Czech University of Life Sciences Prague

Faculty of Environmental Sciences

Faculty of
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Diploma Thesis

Using Open-Source citizen science biodiversity data to determine spatial associations between native/exotic flora and specialist/non-specialist avian species within an urban setting

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Environmental Sciences

DIPLOMA THESIS ASSIGNMENT

B.Sc. Jesse Stanford

Landscape Planning

Thesis title

Using Open-Source citizen science biodiversity data to determine spatial associations between native/exotic flora and specialist/non-specialist avian species within an urban setting

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Objectives of thesis

To examine the influence of native flora and floristic communities on the distribution of specialist bird species along a gradient of urban density.

Methodology

The distribution data of avian and flora species distribution was extracted from open-source: iNaturalist. All data are georeferenced. The limit of the study area is the Prague municipal boundary.

Classification of avian species as specialist or nonspecialist based on the diet specialization index, which was calculated as the GINI coefficient for avian species' dietary preferences within European cities in a prior project. The observed avian species were then assigned the value previously established. Unclassified species were given the average GINI coefficient value of all other members of their genus within the study area.

We distinguished flora as native species or nonnative species (including both naturalized and exotic species) according to their listing in the Pladias. If there was incongruency between naming conventions, it was then determined through the use of Plants of the World Online.

To examine urban density, impervious surface data was obtained from Copernicus.eu.

We then created a fishnet covering the Prague municipality and incorporated the distribution and classification of species, as well as imperviousness, into individual cells. Linear Regression will be used to determine spatial relationships between the aforementioned variables.

The proposed extent of the thesis

45-50 pages

Keywords

avian diet; exotic species; native species; plant species; specialization; urbanization

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Recommended information sources

Benedetti, Y., F. Morelli, C. T. Callaghan, and R. Fuller. 2021. Distribution and protection of avian specialization in Europe. Global Ecology and Biogeography 31:10–24.

Morelli, F., Y. Benedetti, A. P. Møller, and R. A. Fuller. 2019. Measuring avian specialization. Ecology and Evolution 9:8378–8386.

Reif, J., D. Hořák, A. Krištín, L. Kopsová, and V. Devictor. 2016. Linking habitat specialization with species' traits in European birds. Oikos 125:405–413.

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The Diploma Thesis Supervisor

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Dean

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I hereby declare that I have independently elaborated the diploma/final thesis with the topic of: .. “***Using Open-Source citizen science biodiversity data to determine spatial associations between native/exotic flora and specialist/non-specialist avian species within an urban setting”****.. and that I have cited all the information sources that I used in the thesis and that are also listed at the end of the thesis in the list of used information sources.*

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Using Open-Source citizen science biodiversity data to determine spatial associations between native/exotic flora and specialist/non-specialist avian species within an urban setting

ABSTRACT

Urbanization is associated with the decline of biodiversity from consequent habitat conversion into urban fabrics. How taxa respond to this urbanization is contingent on the novel risks and resources created by the urban matrices and the ability of those species to utilize the new conditions. This study used open-source Citizen Science data to identify differing responses of native and nonnative flora species and avian dietary specialist species to Prague municipality’s urban matrix. Native and Nonnative flora species appeared to have both habitat overlap and distributions distinct from each other while native flora species richness decreased with increasing imperviousness and nonnative species increased. Similarly, avian dietary specialists and nonspecialists were not perfectly codistributed, but both declined with increasing imperviousness while nonspecialist species had a greater tolerance of high urban density. Avian specialists also had a higher preference for areas with greater native species richness and higher overall proportions of native flora species. Differences emerged when distinguishing between invertebrate and endotherm specialists with endotherm specialists tolerating areas with greater imperviousness and reduced abundances of flora species. Examining the protection status of avian species within the Czech Republic also revealed that protected species were more likely to have a high degree of dietary specialism and more sensitive to urbanization.

Keywords: avian diet; exotic species; native species; plant species; specialization; urbanization

Použití Open-Source dat o biologické rozmanitosti z občanských věd k určení prostorových asociací mezi původní/exotickou flórou a specializovanými/nespecializovanými ptačími druhy v městském prostředí

ABSTRAKTNÍ

Urbanizace je spojena s úbytkem biodiverzity z následné přeměny stanovišť na městské struktury. Jak taxony reagují na tuto urbanizaci, závisí na nových rizicích a zdrojích vytvořených městskými matricemi a na schopnosti těchto druhů využívat nové podmínky. Tato studie použila data Citizen Science s otevřeným zdrojovým kódem k identifikaci různých reakcí původních a nepůvodních druhů flóry a druhů specializovaných na ptačí výživu na městskou matrici pražského magistrátu. Zdálo se, že původní a nepůvodní druhy flóry se překrývají a distribuce se od sebe liší, zatímco bohatost původních druhů rostlin se s rostoucí nepropustností snižovala a nepůvodní druhy rostly. Podobně, ptačí dietní specialisté a nespecialisté nebyli dokonale kodistribuováni, ale oba klesali s rostoucí nepropustností, zatímco nespecializované druhy měly větší toleranci k vysoké městské hustotě. Specialisté na ptáky také více preferovali oblasti s větší původní druhovou bohatostí a celkově vyšším podílem původních druhů rostlin. Rozdíly se objevily při rozlišování mezi specialisty na bezobratlé a endotermy a specialisty na endotermy tolerujícími oblasti s větší nepropustností a sníženou abundací druhů rostlin. Zkoumání stavu ochrany ptačích druhů v ČR také odhalilo, že chráněné druhy mají vyšší míru dietetické specializace a jsou citlivější k urbanizaci.

Klíčová slova: ptačí dieta; exotické druhy; původní druhy; druhy rostlin; specializace; urbanizace

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Table of Contents

1. INTRODUCTION

Urbanization is a major driver of habitat loss and, consequently, biodiversity loss worldwide. The impact of urbanization on biodiversity is dependent on how urban matrices are constructed and the distribution and composition of remnant habitat patches (Laurance & Bierregaard, 1997, Zhu et al., 2020) Some taxa are more sensitive to novel anthropogenic environments than others (Szlavecz, Warren, & Pickett, 2010). Avian species in particular display a strong filtering response between urban tolerant species and urban avoidant species (Callaghan et al., 2019). The composition of floristic communities and their respective place of origin also may alter the response to urbanization from avian species (Dyson 2020, Narango, 2017, Zietsman et al., 2019). This may be because of a connection to habitat associated with specific floristic communities and increasing dietary specialism of avian species requiring more particular habitat compositions (Clucas & Marzluff, 2015, Reif et al., 2015). Evaluating trends can require intensive sampling methods and the physical presence of researchers; however, the rise of citizen science applications providing open-source, geolocated data, of real-world species observations may shed light on how the composition of flora and avian communities are responding to urbanization without a similar dedication of time and resources (Callaghan,2020, Hewitt, 2022).

2. AIMS OF DIPLOMA THESIS

To examine the influence of native flora and floristic communities on the distribution of specialist bird species along a gradient of urban density.

3. LITERATURE REVIEW

3.1. Biodiversity Loss

Current patterns of globlization have resultted in two crises that threaten to undo it. The more well-known at a popular level are the risks of rapid climate change due to the release of greenhouse gases from fossil fuel acquisiton and use. The second, less popularly addressed crises is pertaining to the rapidly increasing rate of species extinction, or biodiversity loss, from extraction of resources (beyond fossil fuels), habitat conversion for urbanization and food production, or changing in the abiotic conditions to state where previously extant life can not be supported (such as ocean acidification). Among these activities, habitat conversion appears to be the leading cause for biodiversity loss.

Habitat conversion does not only result in the immediate loss of suitable land for biological communities, but will also separate populations of species that can lead to their long term decline due to a lack of genetic diversity among now distinct populations (Hanski, 2011). This general trend aligns with the well-established and researched theory of Island Biogeography which claims that isolated patches of habitat maintain internal equilibrium states related to the area of the patch as well as inflow and outflow of additional species or their populations (MacArthur & Wilson, 2001). The implication of this theory is that as surface area declines, extinction rates increase due to a reduction in resources available to support existing or new members of the biological community. While the model is helpful, the rate of decline of populations associated with habitat conversion does not play out uniformly, but instead varies according to a number of factors such as the make up of the overall matrix, the ratio of edge to internal surface area, and species interactions (Laurance, 2008).

3.2. Urbanization and Biodiversity

Urbanization is a major driver for habitat conversion and the biodiversity loss that follows. By 2030, urban areas are expected to expand by 185% (Oakleaf et al., 2015). A major means of mitigating the loss of biodiversity in urban and landscape planning has been the designation of protected habitat patches, but, as stated previously, many different factors can influence their efficacy, such as size, proximity to other habitat patches, and the ratio between patch edge and patch interior. Furthermore, planning to allow flow between patches is often species specific and dependent on their own dispersal capacity resultting in non-uniform benefits across trophic levels (Turrini & Knop, 2015). The use of ecological corridors has been included in planning practices to improve flow and dispersal between patches. These corridors offer distinct benefits according to the species making use of them.

In some instances the corridors begin to function as patches themself, rather than connecting distinct patches (Angold et al., 2006). While there are benefits to creating designated patches and corridors, intended or accidental, accounting for the influence of the urban matrix surrounding these landscape components is necessary to explore.

As habitat conversion and fragmentation continues in association with urbanization, the make up of the surrounding matrix that emerges gains importance. Structural and microclimatic similarity between the converted matrix and remaining habitat fragments maintains connectivity within the landscape increasing suitability for native species to make use of a greater area (Laurance & Bierregaard, 1997). Habitat quality within remaining patches also appears to be influenced by landscape scale patch patterns such as similarity between patches, clustering of patches, and density of patches per unit area, but the negative or postive influence of these factors varies regionally (Zhu et al., 2020).

Urbanized areas create unique conditions that are highly suitable for some species. This class of synanthropic species appear well adapted for urban environments and occur within different urban areas globally (Szlavecz, Warren, & Pickett, 2010). The reoccurrence of these species risks biotic homogenization as urban centers act as locus for dispersal into surrounding areas (McKinney & Lockwood, 2001). These well adapted species are often, but not always, exotic. They then outcompete potential native species attempting to recolonize the urban environment as well as those that exist exterior to it. In contrast, however, urban environments can also mimic locally rare, but regionally important, ecosystem types that offer conservation benefits to novel biological communities (Richardson, Lundholm, & Larson, 2010). Understanding how different urban development patterns create the risk for homogenization in comparison to offering benefits to rare species is an essential question for creating cities that support biodiversity.

3.3. Urbanization and Flora Species Response

Flora species richness can be a means for understanding the impact of urbanization on local biota. In general, habitat conversion appears to result in a decline in the presence of native flora species but, due to the high number of exotic flora species introduced from urbanization, species richness can increase at a city wide scale in comparison to richness outside of the urban area (Zipperer & Guntenspergen, 2009). At smaller scales, the heterogenous nature of urban environments creates the conditions for varying degrees of species richness dependent on the land use and structural diversity (Walker et al., 2009). Some spatial patterns of development, such as suburban communities as an extension of urban centers, show the ability to regain lost native species after construction-induced local extinctions (McKinney, 2002). Their ability to do so is contingent on the proximty to differing habitat types at the edge of suburban development (McKinney, 2002).

3.4. Urbanization and Avian Species Response

There is also direct relationshipship between habitat conversion the ability for avian communities to persist in urbanized or urbanizing areas. Habitat fragmentation and the reduction in patch size reduces assemblages of urban avian species (Evans et al., 2009). The impact of urbanization on avian communities can also be considered on the urban to rural gradient where greater diversity of avian species persists at the less urbanized fringes and is lost in the urban core (Xie et al., 2019). The loss of some avian species is due to the novel conditions and, as a result, novel risks that urban environments create, such as increased exposure when foraging for food due to low density of vegetation cover (Sol et al., 2014). This does not play out evenly across avian species resultting in classifications of urban tolerant species, those who can make use of the urban matrix, and urban avoiders, those that are confined to remaining habitat patches with sufficient size or migrate to the less developed fringes (Sol et al., 2014). The filtering of these two groups can occur due to species specific nesting and dietary preferences (Clucas & Marzluff, 2015).

3.4.1. Avian Specialism

An alternative means for classifying avian species is the designation of specialist or nonspecialist (generalist) species on the bases of various functional traits such as foraging ecology, breeding, or habitat preferences (Morelli et al., 2019). Within this frame, nonspecialist species trend towards urban tolerance due to their ability to fit within a variety of niches whereas dietary specialists were more sensitive to urbanization (Callaghan et al., 2019). This is not surprising given that dietary specialism is also associated with higher rates of habitat specialism within avian species and the previously mentioned trends in reduction of habitat quality and quantity associated with urbanization (Reif et al., 2015). Consequently, it is possible that the distribution of dietary specialists could be used as an indicator of in-tact, high quality, habitat within urbanized areas.

3.5. Relationships between Avian Species, Flora Species, and Urbanization

While the general trend of urbanization is a reduction in habitat quality leading to a reduction in avian species, there is evidence to support that different development patterns can sustain or even increase local avian species richness. Marzluff (2005) found that moderate levels of urbanization on the edges of Seattle resulted in greater colonization of bird species. A possible reason proposed was that development led to an increase in tree species diversity locally in comparison to the denser urban interior and the forested exterior opening greater niche space for a variety of bird species. This coincides with findings in Evans et al. (2009) that greater structural complexity in woody vegetation and species richness increased local avian species assemblages. Xie et al. (2019) also suggests that increased species and height diversity of trees increases avian species richness and intraspecies abundances.

3.5.1. Native versus Nonnative Flora Species

The origin of the species within floristic communities in urbanized areas may also have an impact on the ability of the urban matrix to sustain avian communities. In Dyson (2020) it was found that forest stand structure and species compositions that mimicked the pre-development forests with mostly native species supported higher avian richness and larger avian communities in comparison to developed areas with high density of exotic tree species. In Narango et al. (2017) the foraging preferences of an insectivorous avian specialist were connected to the distribution of native flora reintroduced into residential landscapes in comparison to exotic flora. Similarly, avian frugivore specialists were observed to use feeding sites within urban areas adjacent to urban nature reserves if the sites possessed the same native, fruit-bearing, tree species (Zietsman et al., 2019). Additionally, it was found that frugivore species would forage either the urban nature reserve or the urban matrix based off availability of fruit in the other area. It is important to note that both relationships between the avian dietary specialists and native flora species are species-specific but understanding how and where those relationships can occur can help to direct research for species of concern.

3.6. Citizen Science and Biodiversity Research

If the structure and species composition of floristic communities within urban areas can have some impact on the functionality of these spaces for avian species generally, it is important then to understand the distribution of both groups to begin to elucidate those relationships at a finer scale. One trend that is helping to clarify the distribution of target taxa globally is the rise of Citizen Science applications such as *iNaturalist* (Hewitt, 2022). *iNaturalist* is a tool that allows for users to take a photograph of a species of interest and then uses Computer Vision, a subdiscipline of Artificial Intelligence, to aid users in identifying species observed (*iNaturalist*, 2016). Those observations then are uploaded and georeferenced allowing fellow users to comment and verify the proposed species identification. After most users have agreed on a species identification, the observation gains “research grade” status. To date, there are 57,000,000 georeferenced, research grade, observations and over 300,000 species identified (*GBIF*, 2012). These identifications are open access and can be exported for research purposes.

The adoption of the *iNaturalist* application and other Citizen Science tools have been evaluated for their capacity to make assessments beyond distribution of species. In Chandler et al. (2017) they claim that information such as ecosystem function, phenology, and population abundances can be gleaned when combined with the larger datasets that *iNaturalist* observations feed into. As a result, a greater number of projects are looking for ways to integrate datasets from Citizen Science applications to efficiently evaluate biodiversity or manage natural resources (Pocock et al., 2017). Despite the potential utility of these platforms, there is resistance to their widespread adoption (Burgess et al., 2017). Part of that resistance emerges from the uneven spatial or temporal sampling of citizen scientists which may limit the types of inferences that can be made from the various datasets (Boakes et al., 2010). It is also clear that there is bias towards specific taxon such as flora, avian species, and Lepidoptera, with charismatic species recurring the most frequently (Pocock et al., 2017).

3.6.1. Utility of Citizen Science for Verifying known Distribution of Target Taxa

Despite the limitations of data gathering through Citizen Science applications, their ability to shed light on ecological phenomenon is growing. In the Western Ghats, *eBird,* another Citizen Science app using bird song to identify species and location, was used by Ramesh et al. (2017) to evaluate the accuracy of IUCN threatened avian species' range maps created by Birdlife International in comparison to their observed range and resulting predicted distribution. The *eBird* data revealed that significant portions of the avian species' proposed range did not contain suitable habitat and that their real range was significantly smaller. Uyeda et al. (2020) compared *iNaturalist* data for open shrubland flora species observations to existing fine scale vegetation maps and found that the majority (87%) of observations were within 10 meters of known individual plants. While these examples help to verify or improve existing knowledge of species range, *iNaturalist* data is limited by only noting occurrence of individual organisms, but not the absence. The lack of absence data can hinder predictive capability of species ranges if other environmental variables are not included. Another major drawback emerges from uneven observation distribution in areas with high user traffic compared to areas less accessible or less frequented by *iNaturalist* users.

3.6.2. Utility of Citizen Science for Illuminating Response to Urbanization of Target Taxa

Citizen Science occurrence data has also been used in relationship to the urbanness of various taxa. In Callaghan et al. (2020) the distribution of *iNaturalist* observations in Boston, Massachusetts were compared to the amount of light pollution associated with developed areas to generate mean urban tolerance levels of commonly reoccurring species. These locations of these reoccurring species were then examined in nearby cities and towns to examine the response of biodiversity within those areas to urbanization. While the previous example used light pollution as a proxy for urbanization, imperviousness in the area where species were observed can similarly reflect the degree of tolerance to urbanization (Yan et al., 2019).

4. METHODS

4.1. Data Acquisition

The study area chosen for this project was the territory within the municipal boundary of the Prague, Czech Republic. The shapefile for the municipal boundary of Prague was downloaded from *Geoportal Praha's* website (*Úvod | Geoportál Hl. M. Prahy*, n.d.).

Distribution data of *iNaturalist* research grade observations for avian and flora species was downloaded using the export tool (*iNaturalist* 2018). Avian observations originally were filtered for a maximum positional accuracy of 50 meters, 10,108 observations remained. Those 10,108 observations were made up of 169 species reoccurring on average 60 times with a median reoccurrence value of 12.5. Species were then eliminated that occurred less than median value. The final number of observations was 9720 with 71 unique species. Each avian species was then given a designated GINI coefficient for dietary specialism that ranged from 0.047 to 1, with 1 being an indication of a specialist species and anything less than one indicating a nonspecialist (Morelli, Benedetti, et al., 2021).

AVIAN OBSERVATION DATA

CATEGORY	**Count**
AVIAN SPECIES	81
DIETARY SPECIALIST SPECIES	9
DIETARY NON-SPECIALIST SPECIES	72
TOTAL NUMBER OF AVIAN OBSERVATIONS	9681
AVERAGE OBSERVATIONS PER SPECIES	119.52

STANDARD DEVIATION OF OBSERVATIONS PER SPECIES	148.83

Table 1. Avian observation data used for this study.

Flora species observations were also filtered for a maximum positional accuracy of 50 meters. Algal and moss species were also removed. The resulting 38,451 observations contained 1174 unique species. These species had an average reoccurrence rate of 32.75 and a median reoccurrence rate of 7. Any species reoccurred less than the median value was removed. The remaining 36,948 observations possessed 586 unique species. Each species was then designated as either native (having the geographic origin of the Czechia) or nonnative (including naturalized, casually invasive, and highly invasive species) through examining their listing in *Pladias: Database of the Czech Flora and Vegetation* (2014). In some cases, the naming convention used by *iNaturalist* did not correspond to any species listing in *Pladias.* When this occurred, the species was searched on *Plants of the World Online* (2017) to identify potential synonyms which were then searched again on *Pladias.*

FLORA OBSERVATION DATA

CATEGORY	**Count**
PLANT SPECIES	586
NATIVE PLANT SPECIES	326
NONNATIVE PLANT SPECIES	260
TOTAL NUMBER OF PLANT OBSERVATIONS	36948
AVERAGE OBSERVATIONS PER SPECIES	63.16
STANDARD DEVIATION OF OBSERVATIONS PER SPECIES	87.67

Table 2. Plant observation data used for this study.

Imperviousness was used as a proxy for urbanization intensity of the Prague municipality. The imperviousness data was downloaded as a raster layer from the Pan European high-resolution layers available on *Copernicus.eu (Imperviousness, 2018).*

4.2. Data Processing

The acquired data was imported into GIS and then processed in two different methods. The first was a first was the use fishnet system that isolated proximate observations into shared cells for analysis. The second was through interpolating the flora species presence to show a predicted distribution based off observations and extracting the values at each georeferenced avian species identification.

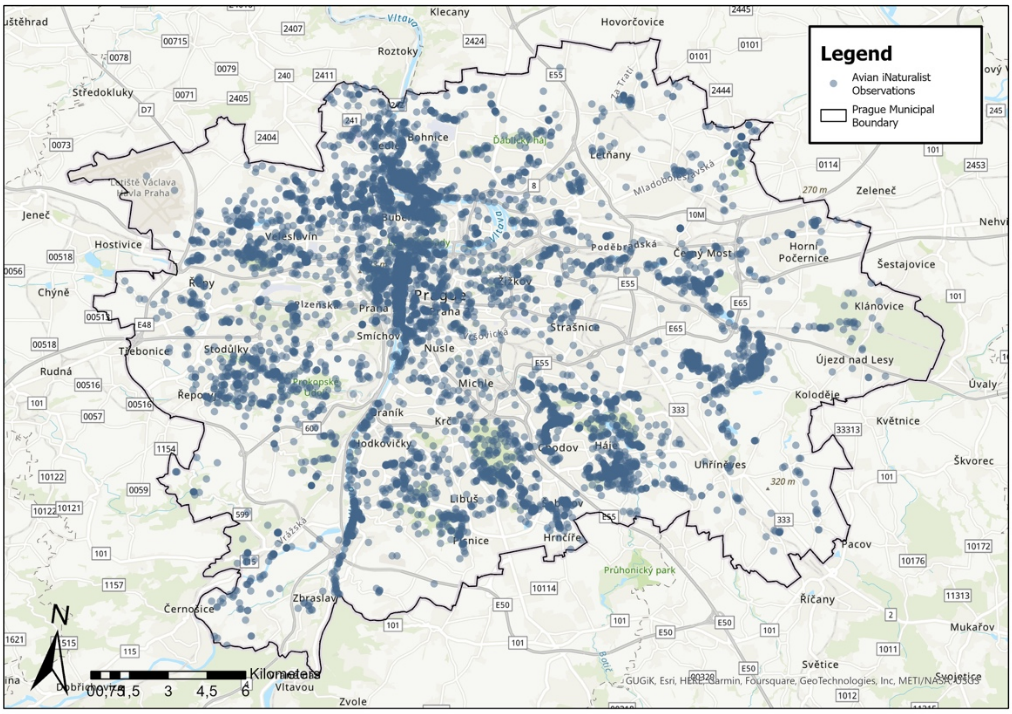


Figure 1. Distribution of all Avian iNaturalist Observations used in this study.

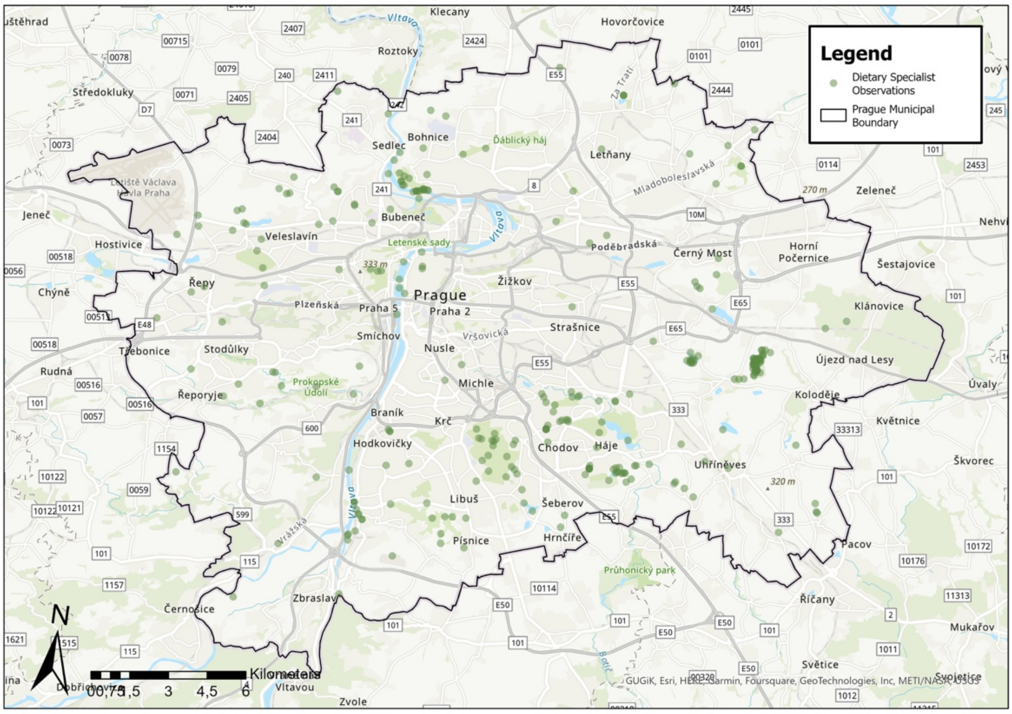


Figure 2. Distribution of avian dietary specialist iNaturalist observations used in this study. .

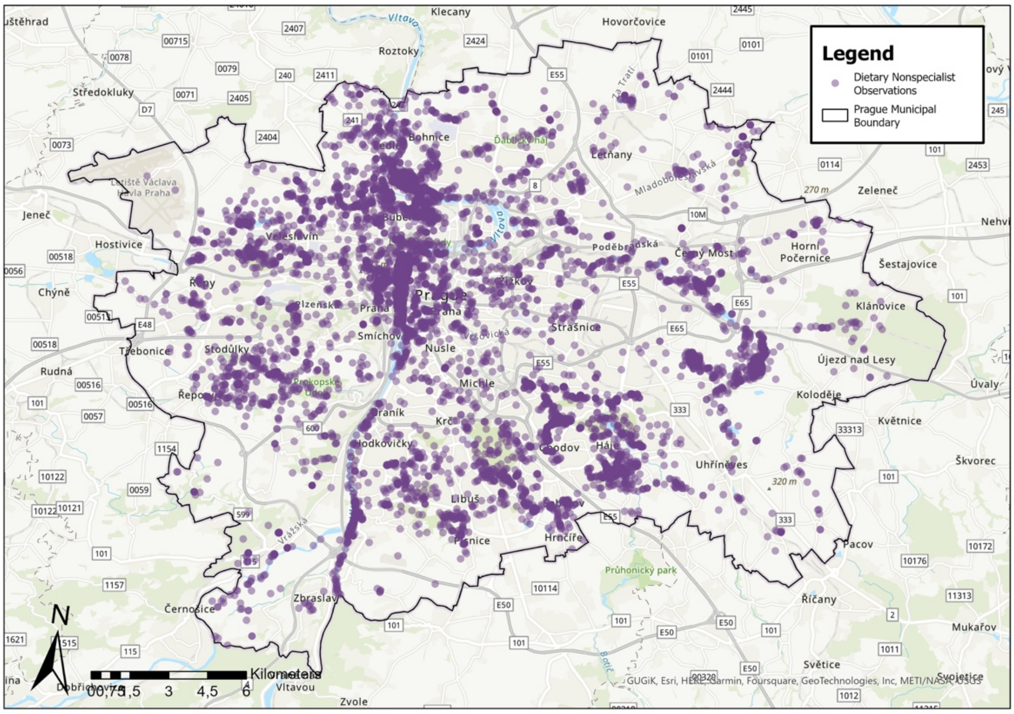


Figure 3. Distribution of avian dietary nonspecialist iNaturalist observations used in this study.

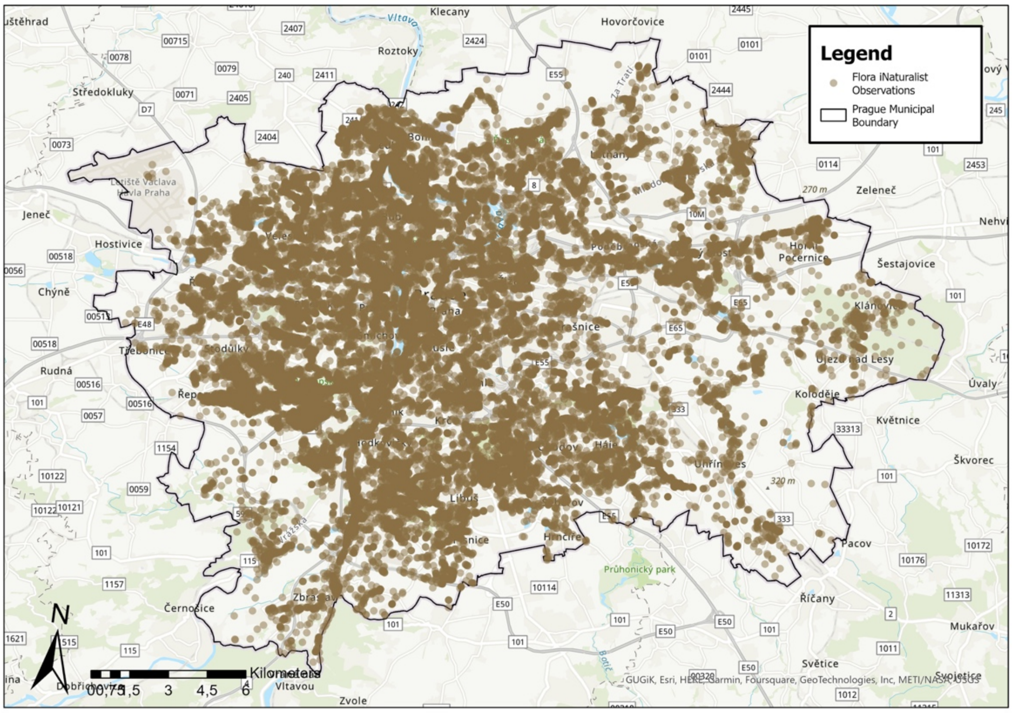


Figure 4. Distribution of all iNaturalist plant observations used in this study.

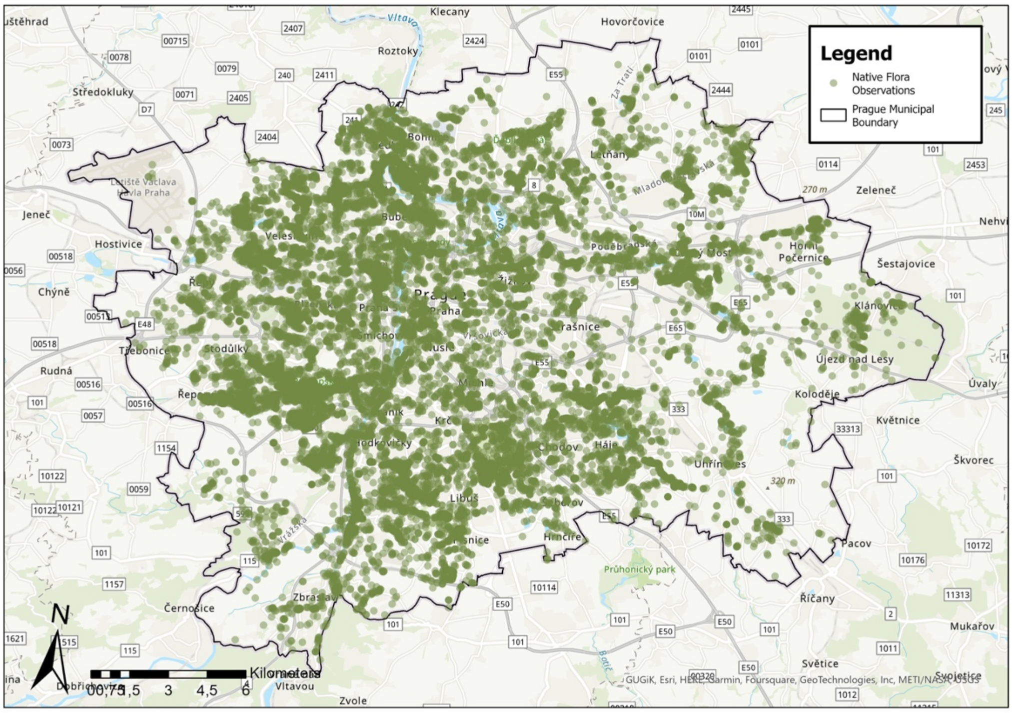


Figure 5. Distribution of iNaturalist native plant observations used in this study.

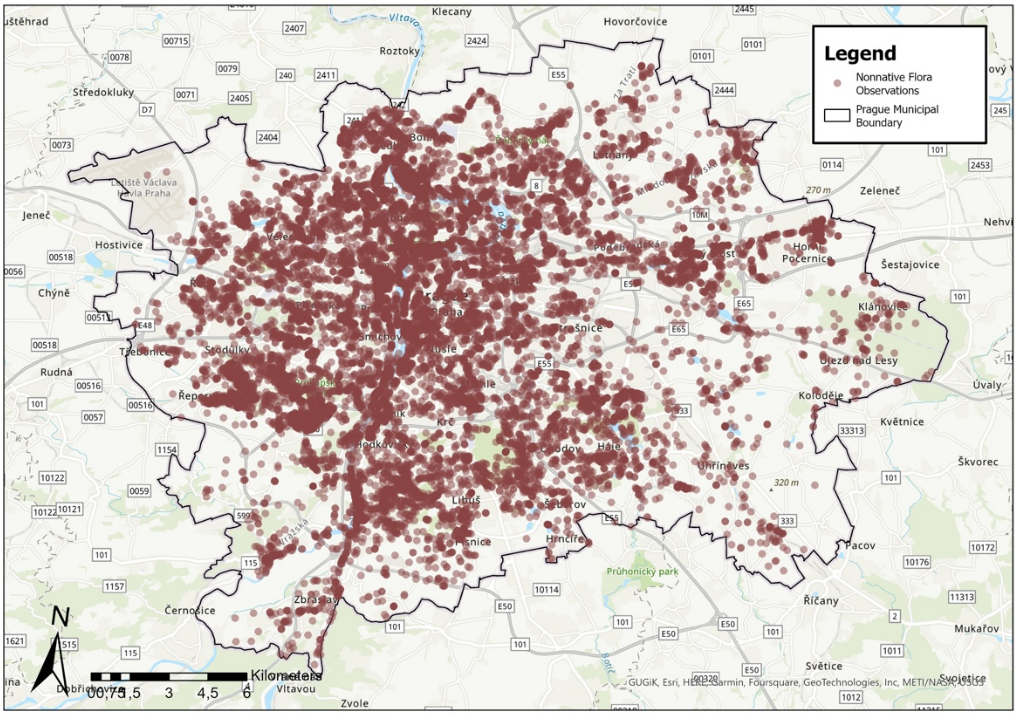


Figure 6. Distribution of iNaturalist nonnative plant observations used in this study.

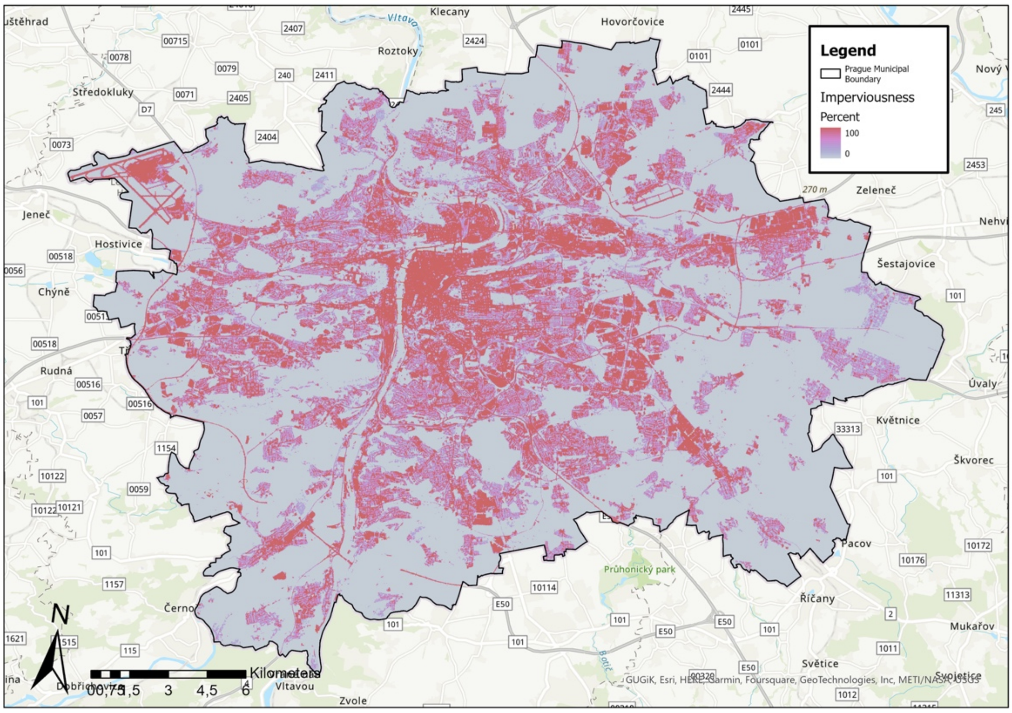


Figure 7. Imperviousness of Prague municipality.

4.3. Fishnet Method

A 100 meter by 100 meter cell fishnet was created for the full extent of the Prague municipal bounds. Plant observation counts were then joined to each cell they were geographically aligned with according to total plant observations, number of native plant observations, and number nonnative plant observations. A ratio of native to nonnative plants was also created and attributed to each cell. Avian observations were similarly attributed to the cell but with distinct categories (ie. total bird observations, specialist birds, and non-specialist birds according to their GINI value for dietary specialism). The average imperviousness of the urban area contained within each cell was also joined to the dataset for comparison. Cells that did not contain any plant observations and any bird observations were removed from analysis. This resulted 1265 cells for analysis due to uneven coverage of observation data. The mean values of plant count per cell, native plant count per cell, nonnative plant count per cell, ratio of native to nonnative plants, and imperviousness, was then calculated for cells that contained either specialist or non-specialist avian species, cells that were absent one of the avian groups, and cells that contained both groups. All independent variables were examined for covariance and linearity with the dependent variables.

A second fishnet analysis was conducted using the species richness of each cell per category instead of the observation count. The mean values and statistically significant differences between the different avian groups was examined once again. Species richness for each category was also examined for linearity and covariance. These results were compared with the prior results for observation counts.

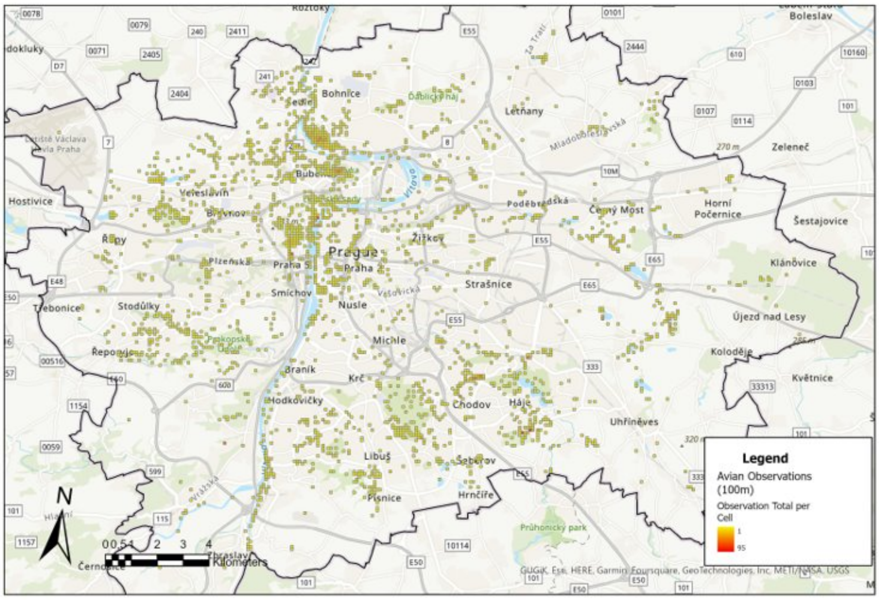


Figure 8. 100 meter by 100 meter Fishnet with cells containing avian observations displayed.

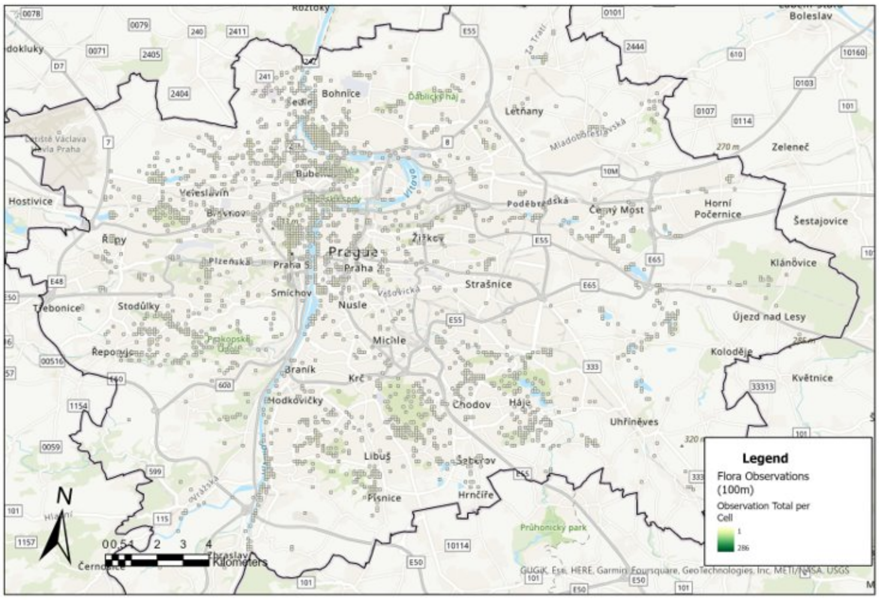


Figure 9. 100 meter by 100 meter fishnet with cells containing plant observations displayed.

4.4. Interpolation Methods

Due to the uneven coverage of observation data, flora distributions were also predicted through using kernel count interpolations. The flora observations were distinguished according to all plant observation count, native plant density, and nonnative plant density. The native and nonnative plant densities were used to create a ratio of native to nonnative plants. Impervious data was once again examined without any manipulation due to it being a continuous surface.

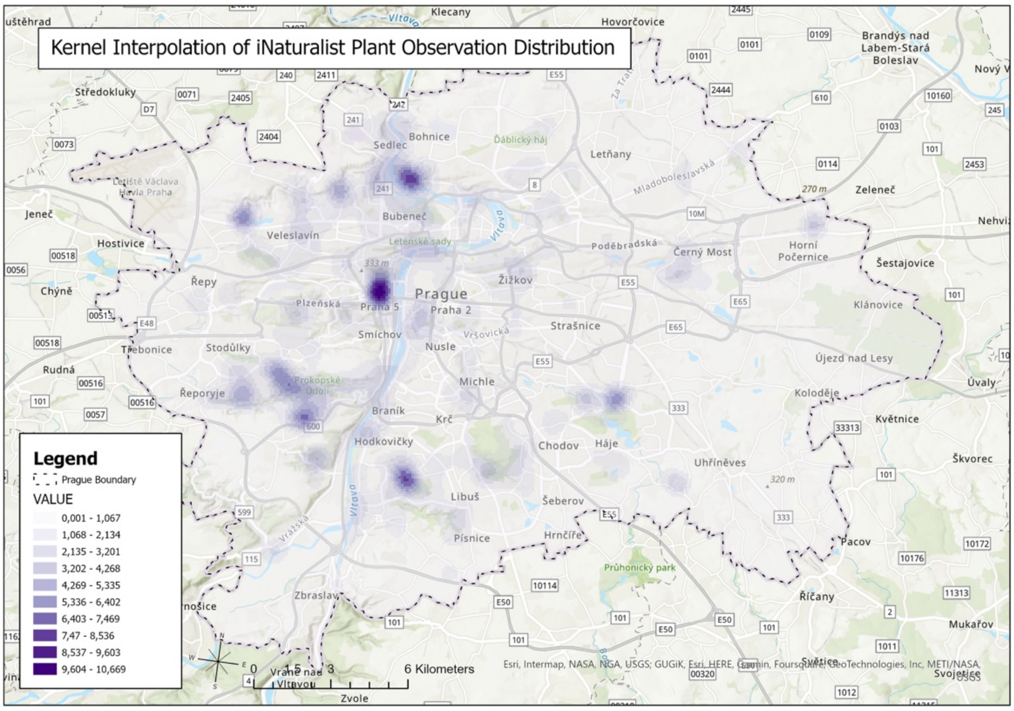


Figure 10. Plant count interpolated from iNaturalist observations.

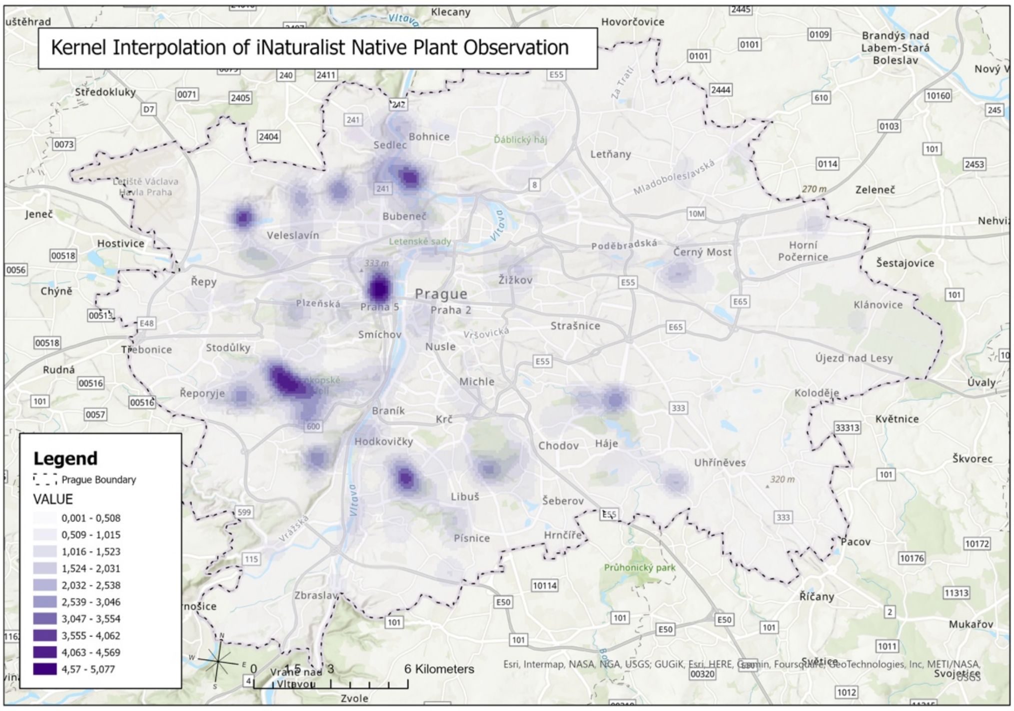


Figure 11. Native plant count interpolated from iNaturalist observations.

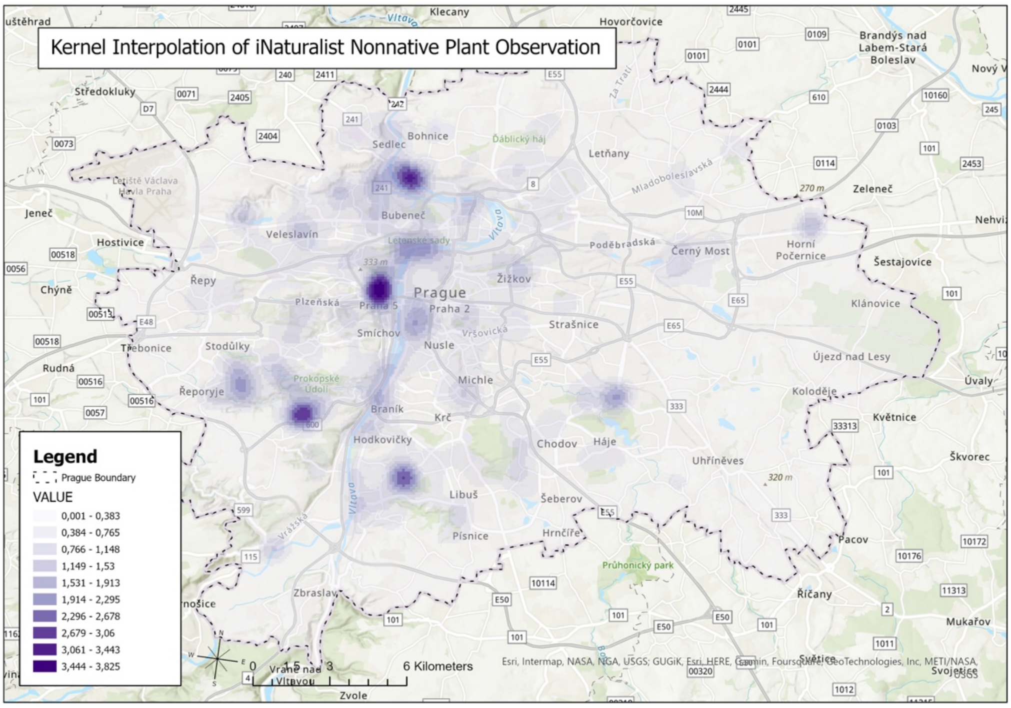


Figure 12. Nonnative plant count interpolated from iNaturalist observations.

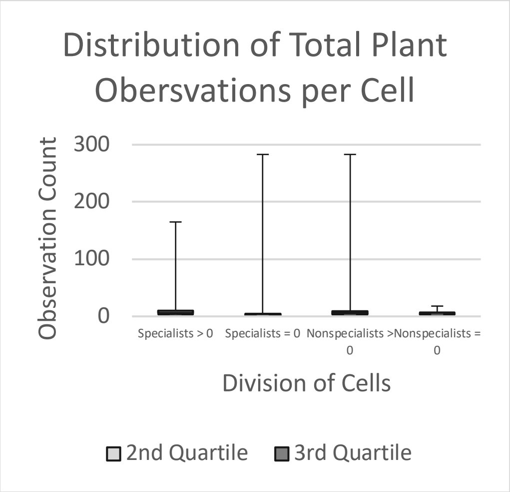
The information about each interpolated distribution was then extracted to the individual location where each avian species was observed. The GINI value for dietary specialism was then used to distinguish avian groups between specialists and nonspecialists. Additional categories were created for the two types of dietary specialism represented in the observation data (invertebrate specialists and endotherm specialists). A subcategory of non-specialists was also examined separately due to their species being previously noted as indicators of high environmental quality by Morelli, Reif, et al. (2021). P-values were then calculated for the mean difference in values of plant count, native plant observation density, nonnative plant observation density, the ratio between native to nonnative plants, and impervious for specialists, invertebrate specialists, endotherm specialists, nonspecialists, and indicators of high environmental quality.

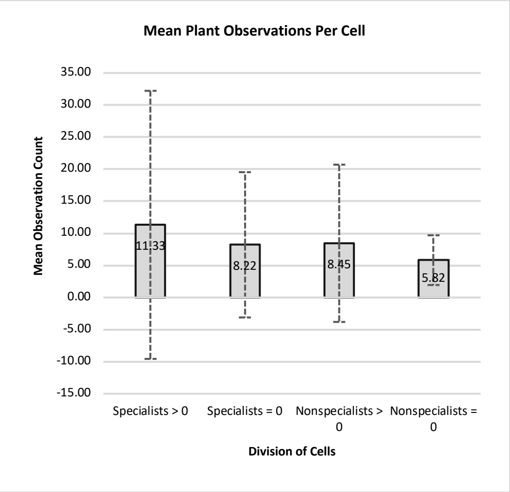
Differences of conservation status was also examined among the avian species represented in this study. The first distinction was made according to the IUCN red list (IUCN, 2022). Because the IUCN red list takes a broader perspective in assigning the status of avian species, the conservation status of avian species according to the Czech Nature Protection Agency was also considered (*Agentura Ochrany Přírody a Krajiny ČR*, 2023).

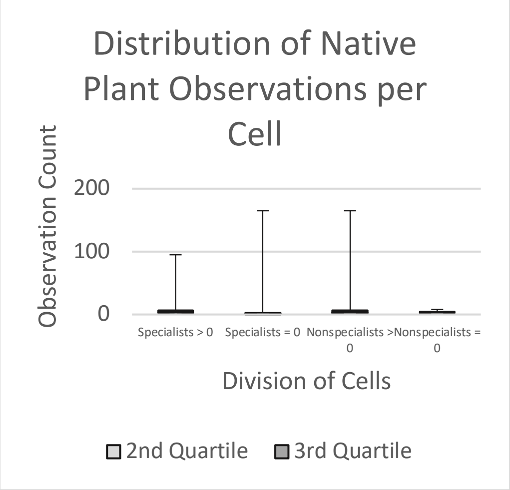
5. RESULTS

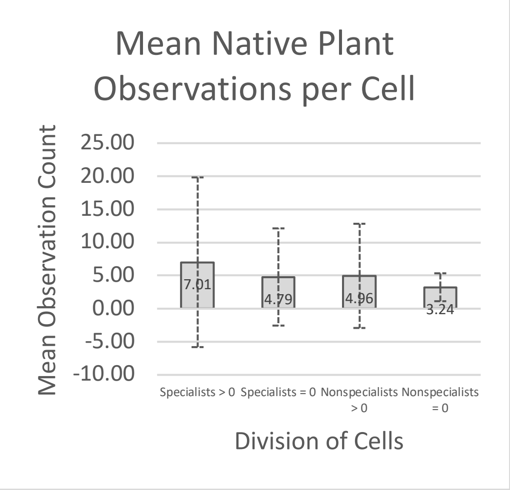
5.1. Fishnet Analysis

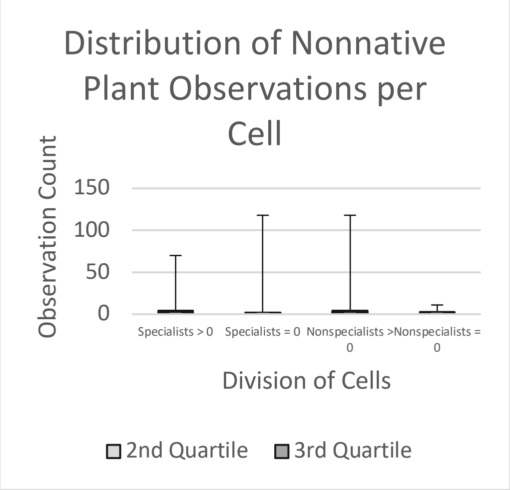
Examination of the fishnet cells compared the differences between mean values of cells that contained avian dietary specialist species, avian dietary nonspecialist species, and cells that were absent each group. Cells with avian dietary specialists (specialists > 0) had the highest mean values for all flora categories (mean plant observations, mean native plant observations, mean nonnative plant observations, and mean ratio of native to nonnative plant observations) (Figure 13). Cells with avian dietary specialists also had the lowest average imperviousness (Figure 13). Cells that were absent any avian dietary nonspecialists (nonspecialists = 0) had the lowest for all flora categories, while cells that did not have any specialists (specialists = 0) had the highest average imperviousness per cell (Figure 13).

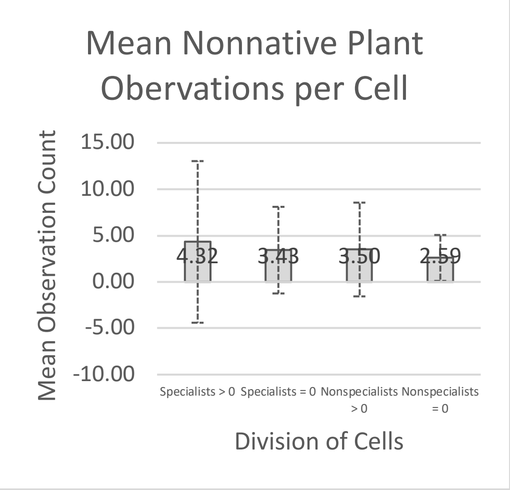

Distribution of Total Plant Obersvations per Cell


Mean Plant Observations Per Cell


Distribution of Native Plant Observations per Cell


Mean Native Plant Observations per Cell


Distribution of Nonnative Plant Observations per Cell


Mean Nonnative Plant Obervations per Cell

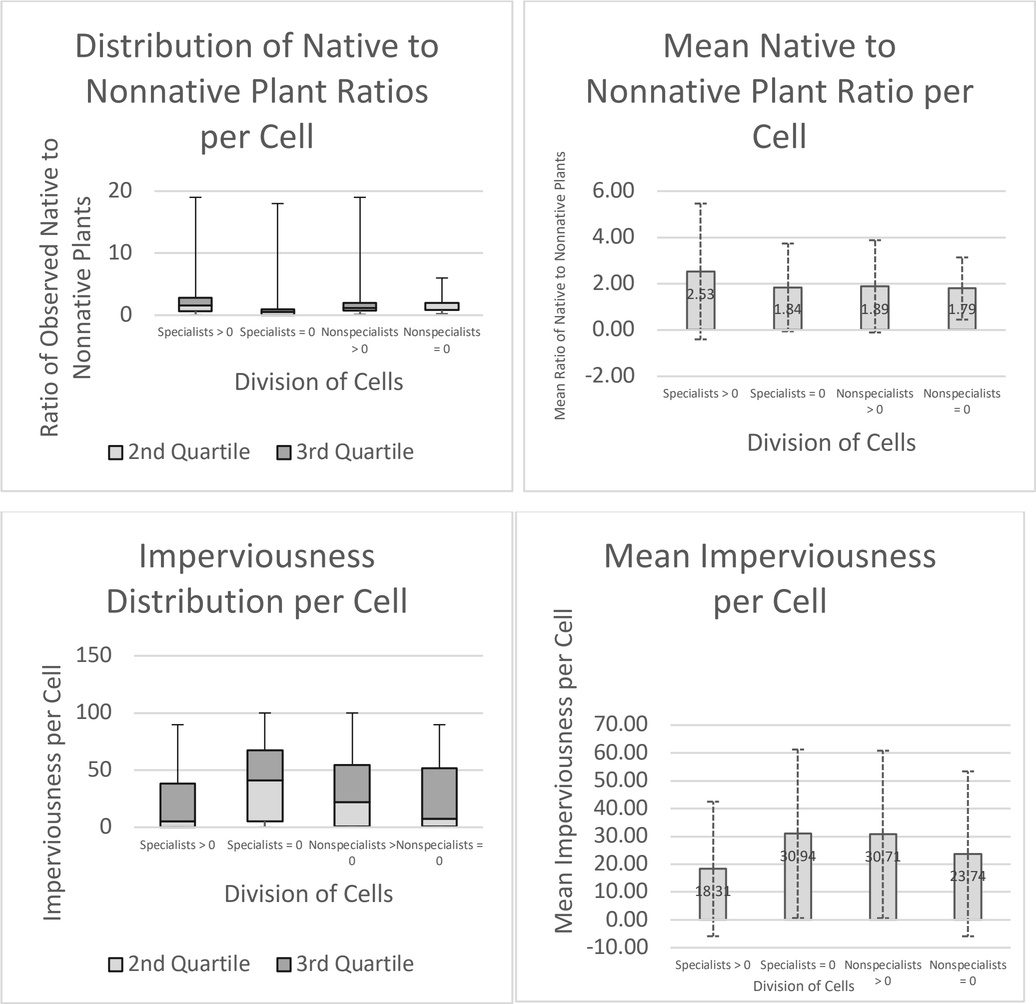


Figure 13. Charts for distribution of observation count values and respective means for each variable according to cells containing specialists and nonspecialists, or excluding specialists and nonspecialists.

5.1.1. Statistically Significant Differences

Cells that contained specialists in comparison to cells that did not were found to have statistically significant differences in mean plant observations (p=0.0254), mean native plant observations (p=0.0129), mean native to nonnative plant observations (p=0.0023), and imperviousness (p=0.0002). Cells that contained dietary specialists in comparison to cells that contained nonspecialists also had statistically significant differences between mean native to nonnative plant observations (p=0.0065), and imperviousness (p=0.0003) (Table 1).

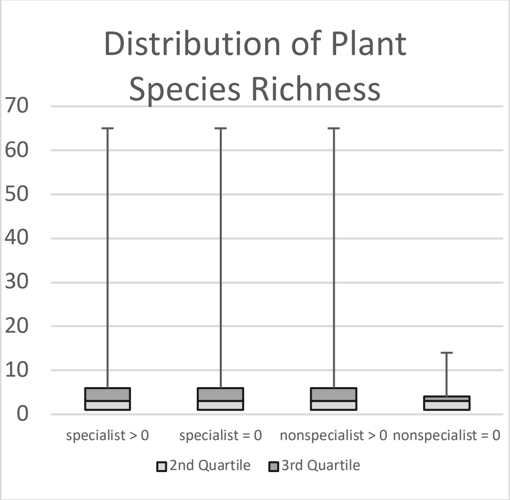
P VALUES

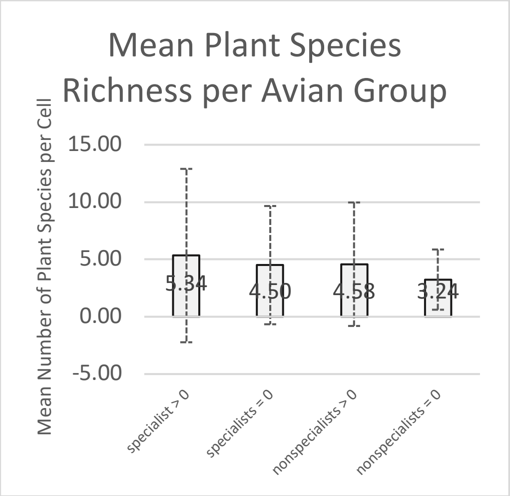
	Mean Plant Obs.	**Mean Native Obs.**	**Mean Nonnative Obs.**	**Native/Nonnative Plant Obs. Ratio**	**Imperviousness**
SPECIALIST = 0, > 0	**0.0254**	**0.0129**	0.1214	**0.0023**	**0.0002**

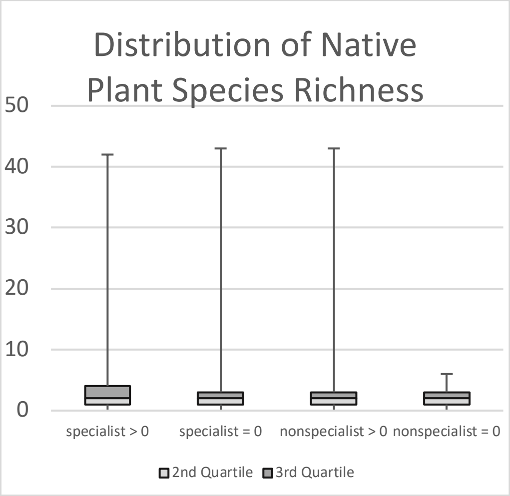
NONSPECIALIST = 0, > 0	0.3771	0.3681	0.4594	0.8364	0.3432
SPECIALIST > 0, NONSPECIALIST > 0	0.5130	0.5973	0.1795	**0.0065**	**0.0003**
SPECIALIST > 0, NONSPECIALIST = 0	0.2831	0.2314	0.4209	0.312	0.4201

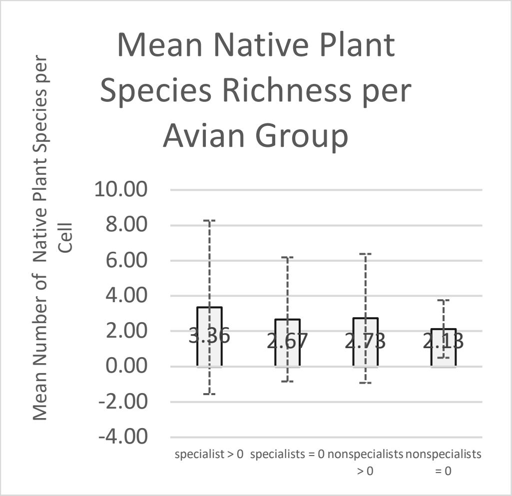
Table 1. Statistical significance of the difference of means between cells containing specialists and nonspecialists or excluding speicalists or nonspecialists. .

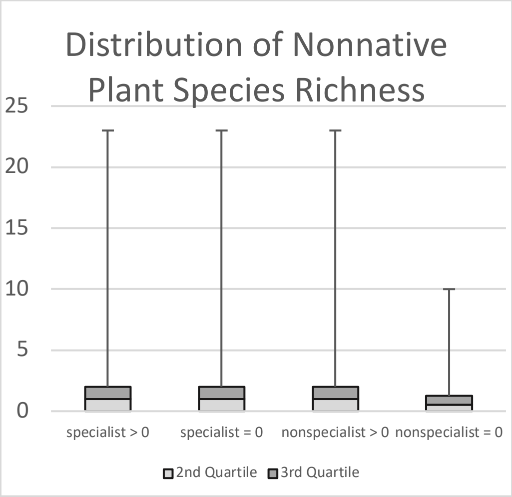
Results for species richness showed that the cells containing specialists had the highest means for all floristic categories except for the proportion of native species within the cell (Figure13). That group with the highest value were cells without nonspecialists (ie cells that did contain some specialists but had no presence of nonspecialists). Cells containing specialists also had the lowest mean imperviousness (Figure 13).

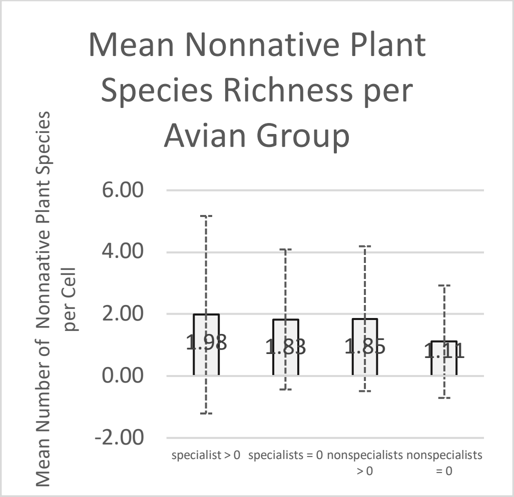


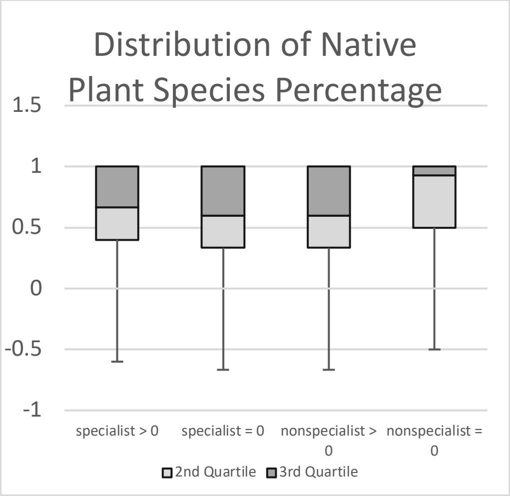


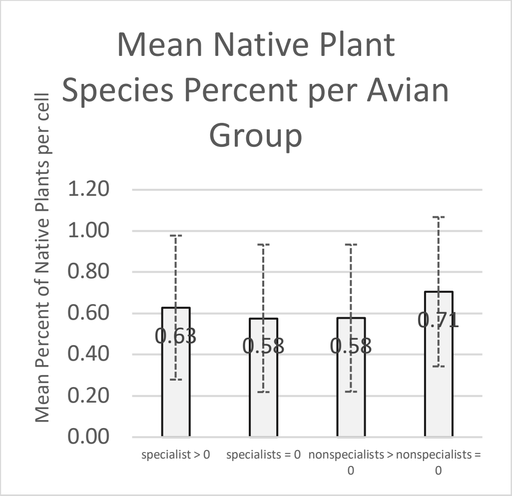

Distribution of Native Plant Species Richness
50
40
30
20
10
0
specialist > 0
specialist = 0
nonspecialist > 0
nonspecialist = 0
2nd Quartile
3rd Quartile


Mean Native Plant Species Richness per Avian Group
Mean Number of Native Plant Species per Cell
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
3.36
2.67
2.73
2.13
specialist > 0
specialists = 0
nonspecialists > 0
nonspecialists = 0


Distribution of Nonnative Plant Species Richness
25
20
15
10
5
0
specialist > 0
specialist = 0
nonspecialist > 0
nonspecialist = 0
2nd Quartile
3rd Quartile


Mean Nonnative Plant Species Richness per Avian Group
Mean Number of Nonnaative Plant Species per Cell
6.00
4.00
2.00
0.00
-2.00
1.98
1.83
1.85
1.11
specialist > 0
specialists = 0
nonspecialists > 0
nonspecialists = 0


Distribution of Native Plant Species Percentage
1.5
1
0.5
0
-0.5
-1
specialist > 0
specialist = 0
nonspecialist > 0
nonspecialist = 0
2nd Quartile
3rd Quartile


Mean Native Plant Species Percent per Avian Group
Mean Percent of Native Plants per cell
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.63
0.58
0.58
0.71
specialist > 0
specialists = 0
nonspecialists > 0
nonspecialists = 0

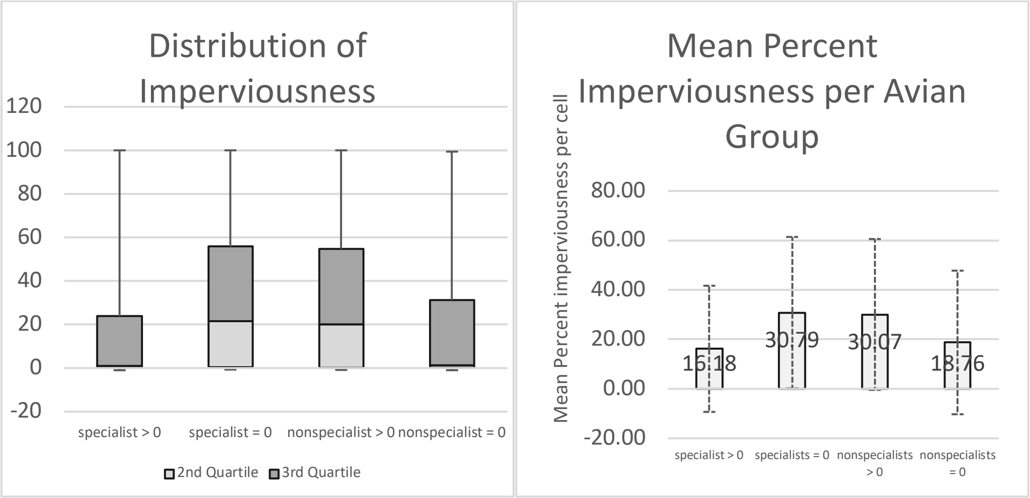


Figure 14. Charts for distribution of species richness values and respective means for each variable according to cells containing specialists and nonspecialists, or excluding specialists and nonspecialists.

P VALUES

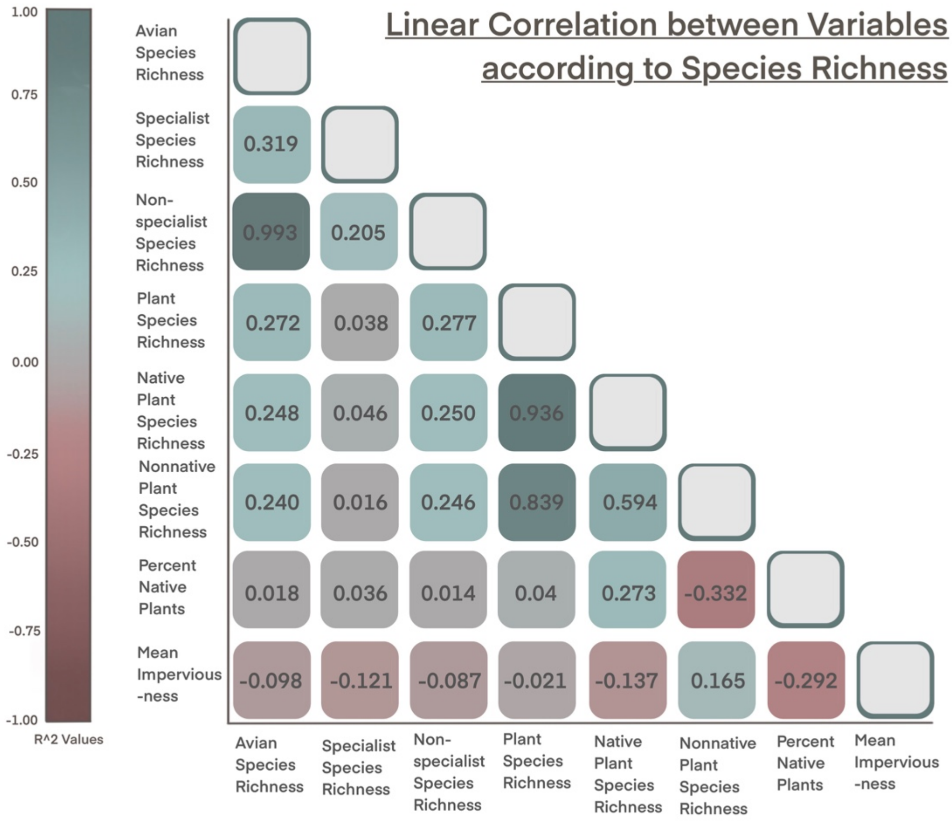
	Plant SR	Native Plant SR	Nonnative Plant SR	Percent Native	Mean Imperviousness
SPEC > 0, SPEC = 0	0.0618	**0.0242**	0.4332	0.0815	**0.0001**
SPEC > 0, NONSPEC > 0	0.103	**0.0449**	0.5218	0.0855	**0.0001**
SPEC > 0, NONSPEC = 0	0.0639	0.0947	0.0759	0.1916	0.5583
NONSPEC > 0, NONSPEC = 0	0.0886	0.2620	**0.0306**	**0.0149**	**0.0118**
SPEC = 0, NONSPEC > 0	0.6095	0.6009	0.7217	0.9358	0.4266

Table 3. Statistical Signficance of difference among means for each variable according to cells containing specialists and nonspecialists or cells excluding specialists and nonspecialists.

Statistically significant differences were found for the species richness of native plants for cells that contained dietary specialists compared to cells that did not, as well as for cells that contained specialists and cells that contained nonspecialists. The same groups had statistically significant differences for mean imperviousness (Table 3).

5.1.2. Linear Regression

Linear regression for both fishnet analysis for observation counts and species richness showed positive correlations for all plants, native plants, and nonnative plants with both observation counts and species richness of specialist and nonspecialist avian species (Figures 14 & 15). The positive correlation was higher for the cells containing avian observations and species richness as well as nonspecialist observations and species richness in comparison to cells containing specialist species (Figures 14 & 15). There was a negative trend for imperviousness across all avian groups (Figures 14 & 15). Observation count had mean higher correlation for all avian species and nonspecialists for plant data than species richness (Figures 15). There was no mean difference in correlation specialist species. Species Richness and imperviousness had a greater negative correlation for all avian species, specialist species, and nonspecialists species, than observation counts (Figures 14 & 15).



	Avian Species Richness	Specialist Species Richness	Non-specialist Species Richness	Plant Species Richness	Native Plant Species Richness	Nonnative Plant Species Richness	Percent Native Plants	Mean Impervious -ness
Avian Species Richness								
Specialist Species Richness	0.319							
Non-specialist Species Richness	0.993	0.205						
Plant Species Richness	0.272	0.038	0.277					
Native Plant Species Richness	0.248	0.046	0.250	0.936				
Nonnative Plant Species Richness	0.240	0.016	0.246	0.839	0.594			
Percent Native Plants	0.018	0.036	0.014	0.04	0.273	-0.332		
Mean Impervious -ness	-0.098	-0.121	-0.087	-0.021	-0.137	0.165	-0.292	

Figure 15. Correlogram for examined variables pertaining to species richness.

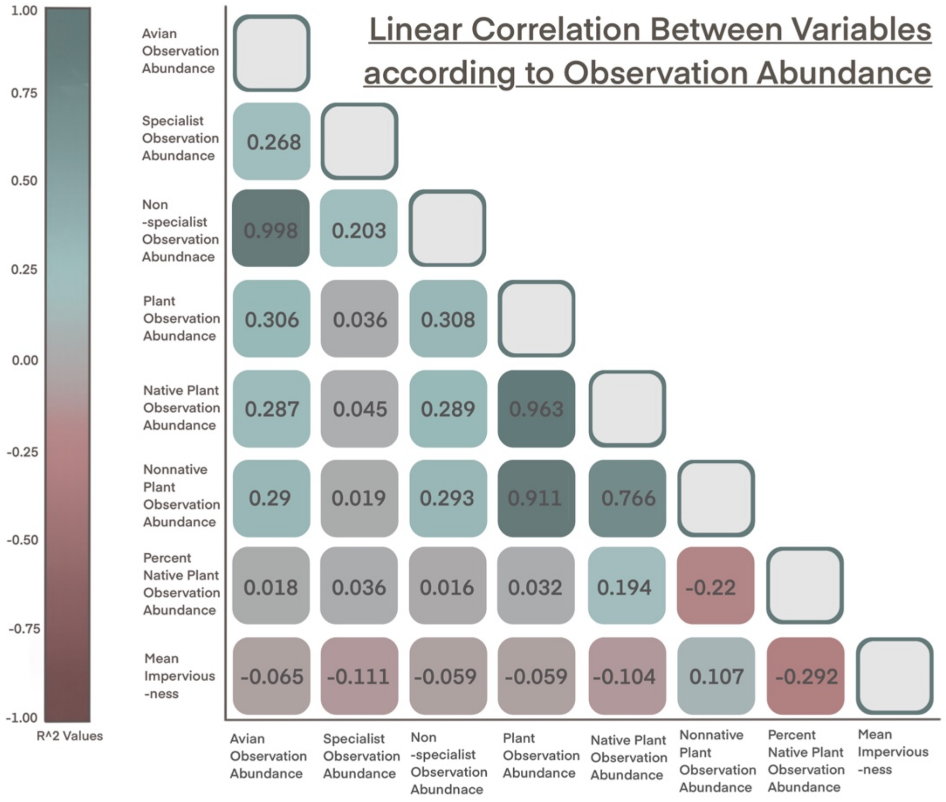


Figure 15. Correlogram for examined variables pertaining to observation abundance

5.2. Interpolation Results

The interpolated kernel map values for the flora categories were extracted for each avian species represented in the study. Impervious surface data was also extracted at each point of observation. These values were then averaged for each species. The avian species were then distinguished according to three different categorization methods for analysis. The first category was according to their IUCN Red List Status (Table 4).

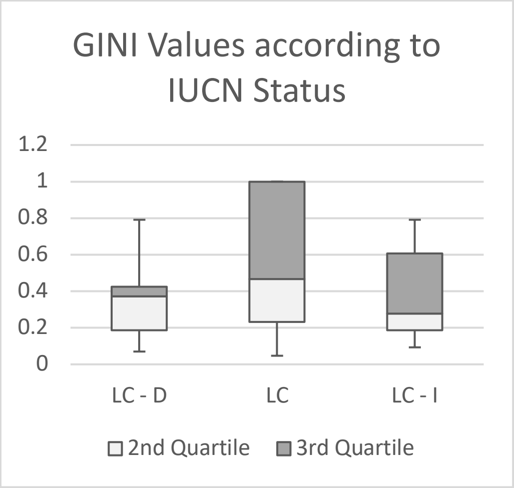
5.2.1. Results According to Conservation Status

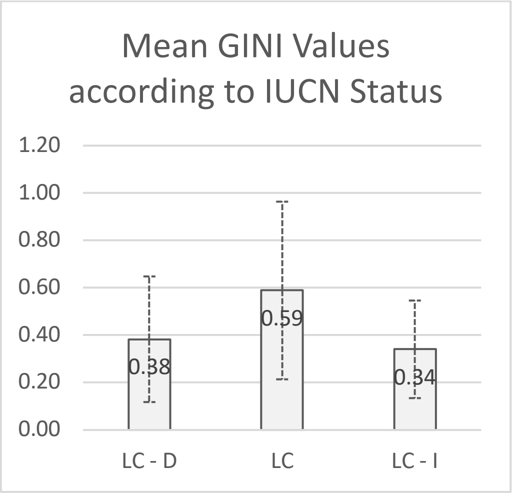
Least Concern – Population Decreasing		**Least Concern – Population Stable**		**Least Concern – Population Increasing**	
Species	GINI	Species	GINI	Species	GINI
Asio otus	1	*Apus apus*	1	*Aix sponsa*	0.419
Aix galericulata	0.186	*Charadrius dubius*	1	*Anas platyrhynchos*	0.14
Carduelis carduelis	0.186	*Delichon urbicum*	1	*Anser anser*	0.605
Columba livia	0.372	*Dryocopus martius*	1	*Buteo buteo*	0.791

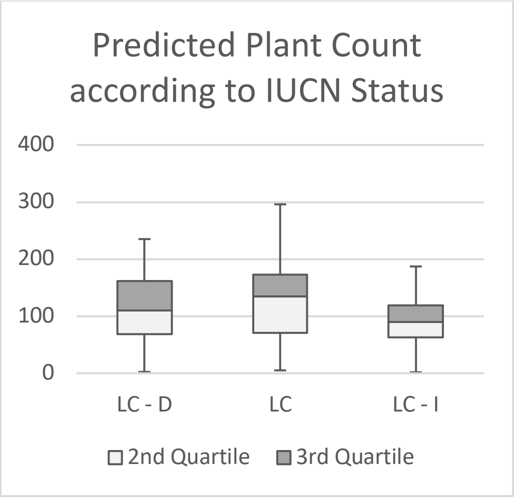
Emberiza citrinella	0.372		*Ficedula hypoleuca*	1		*Coccothraustes coccothraustes*	0.186
Falco tinnunculus	0.791		*Motacilla alba*	1		*Columba palumbus*	0.233
Linaria cannabina	0.186		*Motacilla cinerea*	1		*Curruca communis*	0.326
Passer domesticus	0.372		*Accipiter nisus*	1		*Cyanistes caeruleus*	0.14
Passer montanus	0.442		*Aegithalos caudatus*	0.302		*Cygnus olor*	0.605
Phasianus colchicus	0.163		*Aythya fuligula*	0.233		*Dendrocopos major*	0.256
Poecile palustris	0.185		*Chloris chloris*	0.232		*Erithacus rubecula*	0.116
Spatula clypeata	0.4096		*Curruca curruca*	0.326		*Fringilla coelebs*	0.349
Sturnus vulgaris	0.07		*Gallinula chloropus*	0.2563		*Fulica atra*	0.093
Tachybaptus ruficollis	0.628		*Garrulus glandarius*	0.186		*Parus major*	0.14
			Luscinia megarhynchos	0.465		*Phalacrocorax carbo*	0.605
			Pica pica	0.047		*Phoenicurus ochruros*	0.372
			Sitta europaea	0.442		*Phoenicurus phoenicurus*	0.628
			Spinus spinus	0.186		*Phylloscopus collybita*	0.605
			Turdus pilaris	0.512		*Picus viridis*	0.791
						Streptopelia decaocto	0.186
						Sylvia atricapilla	0.256
						Troglodytes troglodytes	0.302
						Turdus merula	0.233
						Turdus philomelos	0.233

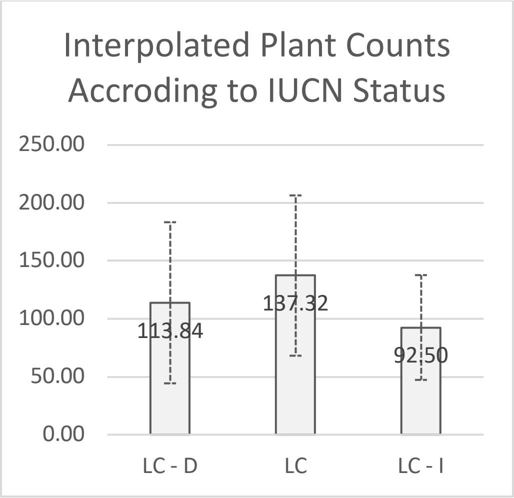
Table 4. Avian species according to their IUCN Status and GINI values for dietary specialism.

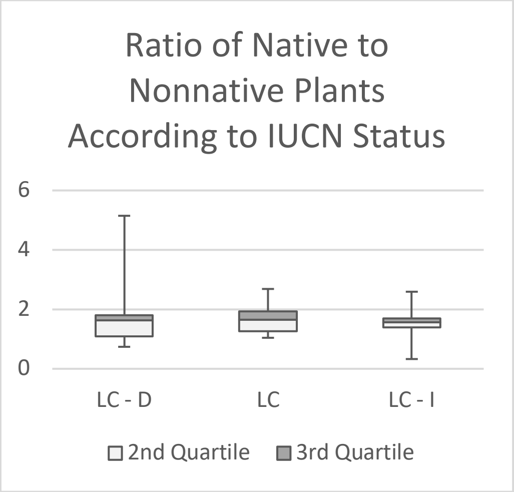
Every species represented in the study was designated as Least Concern. The analysis was conducted according to their population information which was either decreasing, stable, or increasing (abbreviated to LC-D, LC, and LC-I in the following charts) (Figure 15). The information regarding native plant count and nonnative plant count was collapsed into the ratio between the two groups for this portion.

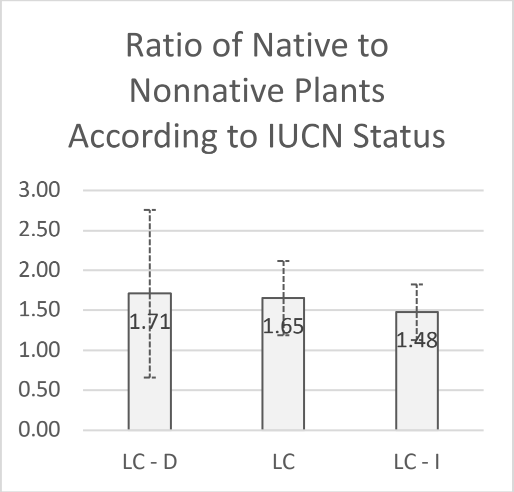

GINI Values according to IUCN Status
1.2
1
0.8
0.6
0.4
0.2
0
LC - D
LC
LC - I
☐ 2nd Quartile
■ 3rd Quartile


Mean GINI Values according to IUCN Status
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0.38
0.59
0.34
LC - D
LC
LC - I


Predicted Plant Count according to IUCN Status
400
300
200
100
0
LC - D
LC
LC - I
☐ 2nd Quartile
■ 3rd Quartile


Interpolated Plant Counts Accroding to IUCN Status
250.00
200.00
150.00
100.00
50.00
0.00
113.84
137.32
92.50
LC - D
LC
LC - I


Ratio of Native to Nonnative Plants According to IUCN Status
6
4
2
0
LC - D
LC
LC - I
☐ 2nd Quartile
■ 3rd Quartile


Ratio of Native to Nonnative Plants According to IUCN Status
3.00
2.50
2.00
1.50
1.00
0.50
0.00
1.71
1.65
1.48
LC - D
LC
LC - I

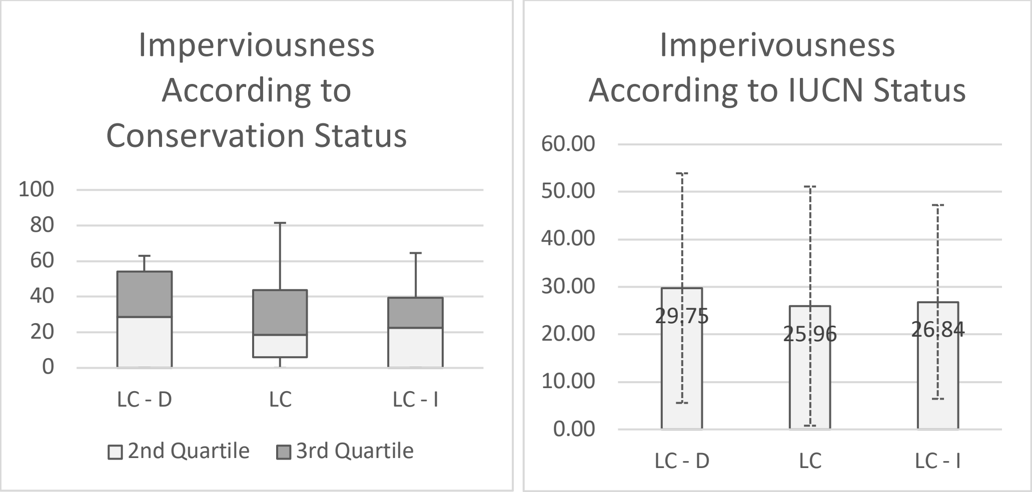


Figure 15. Charts for distribution of values and respective means for each variable avian species' IUCN conservation status.

The species listed under Least Concern with Increasing populations showed a lower mean GINI value for dietary specialism, lower average plant count, and lower native to nonnative plant ratio than the species with stable or decreasing populations (Figure 15). The group with the highest mean GINI value and highest plant count was the stable group (Figure 15). The differences in the means were then examined for statistical significance (Table 5).

P VALUES

	GINI	Average count of Interpolated Plant Oservations	impervious surface	Ratio of Native to Exotic Plants
LC D VS LC	**0.0665**	0.3115	0.6448	0.8290
LC D VS LC I	0.5617	0.2344	0.6759	0.3075
LC VS LC I	**0.0071**	0.0121	0.8973	0.153

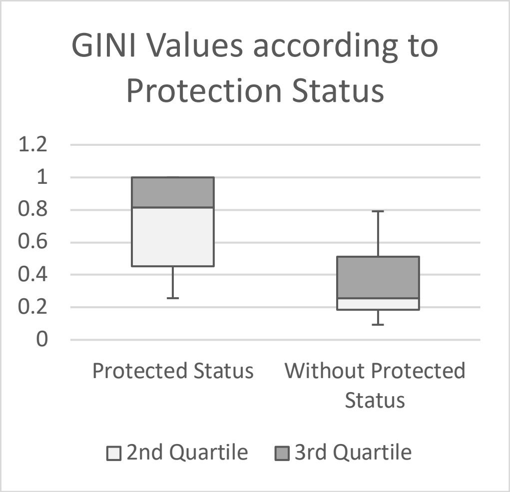
Table 5. Statistical Significance of the difference of means between Avian species according to their IUCN conservation status.

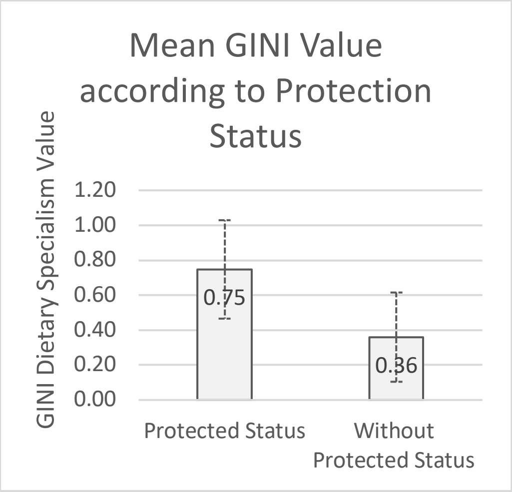
The only groups with statistically significant differences in the mean were the stable and increasing populations groups in reference to their mean GINI values (p=0.0071) and average interpolated plant count (p=0.0121) (Table 5).

The avian species were also examined in reference to their protection status within the Czech Republic (Table 6). There were 9 species total with some form of protection status (protected under the Birds Directive, listed as vulnerable, near endangered, endangered, or severely endangered). Of those 9 species 6 of them were dietary specialists. The protected species were then compared for average plant count, native to nonnative plant ratio, and average imperviousness against the species without a protection status (Figure 16).

Species	**GINI**	**Protection Status**
Dryocopus martius	1	Birds Directive
Anser anser	0.605	Vulnerable
Charadrius dubius	1	Vulnerable
Cygnus olor	0.605	Vulnerable
Delichon urbicum	1	Near Endangered
Ficedula hypoleuca	1	Near Endangered
Gallinula chloropus	0.2563	Near Endangered
Apus apus	1	Endangered
Luscinia megarhynchos	0.465	Endangered
Tachybaptus ruficollis	0.628	Endangered
Accipiter nisus	1	Severely Endangered
Spatula clypeata	0.4096	Severely Endangered

Table 6. Designated species for protected status by the Nature Protection Agency of the Czech Republic.





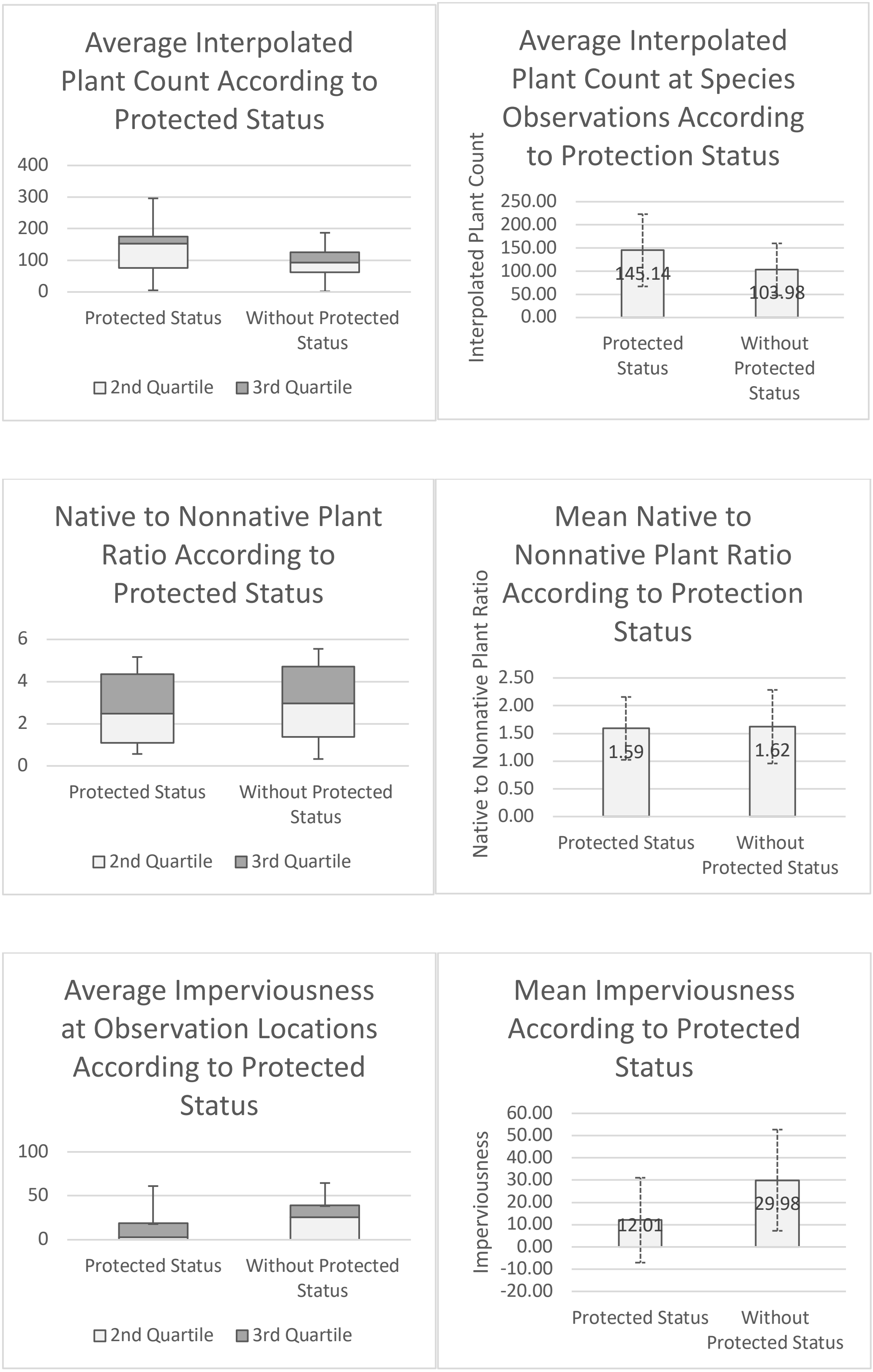


Figure 16. Charts for distribution of values and respective means for each variable avian species' protection status within the Czech Republic.

The protected avian species had higher average GINI values and plant counts while the unprotected birds had a higher average native to nonnative plant ratio and average imperviousness (Figure 16). The difference in these means was found to be statistically significant for the GINI values (p=0.0001), average plant count (p=0.0271), and impervious surface (p=0.0065) (Table 7).

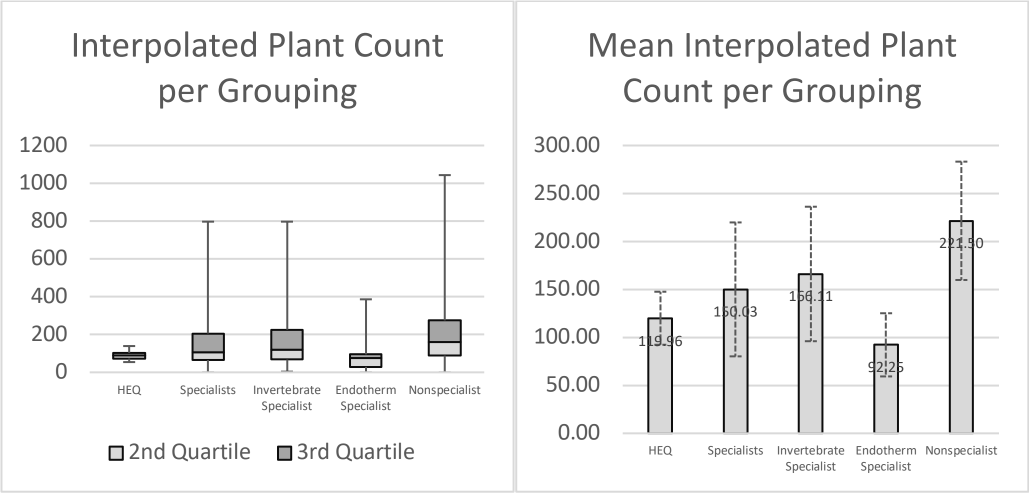
P VALUES

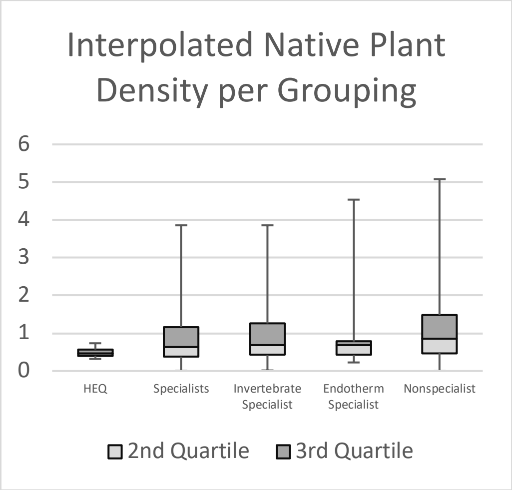
	GINI	Average count of Interpolated Plant Observations	Impervious surface	Ratio of Native to Exotic Plants
PROTECTED STATUS VS NOT PROTECTED STATUS	**0.0001**	0.0271	**0.0065**	0.8681

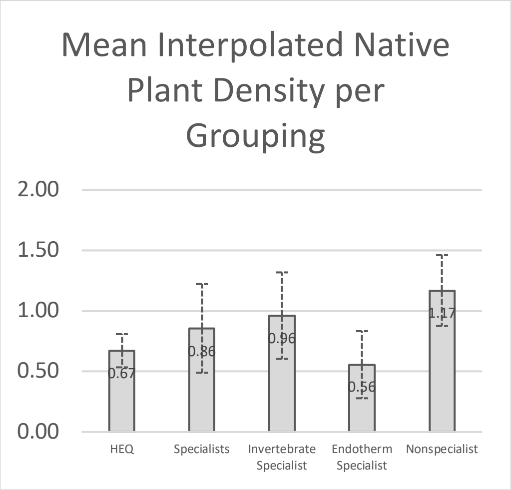
Table 7. Statistical Significance of difference between means for protected and unprotected avian species within the Czech Republic.

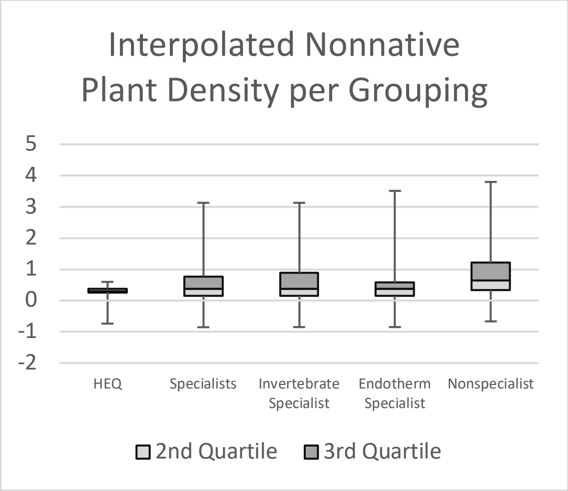
5.2.2. Results According to Dietary Specialism

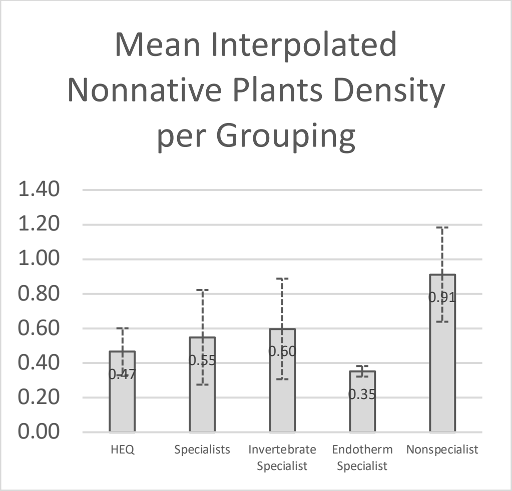
The final way the interpolated kernel values were analyzed was according to dietary specialism for each species. Five groups were created in total, dietary specialists, invertebrate specialists, endotherm specialists, nonspecialists, and indicators of high environmental quality (all belonging to nonspecialists) (Figure 17).

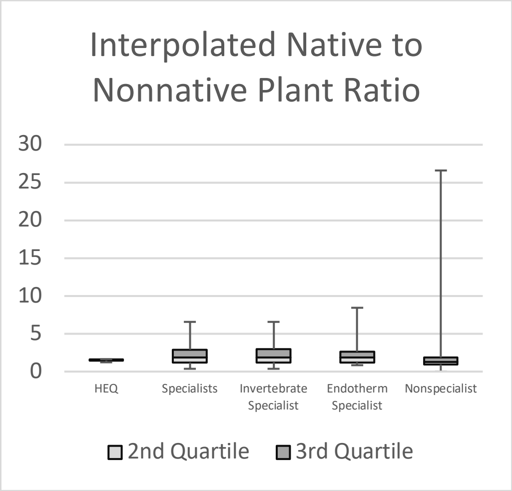


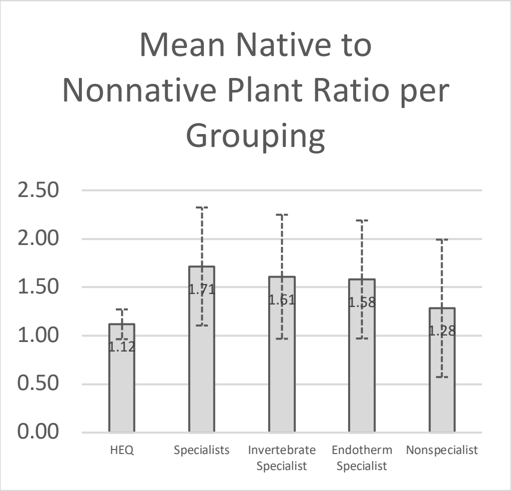

Interpolated Native Plant Density per Grouping


Mean Interpolated Native Plant Density per Grouping


Interpolated Nonnative Plant Density per Grouping


Mean Interpolated Nonnative Plants Density per Grouping


Interpolated Native to Nonnative Plant Ratio


Mean Native to Nonnative Plant Ratio per Grouping

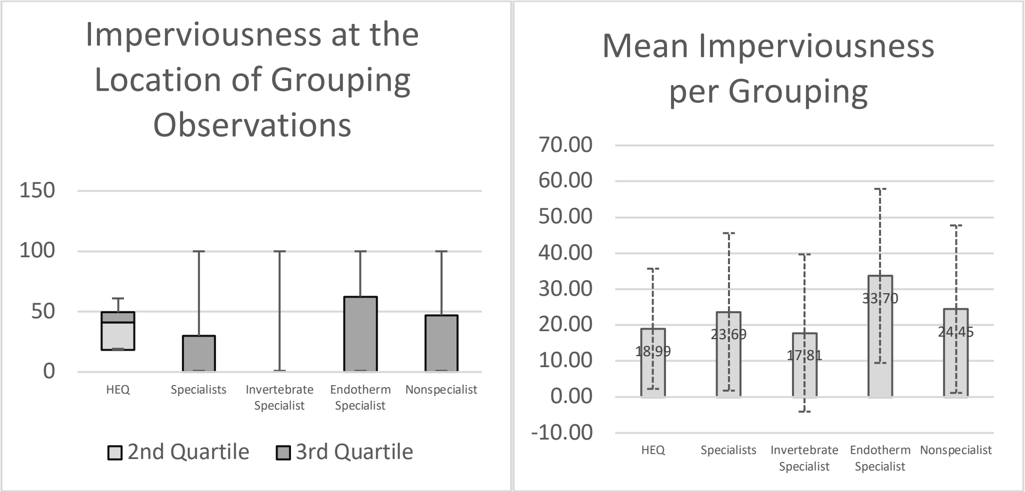


Figure 17. Charts for distribution of values and respective means for each variable avian group.

The nonspecialists had the highest means for the flora categories excluding the ratio of native to nonnative plants for which the specialists had the highest value (Figure 17). The endotherm specialists had the highest imperviousness per group and the lowest values for the flora categories excluding the ratio of native to nonnative plants (Figure 17). The means for the indicators of high environmental quality was towards the middle for each respective category.

P VALUES FOR EACH VARIABLE TESTED

T TEST COMPARISONS	All Plant Count	Native Plant Density	Nonnative Plant Density	Ratio Native to Exotic	Imperviousness
SPECIALIST VS NONSPECIALISTS	0.0026	0.0062	0.0005	0.0914	0.9292
INSECT SPECIALIST VS ENDOTHERM SPECIALIST	0.2058	0.1890	0.2936	0.9577	0.402
HEQ VS SPECIALIST	0.3382	0.2638	0.5043	0.0371	0.6640
HEQ VS NONSPECIALISTS	0.0002	0.0001	0.0002	0.5763	0.5809

Table 8. Statistical significance of the difference of means for avian groups.

The differences in mean values that were statistically significant were for the floristic categories excluding mean ratio of native to exotic plants between specialists and nonspecialists (Table 8). The indicators of high environmental quality also had statistically significant lower values for all floristic categories in comparison to the nonspecialists. There were no statistically significant differences found for imperviousness between the avian groups. The prior averages and sample sizes were determined at the species level for species belonging to each group due to the large sample size of nonspecialist observations (n=9252) diluting the potential statistical significance between results.

The difference in means for insect specialists (n=249) and endotherm specialists (n=40) was reexamined for statistical significance accounting for the number of observations rather than number of species and each variable tested was found to have statistically significant differences (Table 9).

P VALUES FOR EACH VARIABLE TESTED

T TEST COMPARISONS	All Plant Count	Native Plant Density	Nonnative Plant Density	Ratio Native to Exotic	Imperviousness
INSECT SPECIALIST OBSERVATIONS VS ENDOTHERM SPECIALIST OBSERVATIONS	0.0041	0.003	0.001	0.0011	0.0099

Table 9. Statistical significance for the difference of means between invertebrate specialists and endotherm specialists.

6. DISCUSSION

6.1. Distribution of Flora Species

My results showed that, as expected, the distribution of native plants was more strongly correlated with overall plant species richness and observation abundance ($r^2=0.936$, $r^2=0.963$) in comparison to the nonnative plants ($r^2=0.839$, $r^2=0.911$) (Figures 14 & 15). The slightly higher values for native species in comparison to nonnative species can be explained due to the native species making up a higher proportion of overall observations. The collinearity of native and nonnative plants was still positive, but less strong. The correlation between native and nonnative plants for observation abundance ($r^2=0.766$) was higher than the correlation for species richness ($r^2=0.594$). This suggests that while many native and nonnative species may co-occupy areas with observation data, there are still habitats within which distinct floristic communities are observed that may be majority native species or majority exotic species.

6.1.1. Distribution of Flora Species in Comparison to Increasing Imperviousness

The fishnet linear regression of flora observation data both in the form of abundance data and species richness showed overall negative correlations within increasing imperviousness (r^2=-0.21, r^2=-0.21) (Figures 14 & 15). When distinguishing between native and nonnative plant species, increasing imperviousness had a negative correlation for native species richness and abundance (r^2=-0.137, r^2=-0.104), but nonnative species had a slight positive correlation for both species richness and observation abundance (r^2=0.166, r^2=0.107). Similarly, the percent of native plants overall observed within each cell was negatively correlated with increasing imperviousness (r^2=-0.292) (Figure 15). Both the negative correlation for native species and positive correlation for nonnative species with increasing imperviousness were stronger for species richness in comparison to the number of observations. As a surrogate for the urban-to-rural axis, these trends along increasing imperviousness follow the previously described process of biotic homogenization where commonly reoccurring urban species occupy novel habitats created by urban environments that regionally native species may not be well suited for (McKinney & Lockwood, 2001). Because this study only occurs within the municipal region of Prague and the observation data is concentrated in high-traffic areas, it is hard to determine how species richness in the habitat patches within the urban center compares to adjacent rural areas, but in general the decreasing observation counts and species richness with increasing imperviousness contradicts the suggestion by Zipperer and Guntenspergen that species richness would increase overall in urban habitat patches (2009). They observed that overall species richness increases because native species are maintained while nonnative species increase. Their observation of this phenomenon occurred within a relatively young cities in the United States compared to Prague which had its first settlement in the 9th century AD (Richard & Jan, 1998). As a result, the replacement of native species with nonnative may not be as pronounced as in older cities.

6.2. Distribution of Avian Species

The distribution of specialist avian species richness and observation abundance had a low correlation to the distribution of all avian species when examined with linear regression (r^2=0.319, r^2=0.268) (Figures 14 & 15). The slightly higher correlation (+0.051) for species richness compared to observation abundance indicates that specialist species were less likely to have multiple observations within the same fishnet cells. The distribution of nonspecialist species; however, had a near one-to-one correlation for both species richness ($r^2=0.993$) and observation abundance ($r^2=0.998$). This suggests that nearly every cell that had avian observations, had nonspecialist observation numbers and species richness that increased in proportion to the cell totals. Specialist species and nonspecialist species also had a positive, but low, correlation between both groups' species richness and observation abundance ($r^2=0.205$, $r^2=0.203$). This suggests that the specialist and nonspecialist species are making use of distinct habitats within the sampled area or increase at rates independent of each other.

6.2.1. Distribution of Avian Species in comparison to Increasing Imperviousness

There was a slight negative correlation between imperviousness and all avian species, specialist and nonspecialist species, found with linear regression of the fishnet cells for both species richness and observation count abundance (Figures 14 & 15). The negative correlations were slightly higher for each group regarding species richness (+0.031, +0.01, and +0.028 respectively) suggesting that species richness was more negatively affected by increasing imperviousness in comparison to observation count abundances.

T-tests for observation abundance revealed statistically significant differences ($p=0.0002$) between the mean imperviousness of cells that contained specialists ($\mu=18.31$) in comparison to cells that did not ($\mu=30.94$) (Table 1, Figure 13). The mean difference in imperviousness was also statistically significant for the difference between cells that contained specialists ($\mu=18.31$) and cells that contained nonspecialists ($\mu=30.71$). While previous linear regression showed the distribution of the two groups was only slightly colinear, there still is some overlap between cells with specialist species and nonspecialist species. What this second T-test reveals is that there are some specialist species within the cells with nonspecialists making use of the area with high imperviousness that may be unsuitable for most of the specialists.

Distinctions in habitat preferences among avian dietary specialists could be associated to their respective forms of dietary specialism. In the interpolation analysis, the mean values for imperviousness were compared between invertebrate specialist observations ($\mu=17.81$) and endotherm specialist observations ($\mu=33.7$) (Figure 17). The difference between the means was statistically significant ($p=0.0099$) (Table 8). While it is unsurprising that the nonspecialist avian species would display a level of urban tolerance greater than the specialist species, the distinction between types of specialism revealing some specialist species are well suited to an urbanized environment suggests that the class of synanthropic species may not be limited to nonspecialists (Szlavecz, Warren, & Pickett, 2010).

6.2.2. Distribution of Avian Species in Comparison to Flora Species Distribution

Fishnet linear regression of flora species richness and observation abundance in comparison to avian species richness and observation showed a positive correlation for all variables tested (All plants, Native plants, Nonnative Plants, and Percent Native Plants) (Figures 14 & 15). Observation count abundance a slightly higher correlation for All plants, Native Plants, and Nonnative plants (+0.04) than species richness. The r-squared values for nonspecialist species richness and observation abundance were all within 1% of the R-squared values for all avian species richness and observation abundance. The r-squared values for specialist species were still positive but much lower. The highest correlation for specialist species was the species richness and observation abundances of native plants. The Percent Native Plants category had the highest correlation for specialist species (r^2=-0.036) in comparison to all avian species (r^2=-0.018), and nonspecialist species (r^2=-0.014).

T-tests of the mean values for flora observation abundances also revealed that the cells containing specialist species compared to cells without specialists had a statistically significant higher mean plant observation count (p=0.0254), higher mean native plant observation count (p=0.0129), and higher mean native to nonnative plant ratio (p=0.0023) (Table 1). When examining species richness, the only statistically significant category was species richness of native plants (p=0.0242). This category remained significant in comparing cells that possess specialist species in comparison to cells possessing nonspecialists, but not excluding specialists (p=0.0449). This further reinforces the idea that some specialist species persist in areas both floristically and structurally distinct from each other.

Similarly, T-tests revealed statistically significant differences for nonnative plant species richness (p=0.0306) and percent native species (p=0.0149) between cells containing nonspecialists and cells without nonspecialists (Table 2). Cells without nonspecialists had a higher percent native species and lower species richness of nonnative plants. This indicates that while nonspecialists avian species may be suited for many environments, there are some locations with low invasion rates of exotic flora which may act as a filter in favor of dietary specialist avian species.

Linear regression of dietary nonspecialist avian species presence in comparison to the floristic variables (All plants, Native Plants, Nonnative Plants, and Percent Native Plants) showed positive relationships for both species richness and observation abundances (Figure 14 & 15). The difference in linearity for native plants in comparison to nonnative plants was +0.04 for both species richness and abundance suggesting a similar slight preference for native plants like avian specialist species. Nonspecialist species did have a higher correlation with all flora categories compared to specialist species, but the specialist species had higher linearity with the percent native flora category. The linearity of each floristic variable with nonspecialists was slightly higher for observation abundance in comparison to species richness suggesting their presence is more closely related to the broad availability of resources rather than diverse types of resources. This coincides well with the premise of biotic homogenization that the introduction of locally novel species in urban areas results in a decline in species richness but can support urban tolerant, synanthropic, species.

Analysis of the interpolation data portrayed a slightly different distribution of floristic preferences between specialist and nonspecialist groups. The main difference was that nonspecialist avian species were found to have a statistically significant preferences (p=0.0026) for areas with high interpolated overall plant count in comparison to avian dietary specialists (Table 8). This reinforces the idea that nonspecialists may be more influenced by the quantity of resource availability than the type of resources. Furthermore, dietary specialists had a statistically significant higher mean native plant density (p=0.0062) and lower mean nonnative plant density (p=0.0005) suggesting a connection once again to the composition of floristic communities having a greater influence on their distribution.

The interpolation data also revealed differences in floristic preferences of different types of specialist species. The endotherm specialists when compared to invertebrate specialists had statistically significant lower plant counts (p=0.0041), native species density (p=0.003), nonnative species density (p=0.001), and native to nonnative ratios (p=0.011) at their observed locations (Table 9). This trend is unsurprising given the observed endotherm specialist preference for areas with greater imperviousness. The one variable that does stand out, however, is that they also preferred areas with lower nonnative vegetation when previous linear regression showed a positive relationship for both nonnative plant species richness and observation abundance with increasing imperviousness.

For nonspecialist species, the subcategory of indicators of high environmental quality was also examined. These species had statistically significant lower plant counts (p=0.0002), native plant density (p=0.0001), and nonnnative plant density (p=0.0002) when compared to nonspecialists as a whole (Table 8). The indicators of high environmental quality were not selected primarily based off their association with flora, but also their functional trait redundancy and observations in areas with low light pollution. Their connection to flora was from surroundings at observed locations having high green coverage and heterogeneity. Presumably heterogeneity and green coverage would have some sort of connection to the interpolated plant data, but it may also be the case that the plant observation interpolations are not refined enough to reveal heterogeneity at small scales.

6.3. Conservation Status of Examined Species

6.3.1. Dietary Specialism and Conservation Status

According to the IUCN redlist there were three distinct conservation statuses represented by the avian species within this study: Least Concern Population Decreasing, Least Concern Population Stable, and Least Concern Population Increasing. Rather than separating out dietary specialism according to specialists and nonspecialists, the mean GINI value of each group was examined for statistical differences. The only two groups that had statistically significant differences (p=0.0071) in mean GINI values were the Least Concern Population Stable (μ=0.59) and the Least Concern Population Increasing (μ=0.34) (Table 5, Figure 15). The group with the population increase would appear to be generally linked with having wider dietary preferences. It is worth noting; however, that the population decreasing group also had low dietary specialism (μ=0.38) that was borderline significant (p=0.0665) so that trend may not be entirely reliable.

The protection status of avian species specific to the Czech Republic was also examined. There were statistically significant differences (p=0.0001) in GINI values for dietary specialism between avian species with any form of protection status (μ=0.75) and avian species not protected (μ=0.36) (Table 6, Figure 16). This indicates that at a finer resolution species with higher values for GINI specialism are more likely to acquire some sort of protection status.

6.3.2. Imperviousness and Conservation Status

There were no statistically significant differences in means for imperviousness when examining avian species according to IUCN status. There were however differences that emerged when examining according to their protection status for the Czech Republic. The protected avian species had a statistically significant (p=0.0065) lower mean imperviousness (μ =12.01) compared to unprotected avian species (μ=29.98) (Table 6, Figure 16). The lower tolerance for imperviousness may shed light as to why these species are at risk to begin with given widespread increases in urbanization.

6.3.3. Flora Distribution and Conservation Status

According to IUCN status the Least Concern with its population increasing had a statistically significant (p=0.0121) lower interpolated plant count (μ=92.5) when compared to the stable species (μ=137.32). (Table 5, Figure 15) Similar to how a lower GINI value would imply the ability to make use of greater resources, the lower interpolated plant count may imply a greater tolerance for areas with variable plant abundances.

The same trend was observed for avian species with protected status in comparison to species without protected status. Those with protected status had a statistically significant (p=0.0271) higher mean interpolated plant count (μ=145.14) compared to those without (μ=103.98). Together these data imply that the species more sensitive to reduced floristic abundance are more likely to have protection status within the Czech Republic.

6.4. Utility of *iNaturalist* for Urban Ecology and Conservation Studies

Many of the relationships between the impact of urbanization and biodiversity found through utilizing the *iNaturalist* data for fishnet and interpolation analysis align closely with what should be expected based off the scientific literature. While most of the relationships were negative along increasing imperviousness, the relationships between avian and flora show variation at finer resolutions that help to verify the utility of citizen science data as a tool for elucidating further relationships in the future.

6.4.1. Utility of *iNaturalist* for Flora Species Analysis

The increase in exotic species richness with increasing imperviousness accompanied by a decline in overall flora species richness validated the trend of biotic homogenization voiced by McKinney and Lockwood where exotic species introduced in the urban core displace native flora species once extant in the same location (2001). Zipperer and Guntenspergen also noted a decline in native flora with urbanization but an increase in overall species richness when compared to areas external to urban centers (2009). This trend cannot be perfectly rejected or verified because all observation data was within the Prague municipality, but if using imperviousness as a surrogate, we can see that while native species are replaced by exotic in areas with high imperviousness, species richness appears to be higher in areas with low urban density. This is likely due to many of these locations being nature reserves within Prague’s municipal boundaries. These nature reserves are dispersed quite evenly throughout Prague creating highly heterogenous structural conditions within the urban matrix resulting in high species richness from both native and exotic flora present. The influence of matrix heterogeneity creating conditions for high species richness has also been previously noted by Walker et al. (2009).

6.4.2. Utility of *iNaturalist* for Avian Species Analysis

The main phenomena noted with avian species this data helps to verify is the urban to rural gradient in which higher avian species richness exists in areas with lower urban density (Xie et al., 2019). Similar to the flora data, the distribution of avian species follows the trend of species richness declining with increasing imperviousness. This data also shows that not all avian species are affected evenly by imperviousness. The phenomenon of synanthropic species were seen with the reduced negative response of nonspecialist, more urban tolerant, avian species in comparison to specialist avian species with increasing imperviousness (Sol et al., 2014). The increasing sensitivity of specialist avian species to imperviousness seen here also coincides with findings by Callaghan et al., but this data also reveals that the type of specialism (invertebrate vs endotherm) shows varying responses to increased imperviousness (2019). The reduced negative response of endotherm specialists to imperviousness also helps to reaffirm the notion put forth by Richardson, Lundholm, and Larson, that in some instances urban environments may offer unique habitat locations that are preferable for target taxa (2010).

6.4.3. Utility of *iNaturalist* for Establishing Relationships Between Taxa

Analysis of this data reaffirms previous relationships identified between increases in urban flora species richness and increases in avian species richness (Marzluff, 2005, Xie et al., 2009). The data also shows a slight positive correlation between percent of flora that is native to the area and overall avian species richness which is in line with findings by Dyson (2020). Connections between flora origin and the degree of dietary specialism were also seen as increasing rates of native flora had statistically significant positive relationships with specialist avian species. This reaffirms findings by Reif et al. that suggest dietary specialism are closely linked to habitat specialism and that, consequently, dietary specialists are typically distributed within habitats with floristic compositions less altered by urbanization (2015). While the iNaturalist data in this study is not used at a micro level (species to species relationships) like Narango et al. and Zietsman et al., the data does show that the relationship between specialist birds and flora present within urban environments can be examined at a macro level depending on the type of specialism (2007, 2019).

6.4.4. Utility of iNaturalist for Conservation of Avian Taxa

While the IUCN statuses indicated that each species within the study was under the Least Concern category, the Czech Republic specific protection statuses did indicate some species were of concern. Among these species there was higher dietary specialism and lower tolerance for imperviousness compared to unprotected species. When combined with the previously discussed trends of specialism being associated with native plant species richness, this form of analysis may help to identify the habitat characteristics necessary to preserve or recreate in order to sustain their respective populations.

7. CONCLUSION

Worldwide, biodiversity loss is occurring at rapid speed because of anthropogenic activities. Habitat conversion in particular acts as major driver for the loss of species. Similarly, the process of urbanization appears to be accelerating and requires the conversion of intact habitat patches into extensions of the urban fabric.

The response of biodiversity to urbanization depends largely on the functionality of the converted urban matrix for their specific needs. Strategies such as protected habitat patches and creating biological corridors between them have been deployed to preserve populations of species of concern within urban areas, but the response of target taxa to these strategies is dependent on their dispersal capabilities and sensitivity to high heterogeneity of the adjacent urban matrix.

The process of urbanization is not entirely negative for all species. Some species are highly adaptable and tolerant of the novel conditions created by urbanization. Additionally, some species are commonly introduced within urban matrices and disperse into surrounding, less-densely urbanized, areas posing a risk to the species native to the region. Native flora species specifically appear to be commonly displaced by nonnative species both actively (through human intervention) and passively (through their own dispersal abilities). While avian species show uneven responses to urbanization and habitat conversion based off their own functional traits, such as dietary specialism.

Evaluating the trends of biodiversity loss from urbanization occurring at such rapid scales requires access to high-quality and high-resolution data sets in order to inform conservation decisions. Traditional methods for acquiring such data requires intensive field work and methodological variation depending on the taxa of concern. Citizen Science tools such as *iNaturalist* are increasingly being utilized for evaluating the response of species of concern to urbanization or habitat loss generally.

Within this study open source *iNaturalist* data was not only utilized to verify several of the trends in flora and avian species responses to urbanization noted in the literature, but also helped to clarify responses of avian species according to dietary specialism. Furthermore, this research indicates the importance of conserving areas with high compositions of native flora species for urbanization-sensitive avian species.

8. References

Agentura ochrany přírody a krajiny ČR. (2023). AOPK ČR. https://www.nature.cz

Angold, P. G., Sadler, J. P., Hill, M. O., Pullin, A., Rushton, S., Austin, K., … Thompson, K. (2006). Biodiversity in urban habitat patches. *Science of the Total Environment*, *360*(1-3), 196–204. https://doi.org/10.1016/j.scitotenv.2005.08.035

Bai, L., Xiu, C., Feng, X., & Liu, D. (2019). Influence of urbanization on regional habitat quality:a case study of Changchun City. *Habitat International*, *93*, 102042. https://doi.org/10.1016/j.habitatint.2019.102042

Baró, F., Aznarez, C., Svenning, J.-C., Taveira, G., & Pascual, U. (2022). Wildness and habitat quality drive spatial patterns of urban biodiversity. *Landscape and Urban Planning*, *228*, 104570. https://doi.org/10.1016/j.landurbplan.2022.104570

Boakes, E. H., McGowan, P. J. K., Fuller, R. A., Chang-qing, D., Clark, N. E., O’Connor, K., & Mace, G. M. (2010). Distorted Views of Biodiversity: Spatial and Temporal Bias in Species Occurrence Data. *PLoS Biology*, *8*(6), e1000385. https://doi.org/10.1371/journal.pbio.1000385

Bode, R. F., & Maciejewski, A. (2014). Herbivore Biodiversity Varies with Patch Size in an Urban Archipelago. *International Journal of Insect Science*, *6*(6), IJIS.S13896. https://doi.org/10.4137/ijis.s13896

Burgess, H. K., DeBey, L. B., Froehlich, H. E., Schmidt, N., Theobald, E. J., Ettinger, A. K., HilleRisLambers, J., Tewksbury, J., & Parrish, J. K. (2017). The science of citizen science: Exploring barriers to use as a primary research tool. *Biological Conservation*, *208*, 113–120. https://doi.org/10.1016/j.biocon.2016.05.014

Callaghan, C. T., Major, R. E., Wilshire, J. H., Martin, J. M., Kingsford, R. T., & Cornwell, W. K. (2019). Generalists are the most urban-tolerant of birds: a phylogenetically controlled analysis of ecological and life history traits using a novel continuous measure of bird responses to urbanization. *Oikos*, *128*(6), 845–858. https://doi.org/10.1111/oik.06158

Callaghan, C. T., Ozeroff, I., Hitchcock, C., & Chandler, M. (2020). Capitalizing on opportunistic citizen science data to monitor urban biodiversity: A multi-taxa framework. *Biological Conservation*, *251*, 108753. https://doi.org/10.1016/j.biocon.2020.108753

Clucas, B., & Marzluff, J. M. (2015). A cross-continental look at the patterns of avian species diversity and composition across an urbanisation gradient. *Wildlife Research*, *42*(7), 554. https://doi.org/10.1071/wr15007

Dovletyarova, E., & Valentini, R. (2016). *Megacities 2050: from Urbanization Threats to Sustainable Urban Development*.

Dyson, K. (2020). Conserving native trees increases native bird diversity and community composition on commercial office developments. *Journal of Urban Ecology*, *6*(1). https://doi.org/10.1093/jue/juaa033

Evans, K. L., Newson, S. E., & Gaston, K. J. (2009). Habitat influences on urban avian assemblages. *Ibis*, *151*(1), 19–39. https://doi.org/10.1111/j.1474-919x.2008.00898.x

Faeth, S. H., Bang, C., & Saari, S. (2011). Urban biodiversity: patterns and mechanisms. *Annals of the New York Academy of Sciences*, *1223*(1), 69–81. https://doi.org/10.1111/j.1749-6632.2010.05925.x

Gaston, K. J., Blackburn, T. M., & Goldewijk, K. K. (2003). Habitat conversion and global avian biodiversity loss. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *270*(1521), 1293–1300. https://doi.org/10.1098/rspb.2002.2303

Hanski, I. (2011). Habitat Loss, the Dynamics of Biodiversity, and a Perspective on Conservation. *AMBIO*, *40*(3), 248–255. https://doi.org/10.1007/s13280-011-0147-3

Hewitt, E. (2022, July 25). *The Nature Lover's App That Became a Catalog of Earth's Biodiversity*. Reasons to Be Cheerful. https://reasonstobecheerful.world/citizen-scientists-fueling-biodiversity-research/

How can I use it · iNaturalist. (2018). INaturalist. https://www.inaturalist.org/pages/how+can+i+use+it

Imperviousness. (2018). Land.copernicus.eu. https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness

iNaturalist Computer Vision Explorations · iNaturalist. (2016). INaturalist. https://www.inaturalist.org/pages/computer_vision_demo

IUCN, International Union For Conservation Of Nature And Natural Resources, & Al, E. (2000). *Threatened birds of the world : the official source for birds on the IUCN Red List*. Birdlife International.

IUCN. (2022). *The IUCN Red List of Threatened Species*. IUCN Red List of Threatened Species; IUCN. https://www.iucnredlist.org

Keil, P., Storch, D., & Jetz, W. (2015). On the decline of biodiversity due to area loss. *Nature Communications*, *6*(1). https://doi.org/10.1038/ncomms9837

Laurance, W. F., & Bierregaard, R. O. (1997). Tropical Forest Remnants: Ecology, Management, and Conservation of Fragmented Communities. In *Google*

Books. University of Chicago Press. https://books.google.cz/books?hl=cs&lr=&id=hkHBl9I8PCIC&oi=fnd&pg=PR9&dq=Tropical+Forest+Remnants:+Ecology

Laurance, W. F. (2008). Theory meets reality: How habitat fragmentation research has transcended island biogeographic theory. *Biological Conservation*, *141*(7), 1731–1744. https://doi.org/10.1016/j.biocon.2008.05.011

Li, E., Parker, S. S., Pauly, G. B., Randall, J. M., Brown, B. V., & Cohen, B. S. (2019). An Urban Biodiversity Assessment Framework That Combines an Urban Habitat Classification Scheme and Citizen Science Data. *Frontiers in Ecology and Evolution*, *7*. https://doi.org/10.3389/fevo.2019.00277

MacArthur, R. H., & Wilson, E. O. (2001). *The Theory of Island Biogeography*. Princeton University Press. https://doi.org/10.1515/9781400881376

Marzluff, J. M. (2005). Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. *Urban Ecosystems*, *8*(2), 157–177. https://doi.org/10.1007/s11252-005-4378-6

McKinney, M. L., & Lockwood, J. L. (2001). Biotic Homogenization: A Sequential and Selective Process. *Biotic Homogenization*, 1–17. https://doi.org/10.1007/978-1-4615-1261-5_1

McKinney, M. L. (2002). Urbanization, Biodiversity, and Conservation. *BioScience*, *52*(10), 883. https://doi.org/10.1641/0006-3568(2002)052[0883:ubac]2.0.co;2

Morelli, F., Benedetti, Y., Hanson, J. O., & Fuller, R. A. (2021). Global distribution and conservation of avian diet specialization. *Conservation Letters*, *14*(4). https://doi.org/10.1111/conl.12795

Morelli, F., Reif, J., Díaz, M., Tryjanowski, P., Ibáñez-Álamo, J. D., Suhonen, J., … Benedetti, Y. (2021). Top ten birds indicators of high environmental quality in European cities. *Ecological Indicators*, *133*, 108397. https://doi.org/10.1016/j.ecolind.2021.108397

Narango, D. L., Tallamy, D. W., & Marra, P. P. (2017). Native plants improve breeding and foraging habitat for an insectivorous bird. *Biological Conservation*, *213*, 42–50. https://doi.org/10.1016/j.biocon.2017.06.029

Oakleaf, J. R., Kennedy, C. M., Baruch-Mordo, S., West, P. C., Gerber, J. S., Jarvis, L., & Kiesecker, J. (2015). A World at Risk: Aggregating Development Trends to Forecast Global Habitat Conversion. *PLOS ONE*, *10*(10), e0138334. https://doi.org/10.1371/journal.pone.0138334

Pardini, R., Nichols, E., & Püttker, T. (2018). Biodiversity Response to Habitat Loss and Fragmentation. *Encyclopedia of the Anthropocene*, 229–239. https://doi.org/10.1016/b978-0-12-809665-9.09824-4

Pladias: Database of the Czech flora and vegetation. (2014). Pladias.cz. Retrieved March 11, 2023, from https://pladias.cz/en/taxon/

Plants of the World Online. (2017). Plants of the World Online; Kew Royal Botanic Gardens. https://powo.science.kew.org

Pocock, M. J. O., Tweddle, J. C., Savage, J., Robinson, L. D., & Roy, H. E. (2017). The diversity and evolution of ecological and environmental citizen science. *PLOS ONE*, *12*(4), e0172579. https://doi.org/10.1371/journal.pone.0172579

Reif, J., Hořák, D., Krištín, A., Kopsová, L., & Devictor, V. (2015). Linking habitat specialization with species' traits in European birds. *Oikos*, *125*(3), 405–413. https://doi.org/10.1111/oik.02276

Richard, H. O., & Jan, K. (1998). *Prague - History*. Encyclopedia Britannica. https://www.britannica.com/place/Prague/History

Richardson, P. J., Lundholm, J. T., & Larson, D. W. (2010). Natural analogues of degraded ecosystems enhance conservation and reconstruction in extreme environments. *Ecological Applications*, *20*(3), 728–740. https://doi.org/10.1890/08-1092.1

Ritchie, H., & Roser, M. (2018). Urbanization. *Our World in Data*. https://ourworldindata.org/urbanization#how-many-people-will-live-in-urban-areas-in-the-future

Rosa, G., & Pena, J. (2021). *Reconciling humans and birds when designing ecological corridors and parks within urban landscapes*.

Sol, D., González-Lagos, C., Moreira, D., Maspons, J., & Lapiedra, O. (2014). Urbanisation tolerance and the loss of avian diversity. *Ecology Letters*, *17*(8), 942–950. https://doi.org/10.1111/ele.12297

Szlavecz, K., Warren, P., & Pickett, S. (2010). Biodiversity on the Urban Landscape. *Human Population*, 75–101. https://doi.org/10.1007/978-3-642-16707-2_6

Turrini, T., & Knop, E. (2015). A landscape ecology approach identifies important drivers of urban biodiversity. *Global Change Biology*, *21*(4), 1652–1667. https://doi.org/10.1111/gcb.12825

Úvod | Geoportál hl. m. Prahy. (n.d.). Www.geoportalpraha.cz. Retrieved March 11, 2023, from https://www.geoportalpraha.cz

Uyeda, K. A., Stow, D. A., & Richart, C. H. (2020). Assessment of volunteered geographic information for vegetation mapping. *Environmental Monitoring and Assessment*, *192*(8). https://doi.org/10.1007/s10661-020-08522-9

Walker, J. S., Grimm, N. B., Briggs, J. M., Gries, C., & Dugan, L. (2009). Effects of Urbanization on Plant Species Diversity in Central Arizona. *Frontiers in Ecology and the Environment*, *7*(9), 465–470. https://www.jstor.org/stable/25595219?seq=2#metadata_info_tab_contents

Werner, P. (2011). The ecology of urban areas and their functions for species diversity. *Landscape and Ecological Engineering*, *7*(2), 231–240. https://doi.org/10.1007/s11355-011-0153-4

Wilson, M. C., Chen, X.-Y., Corlett, R. T., Didham, R. K., Ding, P., Holt, R. D., … Yu, M. (2015). Habitat fragmentation and biodiversity conservation: key findings and future challenges. *Landscape Ecology*, *31*(2), 219–227. https://doi.org/10.1007/s10980-015-0312-3

Xie, S., Su, Y., Xu, W., Cai, W., Wang, X., Lu, F., & Ouyang, Z. (2019). The effect of habitat changes along the urbanization gradient for breeding birds: an example from the Xiong'an New Area. *PeerJ*, *7*, e7961. https://doi.org/10.7717/peerj.7961

Yan, Z., Teng, M., He, W., Liu, A., Li, Y., & Wang, P. (2019). Impervious surface area is a key predictor for urban plant diversity in a city undergone rapid urbanization. *Science of the Total Environment*, *650*, 335–342. https://doi.org/10.1016/j.scitotenv.2018.09.025

Zietsman, M. Y., Montaldo, N. H., & Devoto, M. (2019). Plant–frugivore interactions in an urban nature reserve and its nearby gardens. *Journal of Urban Ecology*, *5*(1). https://doi.org/10.1093/jue/juz021

Zhu, C., Zhang, X., Zhou, M., He, S., Gan, M., Yang, L., & Wang, K. (2020). Impacts of urbanization and landscape pattern on habitat quality using OLS and GWR models in Hangzhou, China. *Ecological Indicators*, *117*, 106654. https://doi.org/10.1016/j.ecolind.2020.106654

Zipperer, W. C., & Guntenspergen, G. R. (2009). Vegetation composition and structure of forest patches along urban–rural gradients. *Ecology of Cities and Towns*, 274–286. https://doi.org/10.1017/cbo9780511609763.018

9. Appendix

9.1. List of Abbreviations

HEQ: Indicators of High Environmental Quality

LC: Least Concern Population Stable

LC-D: Least Concern Population Decreasing

LC-I: Least Concern Population Increasing

Nonspec: Nonsepcialist

SR: Species Richness

Spec: Specialist

9.2. Supplemental Data

Fishnet Cell Data

specialist > 0

	Plant SR	Native Plant SR	Nonnative Plant SR	Percent Native	Mean Imperviousness
mean	5.335526	3.355263	1.980263	0.628472	16.17862
standard deviation	7.561618	4.910332	3.190363	0.349304	25.49476
sample size	153				

specialists = 0

	Plant SR	Native Plant SR	Nonnative Plant SR	Percent Native	Mean Imperviousness
mean	4.500228	2.672893	1.827335	0.576429	30.7932
standard deviation	5.156562	3.511223	2.261964	0.357731	30.60607
sample size	2195				

nonspecialists > 0

	Plant SR	Native Plant SR	Nonnative Plant SR	Percent Native	Mean Imperviousness
mean	4.58061712	2.72881356	1.85180356	0.57728725	30.0684201
standard deviation	5.38436931	3.64875081	2.33986854	0.35687914	30.5031473
sample size	2301				

nonspecialists = 0

	Plant SR	Native Plant SR	Nonnative Plant SR	Percent Native	Mean Imperviousness
mean	3.23913	2.130435	1.108696	0.705461	18.75609
standard deviation	2.626233	1.627659	1.816324	0.362187	29.02521
sample size	47				

Table 10. Fishnet cell data according to present or absence of specialist or nonspecialist avian species.

Invertebrate Specialists

Species	Count	GINI	Average count of Interpolated Plant Oservations	native plant observation interpolation	exotic plant observation interpolation	impervious surface	Ratio of Native to Exotic Plants
Apus Apus	29.00	1.00	148.88	0.78	0.60	36.90	1.30
Charadrius dubius	17.00	1.00	63.86	0.42	0.15	0.00	2.69
Delichon urbicum	19.00	1.00	157.65	0.78	0.74	61.10	1.04
Dryocopus martius	40.00	1.00	134.61	0.94	0.37	0.00	2.56
Ficedula hypoleuca	15.00	1.00	296.05	1.57	1.08	13.67	1.45
Motacilla alba	80.00	1.00	169.96	0.96	0.67	16.34	1.42
Motacilla cinerea	50.00	1.00	193.60	1.16	0.60	13.45	1.93

Endotherm Specialists

Species	Count	GINI	Average count of Interpolated Plant Oservations	native plant observation interpolation	exotic plant observation interpolation	impervious surface	Ratio of Native to Exotic Plants
Accipiter nisus	21.00	1.00	116.10	0.75	0.38	18.76	1.97
Asio otus	17.00	1.00	69.54	0.36	0.34	53.00	1.06

Nonspecialists

Species	count	GINI	Average count of Interpolated Plant Oservations	native plant observation interpolation	exotic plant observation interpolation	impervious surface	Ratio of Native to Exotic Plants
Aix sponsa	20.00	0.42	9.68	0.08	0.03	0.00	2.59
Anser anser	38.00	0.61	66.23	0.32	0.30	0.00	1.07
Buteo buteo	67.00	0.79	106.28	0.67	0.30	0.00	2.25
Curruca communis	14.00	0.33	1.77	0.00	0.01	0.00	0.33
Emberiza citrinella	93.00	0.37	11.50	0.07	0.05	0.00	1.64
Fringilla coelebs	120.00	0.35	36.09	0.22	0.12	0.00	1.81
Fulica atra	262.00	0.09	154.55	0.72	0.69	0.00	1.04
Hirundo rustica	37.00	0.61	0.00	0.00	0.00	0.00	0.00
Lanius collurio	28.00	0.33	0.00	0.00	0.00	0.00	0.00
Luscinia megarhynchos	32.00	0.47	5.12	0.03	0.03	0.00	1.13
Phalacrocorax carbo	104.00	0.61	187.16	0.91	0.78	0.00	1.16
Phasianus colchicus	100.00	0.16	2.42	0.02	0.00	0.00	5.15
Spatula clypeata	27.00	0.41	228.30	1.07	0.97	0.00	1.10
Tachybaptus ruficollis	75.00	0.63	166.10	0.92	0.57	0.00	1.61
Turdus pilaris	43.00	0.51	130.52	0.76	0.43	0.00	1.74
Cygnus olor	480.00	0.61	158.05	0.92	0.50	5.33	1.83
Aythya fuligula	219.00	0.23	239.86	1.17	1.00	5.86	1.17

Chroicocephalus ridibundus	238.00	0.47	173.73	0.72	0.79	6.33	0.91
Gallinula chloropus	392.00	0.26	200.76	1.04	0.79	8.33	1.32
Passer montanus	98.00	0.44	138.65	0.73	0.49	15.75	1.50
Anas platyrhynchos	818.00	0.14	171.18	0.77	0.76	16.21	1.02
Ardea cinerea	309.00	0.33	101.85	0.40	0.51	17.71	0.78
Phylloscopus collybita	79.00	0.61	88.90	0.51	0.31	18.20	1.64
Sylvia atricapilla	92.00	0.26	87.79	0.45	0.29	18.25	1.57
Aegithalos caudatus	105.00	0.30	62.37	0.34	0.21	21.00	1.65
Sitta europaea	123.00	0.44	55.69	0.32	0.15	21.00	2.11
Turdus philomelos	69.00	0.23	45.90	0.26	0.14	21.00	1.83
Columba palumbus	467.00	0.23	98.86	0.54	0.32	24.29	1.68
Sturnus vulgaris	135.00	0.07	94.57	0.53	0.32	24.50	1.63
Garrulus glandarius	348.00	0.19	172.95	0.91	0.72	25.67	1.26
Falco tinnunculus	178.00	0.79	85.49	0.44	0.33	25.82	1.33
Troglodytes troglodytes	48.00	0.30	93.32	0.49	0.35	27.17	1.41
Cyanistes caeruleus	259.00	0.14	74.25	0.40	0.24	27.50	1.65
Parus major	419.00	0.14	61.64	0.32	0.23	30.50	1.38
Carduelis carduelis	100.00	0.19	65.87	0.36	0.20	31.50	1.74
Dendrocopos major	259.00	0.26	123.06	0.68	0.44	37.00	1.55
Aix galericulata	31.00	0.19	235.14	0.85	1.15	37.75	0.74
Phoenicurus phoenicurus	71.00	0.63	54.26	0.32	0.21	39.00	1.51
Erithacus rubecula	135.00	0.12	89.51	0.46	0.32	39.33	1.44
Pica pica	484.00	0.05	139.04	0.74	0.60	43.60	1.23
Columba livia	358.00	0.37	160.70	0.73	0.74	44.50	0.98
Turdus merula	381.00	0.23	91.28	0.48	0.30	45.45	1.64
Picus viridis	138.00	0.79	93.40	0.52	0.32	51.33	1.65
Coccothraustes coccothraustes	27.00	0.19	106.89	0.58	0.34	57.33	1.69
Passer domesticus	55.00	0.37	84.31	0.45	0.25	57.67	1.79
Streptopelia decaocto	168.00	0.19	78.87	0.43	0.28	61.00	1.55
Curruca curruca	38.00	0.33	125.57	0.68	0.37	63.00	1.83
Linaria cannabina	22.00	0.19	125.57	0.68	0.37	63.00	1.83
Poecile palustris	14.00	0.19	125.57	0.68	0.37	63.00	1.83
Spinus spinus	18.00	0.19	125.57	0.68	0.37	63.00	1.83
Phoenicurus ochruros	97.00	0.37	138.90	0.72	0.52	64.57	1.39
Chloris chloris	57.00	0.23	70.99	0.41	0.23	81.50	1.77

Table 11. Avian species present within the study area with interpolated data for floristic values and mean imperviousness extracted at their point of observation.

Flora Species and Origin

species	origin	count	species	origin	count	species	origin	count
Abies alba	native	9	***Fallopia aubertii***	nonnative	32	***Prunella vulgaris***	nonnative	28
Abies concolor	nonnative	7	***Fallopia dumetorum***	native	21	***Prunus armeniaca***	nonnative	7
Acer campestre	native	155	***Ficaria verna***	native	503	***Prunus avium***	native	169
Acer negundo	nonnative	120	***Filipendula ulmaria***	native	53	***Prunus cerasifera***	nonnative	48
Acer platanoides	native	423	***Filipendula vulgaris***	nonnative	10	***Prunus laurocerasus***	nonnative	92
Acer pseudoplatanus	native	222	***Fragaria vesca***	native	89	***Prunus mahaleb***	native	112
Acer tataricum	nonnative	15	***Fragaria viridis***	native	40	***Prunus padus***	native	166
Achillea millefolium	native	171	***Fraxinus excelsior***	native	78	***Prunus serotina***	nonnative	8
Aegonychon purpurocaeruleum	native	14	***Fumaria officinalis***	nonnative	136	***Prunus serrulata***	nonnative	114
Aegopodium podagraria	native	95	***Funaria hygrometrica***	native	10	***Prunus spinosa***	native	38
Aesculus hippocastanum	nonnative	281	***Gagea bohemica***	native	52	***Pseudofumaria lutea***	nonnative	8
Agrimonia eupatoria	native	35	***Gagea lutea***	native	54	***Pseudotsuga menziesii***	nonnative	18
Agrostemma githago	nonnative	8	***Gagea pratensis***	native	22	***Pulmonaria obscura***	native	10
Ailanthus altissima	nonnative	216	***Gagea villosa***	nonnative	21	***Pulmonaria officinalis***	native	12
Ajuga genevensis	native	12	***Galanthus nivalis***	native	105	***Pulsatilla pratensis***	native	58
Ajuga reptans	native	29	***Galatella linosyris***	native	9	***Puschkinia scilloides***	nonnative	23
Alcea rosea	nonnative	25	***Galeopsis pubescens***	native	20	***Pyracantha coccinea***	nonnative	63
Alisma plantago-aquatica	native	9	***Galeopsis speciosa***	native	10	***Pyrus communis***	nonnative	41
Alkekengi officinarum	native	16	***Galinsoga parviflora***	nonnative	49	***Quercus petraea***	native	17
Alliaria petiolata	native	502	***Galinsoga quadriradiata***	nonnative	52	***Quercus robur***	native	56
Allium lusitanicum	native	20	***Galium album***	native	69	***Quercus rubra***	nonnative	56
Allium paradoxum	nonnative	131	***Galium aparine***	native	152	***Rabelera holostea***	native	221
Allium ursinum	native	15	***Galium mollugo***	native	21	***Ranunculus acris***	nonnative	52
Alnus glutinosa	native	69	***Galium odoratum***	native	14	***Ranunculus auricomus***	native	42
Alopecurus pratensis	native	41	***Galium verum***	native	40	***Ranunculus bulbosus***	native	84
Alyssum montanum	native	26	***Geranium columbinum***	nonnative	9	***Ranunculus repens***	native	130
Amaranthus retroflexus	nonnative	65	***Geranium molle***	nonnative	10	***Ranunculus sceleratus***	native	15
Amorpha fruticosa	nonnative	19	***Geranium palustre***	native	13	***Reseda lutea***	nonnative	57
Anchusa arvensis	native	22	***Geranium pratense***	native	146	***Reseda luteola***	nonnative	10
Anchusa officinalis	nonnative	141	***Geranium purpureum***	nonnative	8	***Reynoutria japonica***	nonnative	45
Anemonoides blanda	nonnative	10	***Geranium pusillum***	nonnative	55	***Rhus typhina***	nonnative	58
Anemonoides nemorosa	native	269	***Geranium pyrenaicum***	nonnative	149	***Ribes alpinum***	native	13

Anemonoides ranunculoides	native	97	***Geranium robertianum***	native	198	***Ribes aureum***	nonnative	14
Anemonoides sylvestris	native	12	***Geranium sanguineum***	native	19	***Ribes rubrum***	nonnative	13
Anthericum liliago	native	24	***Geum urbanum***	native	164	***Ribes sanguineum***	nonnative	25
Anthoxanthum odoratum	native	17	***Glechoma hederacea***	native	485	***Ribes uva-crispa***	native	14
Anthriscus caucalis	nonnative	22	***Gleditsia triacanthos***	nonnative	28	***Robinia pseudoacacia***	nonnative	210
Anthriscus sylvestris	native	145	***Glyceria maxima***	native	9	***Rosa canina***	native	81
Anthyllis vulneraria	native	20	***Hedera helix***	native	306	***Rosa rubiginosa***	native	7
Antirrhinum majus	nonnative	7	***Helianthemum canum***	native	19	***Rosa rugosa***	nonnative	17
Aquilegia vulgaris	native	54	***Helianthus annuus***	nonnative	17	***Rubus caesius***	native	12
Arabidopsis arenosa	native	9	***Helianthus tuberosus***	nonnative	16	***Rubus idaeus***	native	13
Arabidopsis thaliana	native	53	***Helleborus orientalis***	nonnative	8	***Rubus laciniatus***	nonnative	7
Arctium lappa	nonnative	30	***Hepatica nobilis***	native	65	***Rumex acetosa***	native	10
Arctium tomentosum	nonnative	49	***Heracleum sphondylium***	native	45	***Rumex acetosella***	native	32
Arenaria serpyllifolia	native	26	***Herniaria glabra***	native	9	***Rumex crispus***	native	28
Argentina anserina	native	24	***Hieracium murorum***	native	31	***Rumex obtusifolius***	native	88
Armoracia rusticana	nonnative	26	***Hieracium sabaudum***	native	19	***Rumex thyrsiflorus***	native	12
Arrhenatherum elatius	nonnative	32	***Hippophae rhamnoides***	nonnative	20	***Sagina procumbens***	native	32
Artemisia campestris	native	16	***Hippuris vulgaris***	native	14	***Salix caprea***	native	62
Artemisia vulgaris	native	126	***Holosteum umbellatum***	native	22	***Salvia nemorosa***	native	28
Arum maculatum	native	10	***Hordeum murinum***	nonnative	118	***Salvia pratensis***	native	122
Asarum europaeum	native	9	***Humulus lupulus***	native	61	***Salvia verticillata***	native	35
Asparagus officinalis	nonnative	7	***Hylotelephium maximum***	native	17	***Sambucus nigra***	native	312
Asperugo procumbens	nonnative	27	***Hyoscyamus niger***	native	58	***Sanguisorba minor***	nonnative	65
Asplenium ruta-muraria	native	86	***Hypericum perforatum***	native	101	***Sanguisorba officinalis***	nonnative	21
Asplenium septentrionale	native	11	***Hypochaeris radicata***	native	12	***Saponaria officinalis***	nonnative	115
Asplenium trichomanes	native	25	***Impatiens glandulifera***	nonnative	19	***Saxifraga tridactylites***	native	18
Astragalus glycyphyllos	nonnative	17	***Impatiens parviflora***	nonnative	82	***Scabiosa ochroleuca***	native	56
Atriplex patula	nonnative	8	***Ipomoea purpurea***	nonnative	11	***Scandosorbus intermedia***	nonnative	7
Atriplex sagittata	nonnative	31	***Iris pseudacorus***	native	151	***Scilla luciliae***	nonnative	14
Aurinia saxatilis	native	53	***Jacobaea vulgaris***	native	134	***Scilla siberica***	nonnative	76
Ballota nigra	nonnative	220	***Jasminum nudiflorum***	nonnative	8	***Scirpus sylvaticus***	native	12
Barbarea vulgaris	native	73	***Juglans nigra***	nonnative	9	***Scleranthus perennis***	native	23
Bellis perennis	native	639	***Juglans regia***	nonnative	109	***Scorzoneroides autumnalis***	native	8
Berberis aquifolium	nonnative	217	***Juncus effusus***	native	33	***Scrophularia nodosa***	native	20
Berberis julianae	nonnative	26	***Juncus inflexus***	native	7	***Securigera varia***	native	162
Berberis thunbergii	nonnative	47	***Juniperus communis***	native	7	***Sedum acre***	native	84
Berberis vulgaris	native	56	***Kerria japonica***	nonnative	53	***Sedum album***	native	178
Berteroa incana	nonnative	73	***Knautia arvensis***	native	25	***Sedum hispanicum***	nonnative	18
Betonica officinalis	native	7	***Koelreuteria paniculata***	nonnative	27	***Sedum sexangulare***	native	110
Betula pendula	native	160	***Laburnum anagyroides***	nonnative	86	***Sempervivum globiferum***	native	15
Bidens frondosa	nonnative	19	***Lactuca perennis***	native	11	***Sempervivum tectorum***	nonnative	13
Borago officinalis	nonnative	12	***Lactuca serriola***	nonnative	178	***Senecio inaequidens***	nonnative	33
Brassica napus	nonnative	30	***Lamium album***	nonnative	476	***Senecio vernalis***	nonnative	51
Bromus hordeaceus	nonnative	16	***Lamium amplexicaule***	nonnative	28	***Senecio vulgaris***	nonnative	230
Bromus sterilis	nonnative	136	***Lamium galeobdolon***	native	196	***Seseli hippomarathrum***	native	8
Bromus tectorum	nonnative	15	***Lamium maculatum***	native	189	***Seseli osseum***	native	25

Brunnera macrophylla	nonnative	17
Buddleja davidii	nonnative	28
Buglossoides arvensis	nonnative	12
Bunias orientalis	nonnative	30
Bupleurum falcatum	native	12
Buxus sempervirens	nonnative	11
Calamagrostis epigejos	native	69
Calendula officinalis	nonnative	32
Calluna vulgaris	native	42
Caltha palustris	native	80
Calystegia sepium	native	41
Campanula glomerata	native	10
Campanula persicifolia	native	17
Campanula rapunculoides	native	77
Campanula trachelium	native	33
Capsella bursa-pastoris	nonnative	500
Caragana arborescens	nonnative	25
Cardamine hirsuta	nonnative	36
Cardamine occulta	nonnative	9
Cardamine pratensis	native	47
Carduus acanthoides	nonnative	89
Carduus crispus	native	17
Carex hirta	native	8
Carex praecox	native	15
Carpinus betulus	native	237
Castanea sativa	nonnative	29
Catalpa bignonioides	nonnative	15
Centaurea cyanus	nonnative	33
Centaurea jacea	native	84
Centaurea montana	native	7
Centaurea scabiosa	native	19
Centaurea stoebe	native	59
Centranthus ruber	nonnative	9
Cephalanthera damasonium	native	32
Cerastium arvense	nonnative	139
Cerastium glomeratum	native	17
Cerastium holosteoides	native	38
Cerastium semidecandrum	native	8
Cerastium tomentosum	nonnative	22
Chaenomeles speciosa	nonnative	32
Chaenorhinum minus	nonnative	7
Chaerophyllum aromaticum	native	12
Chaerophyllum temulum	native	66
Chamaecytisus ratisbonensis	native	7
Chamaenerion angustifolium	native	13
Chelidonium majus	nonnative	675
Lamium purpureum	nonnative	489
Lapsana communis	nonnative	48
Larix decidua	native	95
Lathraea squamaria	native	53
Lathyrus latifolius	native	17
Lathyrus pratensis	native	22
Lathyrus sylvestris	native	8
Lathyrus tuberosus	nonnative	61
Lathyrus vernus	native	57
Leonurus cardiaca	nonnative	33
Lepidium campestre	nonnative	12
Lepidium draba	nonnative	337
Lepidium ruderale	nonnative	30
Leucanthemum vulgare	native	29
Ligustrum vulgare	native	176
Lilium martagon	native	8
Linaria vulgaris	nonnative	113
Linum austriacum	native	25
Lolium perenne	native	10
Lonicera caprifolium	nonnative	8
Lonicera tatarica	nonnative	129
Lonicera xylosteum	native	20
Lotus corniculatus	native	203
Lunaria annua	nonnative	124
Luzula campestris	native	24
Lycium barbarum	nonnative	81
Lycopus europaeus	nonnative	19
Lysimachia arvensis	native	26
Lysimachia nummularia	native	28
Lysimachia punctata	nonnative	28
Lysimachia vulgaris	native	20
Lythrum salicaria	native	63
Maianthemum bifolium	native	13
Malus domestica	nonnative	83
Malva neglecta	nonnative	85
Malva sylvestris	nonnative	144
Matricaria discoidea	nonnative	29
Medicago falcata	native	24
Medicago lupulina	native	90
Medicago minima	native	7
Medicago sativa	nonnative	83
Melampyrum arvense	nonnative	8
Melampyrum pratense	nonnative	9
Melilotus albus	nonnative	79
Melilotus officinalis	nonnative	55
Mentha longifolia	native	8
Setaria pumila	nonnative	24
Setaria verticillata	nonnative	11
Setaria viridis	nonnative	52
Silene coronaria	native	27
Silene dioica	native	11
Silene flos-cuculi	native	15
Silene latifolia	nonnative	189
Silene nutans	native	17
Silene vulgaris	native	77
Silybum marianum	nonnative	15
Sinapis arvensis	nonnative	51
Sisymbrium loeselii	nonnative	105
Sisymbrium officinale	nonnative	46
Smyrnium perfoliatum	nonnative	71
Solanum dulcamara	native	21
Solanum lycopersicum	nonnative	24
Solanum nigrum	nonnative	104
Solidago canadensis	nonnative	129
Solidago gigantea	nonnative	7
Sonchus asper	nonnative	23
Sonchus oleraceus	nonnative	131
Sorbaria sorbifolia	nonnative	7
Sorbus aucuparia	native	92
Spergula morisonii	native	7
Stachys byzantina	nonnative	14
Stachys palustris	native	22
Stachys recta	native	58
Stachys sylvatica	native	32
Staphylea pinnata	native	11
Stellaria apetala	nonnative	9
Stellaria aquatica	nonnative	34
Stellaria media	native	94
Styphnolobium japonicum	nonnative	25
Symphoricarpos albus	nonnative	104
Symphytum officinale	native	153
Symphytum tuberosum	native	21
Syringa vulgaris	nonnative	404
Tanacetum corymbosum	native	8
Tanacetum vulgare	nonnative	178
Taraxacum officinale	native	261
Taxus baccata	native	123
Teucrium chamaedrys	native	14
Thlaspi arvense	nonnative	83
Thuja occidentalis	nonnative	9
Tilia cordata	native	36
Torminalis glaberrima	native	15

Chenopodium album	native	55
Chrysosplenium alternifolium	native	8
Cichorium intybus	nonnative	214
Cirsium arvense	nonnative	172
Cirsium eriophorum	native	12
Cirsium oleraceum	native	9
Cirsium vulgare	native	145
Clematis vitalba	native	148
Clinopodium acinos	native	19
Clinopodium vulgare	native	12
Colutea arborescens	nonnative	13
Commelina communis	nonnative	11
Conium maculatum	nonnative	7
Consolida orientalis	nonnative	15
Convallaria majalis	nonnative	67
Convolvulus arvensis	nonnative	108
Cornus mas	native	49
Cornus sanguinea	native	78
Corydalis cava	native	136
Corydalis solida	native	25
Corylus avellana	native	91
Corylus colurna	nonnative	26
Cota tinctoria	native	24
Cotinus coggygria	nonnative	9
Cotoneaster horizontalis	nonnative	9
Cotoneaster integerrimus	native	34
Crataegus germanica	nonnative	8
Crataegus monogyna	native	8
Crepis biennis	native	64
Crepis foetida	nonnative	25
Cymbalaria muralis	nonnative	30
Cytisus scoparius	nonnative	26
Dactylis glomerata	native	164
Dasiphora fruticosa	nonnative	67
Datura stramonium	nonnative	32
Daucus carota	nonnative	112
Delphinium consolida	native	38
Descurainia sophia	nonnative	67
Dianthus carthusianorum	native	103
Dianthus deltoides	native	9
Dictamnus albus	native	12
Digitalis purpurea	nonnative	24
Digitaria sanguinalis	nonnative	41
Diplotaxis tenuifolia	nonnative	7
Dipsacus fullonum	native	188
Dipsacus laciniatus	native	15
Mercurialis annua	nonnative	59
Mercurialis perennis	native	31
Moehringia trinervia	nonnative	7
Muscari armeniacum	nonnative	12
Muscari neglectum	native	32
Muscari tenuiflorum	native	7
Mycelis muralis	native	22
Myosotis arvensis	nonnative	19
Myosotis ramosissima	native	24
Myosotis stricta	native	19
Myosotis sylvatica	native	50
Noccaea perfoliata	native	39
Nonea pulla	native	20
Nuphar lutea	native	12
Odontites vulgaris	native	19
Oenothera glazioviana	nonnative	7
Oenothera lindheimeri	nonnative	8
Onobrychis viciifolia	nonnative	57
Ononis spinosa	native	7
Onopordum acanthium	nonnative	68
Origanum vulgare	native	20
Ornithogalum nutans	nonnative	13
Ornithogalum umbellatum	nonnative	17
Oxalis acetosella	native	36
Oxalis corniculata	nonnative	88
Oxalis stricta	nonnative	13
Oxytropis pilosa	native	8
Papaver argemone	nonnative	7
Papaver dubium	nonnative	16
Papaver rhoeas	nonnative	123
Papaver somniferum	nonnative	10
Parthenocissus quinquefolia	nonnative	16
Parthenocissus tricuspidata	nonnative	27
Pastinaca sativa	nonnative	32
Paulownia tomentosa	nonnative	66
Pentanema squarrosum	native	11
Persicaria lapathifolia	native	28
Petrorhagia prolifera	native	17
Phacelia tanacetifolia	nonnative	28
Phalaris arundinacea	nonnative	10
Phedimus spurius	nonnative	64
Philadelphus coronarius	nonnative	65
Phleum pratense	native	14
Phlox subulata	nonnative	7
Phragmites australis	native	77
Physocarpus opulifolius	nonnative	15
Tortula muralis	nonnative	39
Tragopogon dubius	nonnative	45
Tragopogon orientalis	native	13
Trifolium arvense	native	36
Trifolium campestre	native	36
Trifolium dubium	native	21
Trifolium hybridum	nonnative	11
Trifolium incarnatum	nonnative	36
Trifolium montanum	native	9
Trifolium pratense	native	254
Trifolium repens	native	211
Tripleurospermum inodorum	nonnative	160
Trisetum flavescens	native	7
Triticum aestivum	nonnative	8
Tulipa sylvestris	nonnative	20
Tussilago farfara	native	131
Typha latifolia	native	31
Ulmus glabra	native	16
Ulmus laevis	native	11
Urtica dioica	native	431
Urtica urens	nonnative	14
Vaccinium myrtillus	native	17
Valerianella locusta	native	32
Verbascum densiflorum	native	27
Verbascum lychnitis	native	61
Verbascum nigrum	native	10
Verbascum phlomoides	native	8
Verbascum thapsus	native	18
Verbena bonariensis	nonnative	9
Verbena officinalis	nonnative	7
Veronica arvensis	nonnative	57
Veronica beccabunga	native	20
Veronica chamaedrys	native	324
Veronica officinalis	native	12
Veronica persica	nonnative	286
Veronica polita	nonnative	18
Veronica prostrata	native	38
Veronica spicata	native	13
Veronica sublobata	native	198
Veronica teucrium	native	8
Veronica triphyllos	nonnative	8
Viburnum farreri	nonnative	8
Viburnum lantana	nonnative	64
Viburnum opulus	nonnative	31
Viburnum rhytidophyllum	nonnative	63
Vicia cracca	native	25

Dipsacus strigosus	nonnative	56	***Phytolacca acinosa***	nonnative	56	***Vicia hirsuta***	native	47
Draba verna	native	71	***Picea abies***	native	51	***Vicia sativa***	nonnative	149
Dryopteris filix-mas	native	127	***Picris hieracioides***	native	25	***Vicia sepium***	native	61
Dysphania pumilio	nonnative	35	***Pilosella aurantiaca***	native	20	***Vicia tenuifolia***	native	18
Echinochloa crus-galli	nonnative	45	***Pilosella officinarum***	native	44	***Vicia villosa***	nonnative	58
Echinops sphaerocephalus	nonnative	69	***Pinus nigra***	nonnative	19	***Vinca major***	native	30
Echium vulgare	native	300	***Pinus sylvestris***	native	53	***Vinca minor***	native	232
Elaeagnus angustifolia	nonnative	18	***Plantago lanceolata***	native	271	***Vincetoxicum hirundinaria***	native	28
Epilobium hirsutum	native	38	***Plantago major***	native	161	***Viola arvensis***	native	95
Equisetum arvense	native	59	***Plantago media***	native	102	***Viola odorata***	nonnative	137
Eragrostis minor	nonnative	41	***Poa annua***	native	61	***Viola reichenbachiana***	native	9
Eranthis hyemalis	nonnative	64	***Poa bulbosa***	native	33	***Viola riviniana***	native	8
Erigeron annuus	nonnative	240	***Poa nemoralis***	native	7	***Viola tricolor***	nonnative	10
Erigeron canadensis	nonnative	58	***Poa pratensis***	native	38	***Viscaria vulgaris***	native	16
Erodium cicutarium	nonnative	368	***Polygonatum multiflorum***	native	64	***Viscum album***	native	7
Eryngium campestre	native	65	***Polygonatum odoratum***	native	19			
Erysimum cheiranthoides	nonnative	7	***Polygonum aviculare***	native	21			
Erysimum crepidifolium	nonnative	67	***Polypodium vulgare***	native	18			
Eschscholzia californica	nonnative	8	***Populus alba***	native	15			
Euonymus europaeus	native	105	***Populus nigra***	native	44			
Euphorbia cyparissias	native	312	***Populus tremula***	native	14			
Euphorbia esula	native	11	***Portulaca oleracea***	nonnative	74			
Euphorbia helioscopia	nonnative	110	***Potentilla argentea***	native	137			
Euphorbia lathyris	nonnative	15	***Potentilla incana***	native	39			
Euphorbia maculata	nonnative	15	***Potentilla indica***	nonnative	31			
Euphorbia peplus	nonnative	34	***Potentilla recta***	native	16			
Euphorbia serpens	nonnative	7	***Potentilla reptans***	native	105			
Fagopyrum esculentum	nonnative	9	***Potentilla verna***	native	13			
Fagus sylvatica	native	109	***Primula veris***	native	96			
Falcaria vulgaris	native	46	***Primula vulgaris***	nonnative	38			

Table 12. List of flora species present in the study area, their status of native or nonnative to Czech Republic, and their observation count.