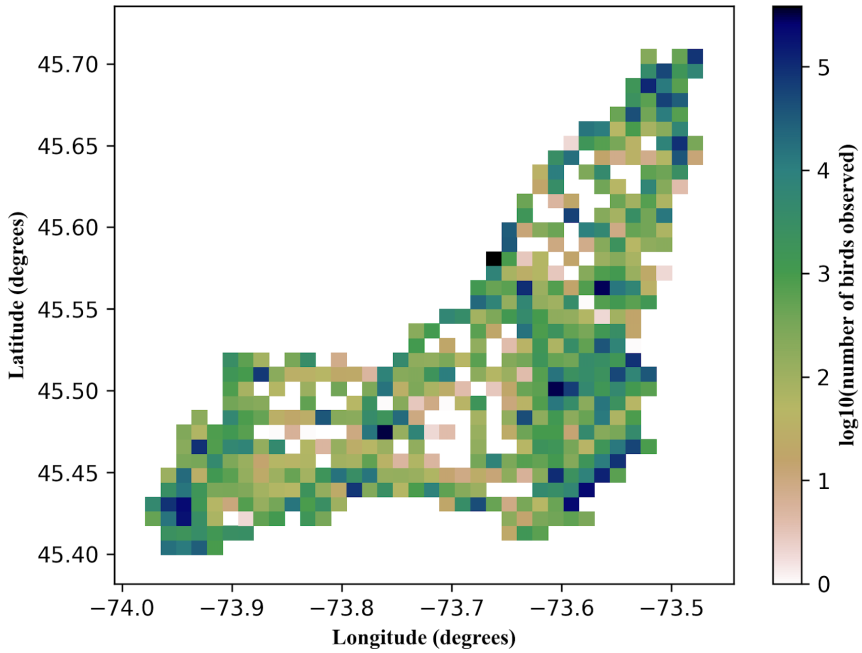

Figure 1: Map of the number of birds observed on the island of Montreal by quadrat.

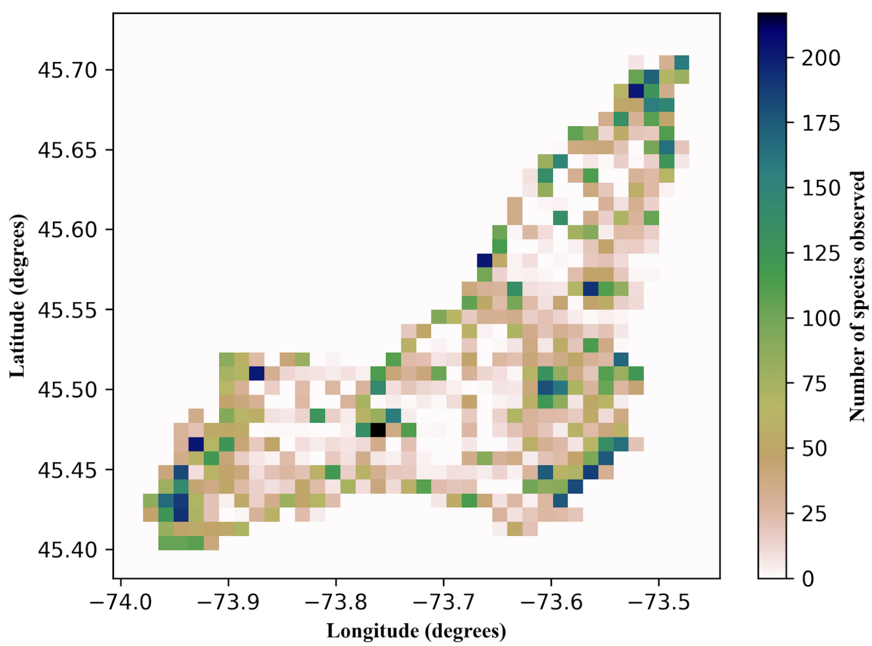

Figure 2: Map of the bird species richness on the island of Montreal by quadrat.

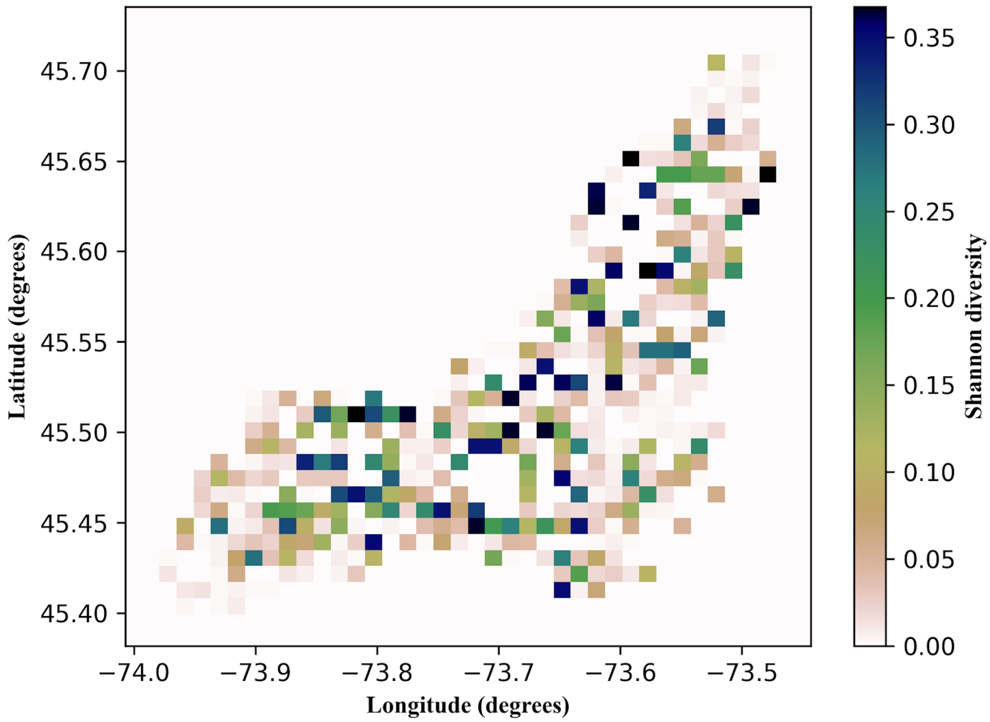

Figure 3: Map of the Shannon diversity on the island of Montreal by quadrat.

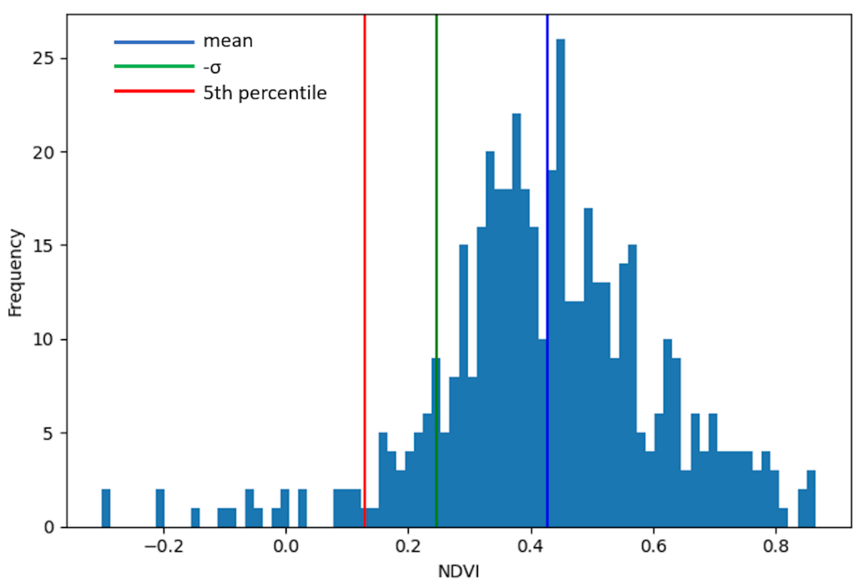

Figure 4: Frequency distribution of NDVI for quadrats in which birds were observed.

4 Discussion

We found that considering ecosystem factors alone and in conjunction does not linearly predict bird abundance nor diversity at a sufficient accuracy. Instead we found that birds are present and in relatively high diversities across a range of values of NDVI, temperature, and precipitation. This suggests that healthy bird communities persist across a range of environmental conditions. Such a conclusion is not necessarily unexpected, as species have optimal temperature ranges, and perhaps simple presence of vegetation, rather than vegetation density or greenness, are sufficient to promoting or sustaining bird populations. This could in fact be promising, because as long as urban planners can preserve the range of environmental conditions, birds can persist and thrive in the urban environment.

We define a minimum threshold NDVI of approximately 0.25 as a predictor of bird presence based on Figure 4. Per Mehta et al. (2021), an NDVI of 0.25 corresponds to bare soil cover, with increasing values representing increasingly dense vegetation. Clearly, birds prefer natural cover over non-vegetated, impervious surfaces.

Referencing Figures 1 and 2, we notice an especially high number of recorded birds and bird species along the Lachine Canal, in Grand Parc de l'Ouest, Parc du Mont-Royal and Technoparc. These results highlight the importance of substantial green and blue spaces to bird populations.

Despite the high bird abundance and species richness in Parc du Mont-Royal and along the Lachine Canal, we note, as illustrated in Figure 3, that the entirety of downtown Montreal has relatively low Shannon diversity. This suggests that there are a few dominant species in this area of the island, which are likely better adapted to the heavily urbanized environment and heightened human influence. Examples of these species could include the rock pigeon, the house sparrow, and the European starling. Because it is an area of central location and high human population, the heightened bird abundance and species richness may be explained by more birders visiting the region.

Surprisingly, we see relatively low Shannon diversity in Grand Parc de l'Ouest, which is over 3,000 hectares (*Montreal*, 2022), and thus expected to be less vulnerable to edge effects than more urban areas of the island.

We also note that the Montréal–Trudeau International Airport scores low across all bird diversity metrics, including bird abundance, species richness, and Shannon diversity (Figures 1, 2 and 3). This may be explained by the lack of green space or potentially a lack of birders birding at the airport.

Limitations and Uncertainties

The climate data has a spatial resolution of 30s (approximately 1 km), while the NDVI data has a resolution of 250 m. We were therefore limited to the coarser spatial resolution of $\sim$1km for bird and NDVI data in addition to the climate data in order to have a consistent level of comparison. A finer spatial resolution may have yielded more accurate results, in terms of NDVI and species observations per quadrat, potentially showing a different relationship between NDVI and diversity.

Only entire checklists are geolocated in eBird, not individual species observations, meaning that there is inherent uncertainty of the spatial and temporal heterogeneity of individual species observations. While filtering checklists by time spent and distance travelled accounts for the records with the highest uncertainty, it is still possible that some species occurrence records that occurred in one quadrat were captured by the adjacent quadrat in our analysis.

Our data also has a temporal mismatch. The bird data was acquired between January

1, 2016 and December 31, 2021, while the NDVI data was obtained for June 9, 2020, and the climate data was obtained between 1970 and 2000. We were thus correlating data from different dates and assuming no change through time. If we had obtained and compared data from the same dates, a more linear correlation may have been observed.

We were cautious of potential sampling bias impacting the accuracy of our results. Specifically, we were wary that birders may preferentially frequent greener areas such as parks, where they expect to see birds. As seen in Figure 5, NDVI is a poor predictor of the number of birders (defined by the number of unique checklists in a quadrat) that visit a given area. However, we do note that there are a few quadrats that an outstanding number of birders visited and they have relatively high NDVI values. Despite the poor linear correlation between greenness and number of birders, we included several biodiversity metrics in our analyses to minimize the impact of spatial bias in the sampling process, including Shannon diversity which only considers the proportion of the population each species made up rather than bulk numbers of birds observed.

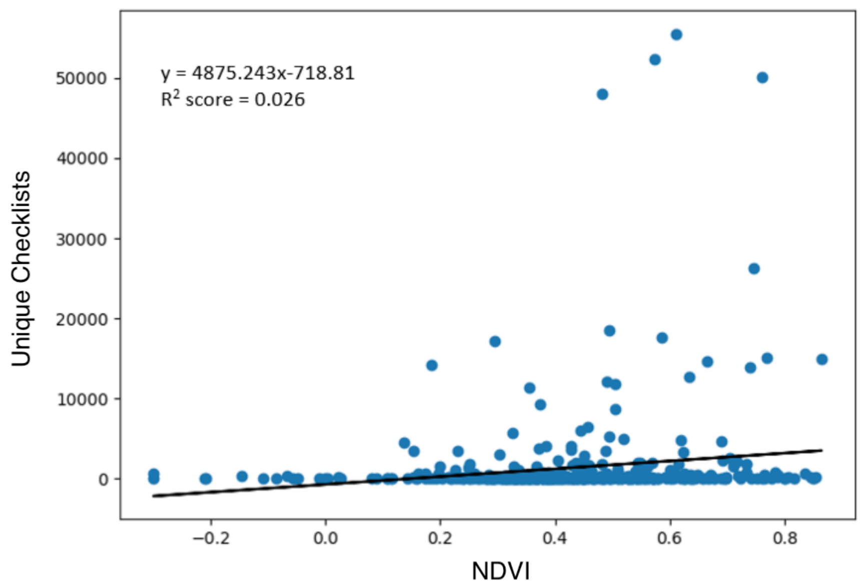

Figure 5: Plot of NDVI and the number of unique checklists.

Future Work

As a preliminary analysis, the scope of this study explores limited causal predictors of the distribution of bird diversity on the island of Montreal and only attempts to correlate such predictors with this distribution individually. We do not account for the possibility of an assemblage of urban, natural, and ecosystem factors working in tandem. Perhaps machine learning methods such as recurrent neural networks can uncover data patterns between such assemblages and the bird diversity distribution. We suggest an analysis of additional landscape aspects in order to develop a more complete understanding on what determines bird distribution. Such additional factors include, but are not limited to, noise levels, metrics of greenspace connectivity, proximity to roads, and residential population density.

We also recognize the value of a temporal analysis for future work. eBird has robust datasets dating back to around 2010. Using more data would allow for the analysis of changing bird biodiversity over a given spatial extent over time as climate and landscape variables too evolve.

Moreover, examining temperature on a finer spatial scale may uncover more precise patterns of microclimate that impact where birds live or frequent that may be masked by the coarse spatial resolution by which this study is constrained.

Additionally, we suggest exploring metrics of biodiversity beyond species richness (e.g., Shannon Diversity). Further analyses may discriminate by bird species, order, or ecological niche. This will give more precise insight into the distribution of bird diversity across the island: are birds of different body sizes, diets, and traits favorable to thriving in the urban landscape distributed analogously? All represented? Over or underrepresented in zones with certain characteristics (e.g., very green, not vegetated, warm, cool, etc.)? The manifestation of the influence of ecosystem variables on birds in Montreal may be better elucidated by such analyses.

Appendix

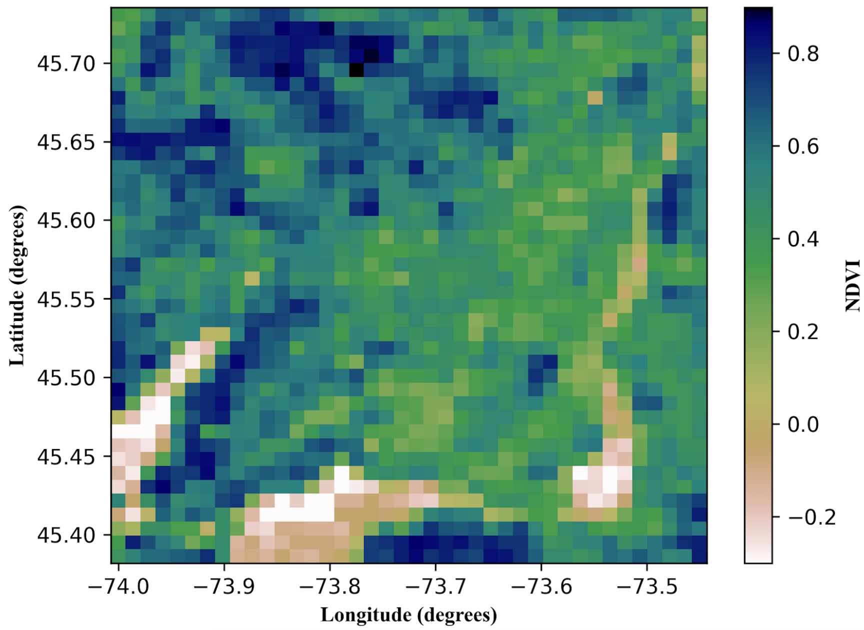

Figure 6: Map of the NDVI on the island of Montreal by quadrat.

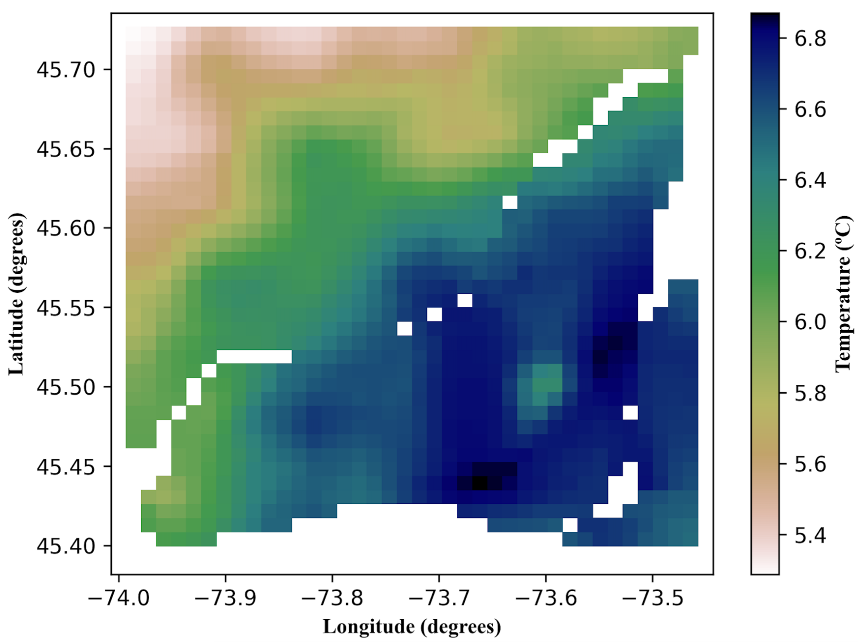

Figure 7: Map of the average annual temperature on the island of Montreal by quadrat.

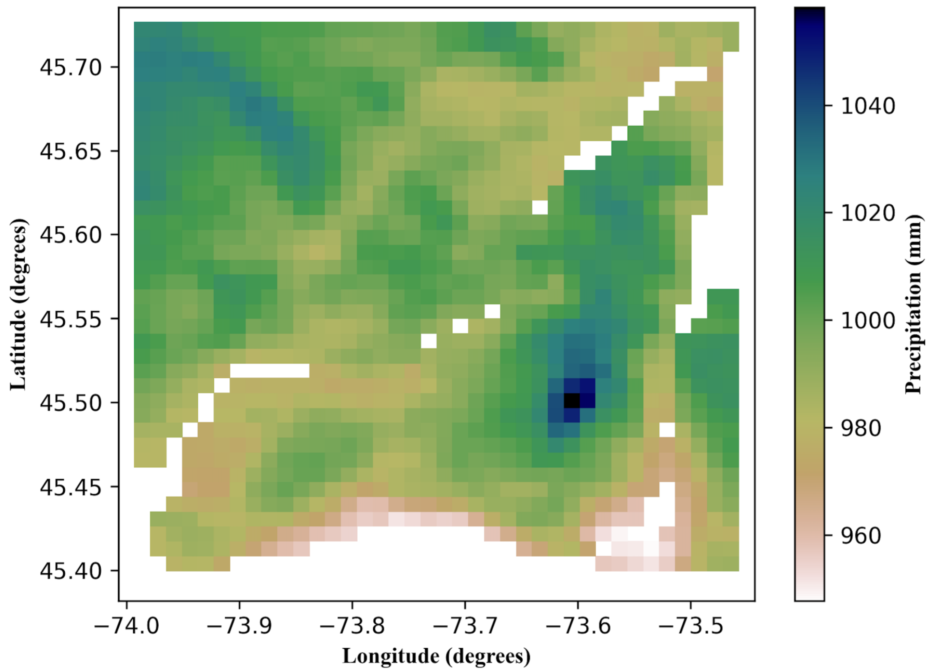

Figure 8: Map of the cummulative annual precipitation on the island of Montreal by quadrat.

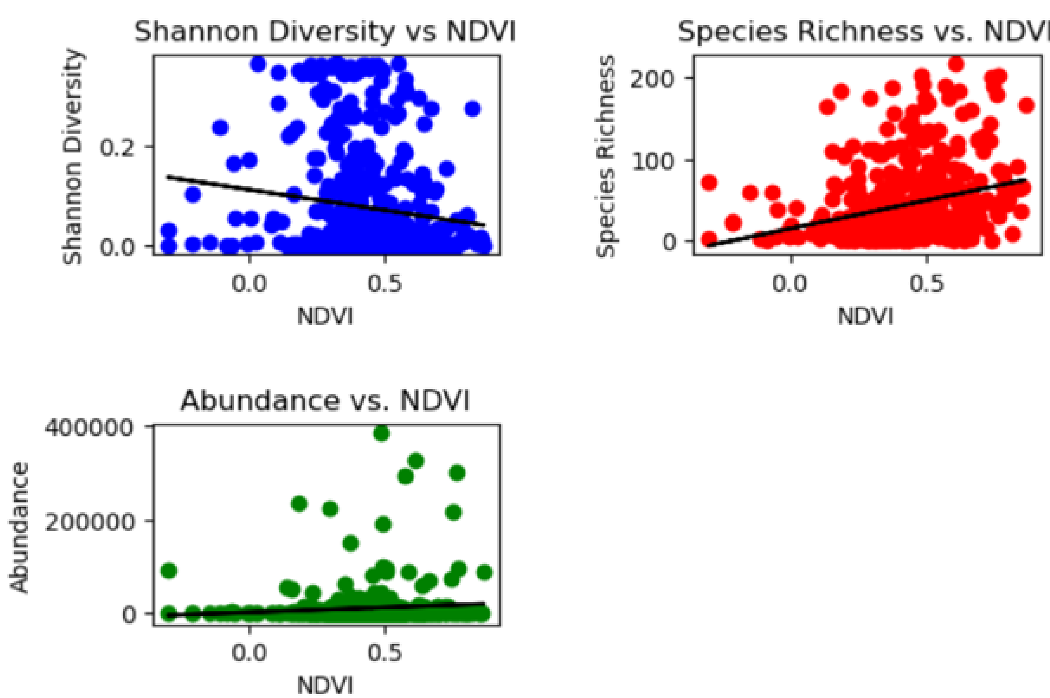

Figure 9: Plots of bird metrics (Shannon diversity, species richness, abundance) versus NDVI.

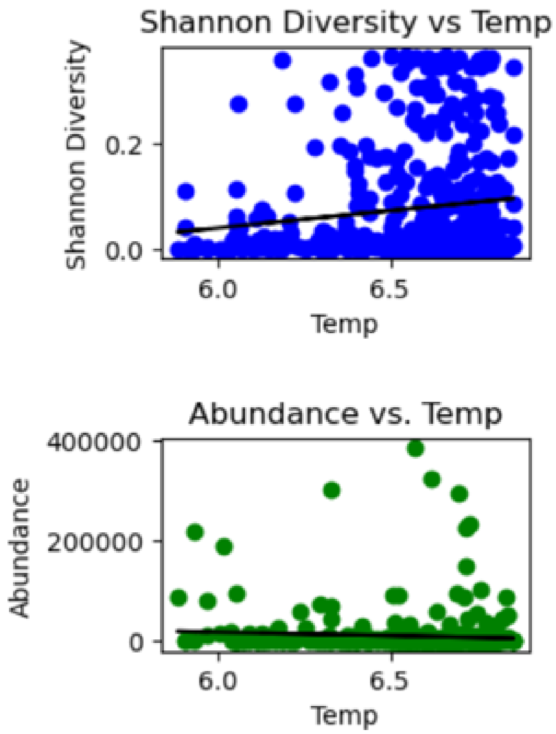

Figure 10: Plots of bird metrics (Shannon diversity, species richness, abundance) versus temperature.

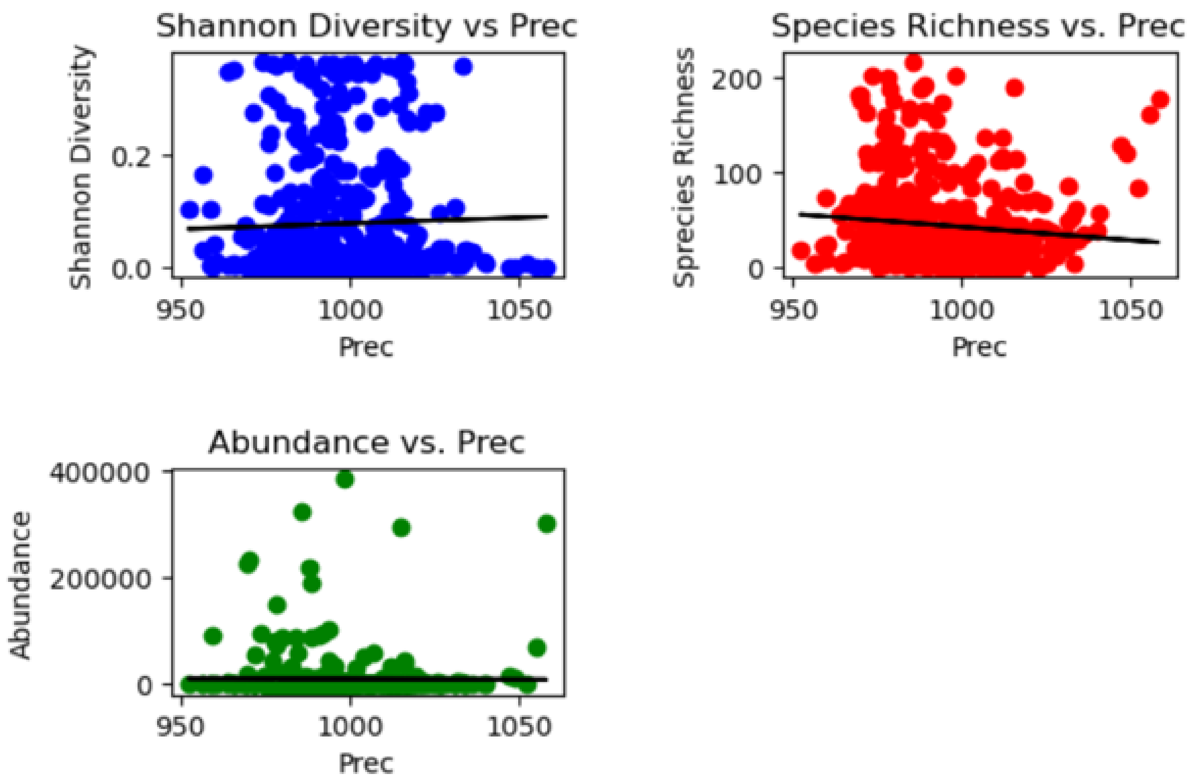

Figure 11: Plots of bird metrics (Shannon diversity, species richness, abundance) versus precipitation.

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