



**Making the Urban Matrix Matter: Characteristics of the  
Avifaunal Community of the Urban Matrix relative to  
the Urban Green Spaces of Dehradun**

*Thesis submitted for the award of the Degree of  
Masters in Wildlife Science*

*By*

**Jason Bismarck Coutinho**

*To*

**Saurashtra University  
Rajkot-360005 (Gujarat)**

*Under the Supervision of*  
Dr. Malvika Onial, Scientist-D  
Dr. Dhananjai Mohan, IFS  
Dr. Monica Kaushik



**भारतीय वन्यजीव संस्थान  
Wildlife Institute of India**

**July, 2021**



## DECLARATION

I, **Jason Bismarck Coutinho**, hereby declare that the research work entitled “**Making the Urban Matrix Matter: Characteristics of the Avifaunal Community of the Urban Matrix relative to the Urban Green Spaces of Dehradun**”, carried out in partial fulfilment of M.Sc. (Wildlife Science) Degree of Saurashtra University, Rajkot is an original research work. This research work was carried out under the supervision of **Dr. Malvika Onial** and the co-supervision of **Dr. Dhananjai Mohan, IFS** and **Dr. Monica Kaushik**, at the Wildlife Institute of India from December 2020 to July 2021. I hereby declare that this work has not been submitted for any other degree of any other university.

Date: August 18, 2021

Place: Dehradun

**Mr. Jason Bismarck Coutinho**  
(XVII M.Sc. Wildlife Science)



## CERTIFICATE

This is to certify that **Mr. Jason Bismarck Coutinho** has carried out an original research work in partial fulfilment of Master's Degree in Wildlife Science of the Saurashtra University, Rajkot, Gujarat. The topic of his dissertation is entitled "**Making the Urban Matrix Matter: Characteristics of the Avifaunal Community of the Urban Matrix relative to the Urban Green Spaces of Dehradun**". The study was carried out under our supervision from December 2020 to July 2021. We hereby certify that this work has not been submitted for any other degree to any other university.

*Malvika Onial*

**Dr. Malvika Onial**

Supervisor  
Scientist D,  
Wildlife Institute of India,  
Chandrabani, Dehradun - 01

*Dhananjai Mohan*

**Dr. Dhananjai Mohan, IFS**

Co-supervisor  
Director,  
Wildlife Institute of India,  
Chandrabani, Dehradun - 01

*Monica*

**Dr. Monica Kaushik**

Co-supervisor  
Visiting Assistant Professor,  
School of Human Ecology, Ambedkar University,  
Kashmere Gate, Delhi - 06

Date:

Place: Dehradun



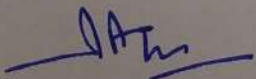
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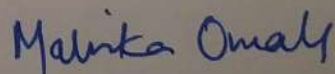
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(Smt. Sunita Agarwal)

Librarian

**(Sunita Agarwal)**  
Librarian  
Wildlife Institute of India  
Dehradun

  
(Dr. Malvika Onial)

Supervisor

***Ultimately, we need to recognize that while humans continue to build urban landscapes, we share these spaces with other species***

***~ David Suzuki***

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## List of Abbreviations

AWHO	- Army Welfare Housing Organization Colony
CBI	- Centre Bureau of Investigation Colony
FRI C	- Forest Research Institute Colony
GEU	- Graphic Era University
GP	- Gandhi Park
JBC	- Jason Bismarck Coutinho
MDDA	- Mussoorie Dehradun Development Authority
MKP	- Mahadevi Kanya Pathshala College
NIVH	- National Institute for the Visually Handicapped
NP	- Netaji Park
RA	- Relative Abundance
TE	- Tea Estate
TO	- Tourism Office
UGS	- Urban Green Space
UPES	- University of Petroleum & Energy Studies
VV	- Vasant Vihar Park
WII	- Wildlife Institute of India
WII C	- Wildlife Institute of India Colony
ZSI	- Zoological Survey of India

## SUMMARY

1. Urban ecology is a field in science which deals with understanding the ecological synergies within urban systems. This is a relatively new field which started out when ecologists recognized the importance of quantifying human impacts on ecosystems globally. This field is ever so pertinent now that no ecosystem remains which doesn't have human induced changes.
2. Urban ecosystems are dynamic ecosystems with interactions similar to those of natural ecosystems, but they are also directly influenced by the culture, politics, economics and social organization of human society. Urban has different definitions all over the world with no single consensus and such disparities make it impossible to compare 'what is urban' across the globe. Simply urban areas are cities and suburban areas with the landscape being called as the 'built environment'. Urbanization and the urban sprawl have impacted not only the land covers across an urban area, but also the biodiversity in it. This urbanization filters the biological community at various levels and it is pertinent that we understand this filtering.
3. The urban landscape can be divided into two major categories for simplicity. The urban green spaces are terrestrial areas, both public and private covered with vegetation, made available to users. These are very important to the health of the city. They enhance the wellbeing of the people in the city and also are habitats for urban wildlife. The urban grey on the other hand is the 'built' or 'artificial' environment. This is usually seen increasing as we reach the center of a city or urban area.
4. The urban matrix is a mix of the greens and the grey and has no clear definition. It is all the habitat patches in the urban landscape that lie outside the urban green spaces. This urban matrix is highly dynamic and every urban area has its own unique habitat

mosaic. This important matrix however has not been studied extensively. In most areas of urban ecological research, the matrix's relevance is undervalued. The current study was conducted in the city of Dehradun from March 2021 to April 2021. To understand the importance of the urban matrix's contribution in maintaining an urban areas biological diversity, this study aims to quantify the avifaunal community in the urban matrix. Further it looks to understand the relevance of the avifaunal assemblage characteristics of the urban matrix relative to that of the urban green spaces.

5. To study this, the patterns of the avifaunal community in Dehradun were explored. Fundamental properties of biological communities like species richness, abundance, density and composition were looked at the habitat scale. At the landscape scale, potential habitat correlates of the species richness and density were studied so as to shed some light on the factors and processes that might be driving the community assembly in the urban matrix. The comparison of the avifaunal assemblage was done by comparing the overall richness, density and composition in the urban matrix and urban green spaces.
6. In the urban matrix, 109 sampling units were laid and then sampled using a variable radius point count method. A total of 3775 individuals belonging to 81 species were recorded. Feral Pigeon was the most dominant species, habitat-wise species richness was maximum in the built – up areas (54 species) and species density was maximum in scrublands ( $13.12_{\text{mean}} \pm 4.35_{\text{SD}}$  per hectare). Ordination graphs showed that plots of green cover were dissimilar from the other habitats. The species richness in the urban matrix was positively influenced by the increasing proportions of open areas and scrublands. Built – up had negative influence on the species richness but showed peaking at moderate levels of human development. Density in the matrix was

positively influenced by increasing proportion of scrublands and the landscape heterogeneity. It was negatively influenced by increasing proportions of built – up and green cover. Comparisons of the richness and density of the urban matrix and urban green spaces showed that there was a huge difference in both the parameters, with urban green spaces showing higher values for both. The species composition Venn diagram showed that the matrix and urban green spaces share 64 species among them, with the urban green spaces and urban matrix showing 50 and 17 unique species respectively.

7. In general, the current study shows the relative importance of the urban matrix in maintaining the urban biodiversity and the need of conserving the habitats in the matrix to boost the urban biodiversity.

# **INTRODUCTION**

## **1.1 Urban Ecology**

Ecology has been described as the study of the mechanisms that determine the population and distribution of species, as well as the interactions between organisms, relationships between organisms and the environment, and energetics within ecosystems. Urban ecology can then simply be defined as the study of these synergies within urban systems. It is a relatively new natural science and at this stage consists of vastly more questions than solutions (Collins et al. 2000).

In the late 1950s and early 60s it was understood that humans had significantly altered the local and regional ecosystems on Earth (M. J. McDonnell and Pickett 1990; Vitousek et al. 1997). This marked an increase in the recognition by ecologists the inclusion of the 'human component' in an ecosystem after the publication of rising atmospheric CO<sub>2</sub> levels by Keeling et al. (1998). Around this time UNESCO told the steps to initiate the Man and Biosphere (MAB) program to study and conserve the natural and cultural ecosystems (Boyden et al. 1981; Douglas 1983). This stimulated the study of human dominated areas all around the world. Till the 1970s though, it was still considered that studying urban areas in terms of ecology was pointless. Cities were thought to be anti-life and people considered cities to be the opposite of nature. Few plants or animals were thought to be able to thrive in an urban environment. This was met with opposition from a few, but was shrugged off and focus was solely shifted to working in supposedly pristine ecosystems (Gaston 2010). This 'pristine' viewpoint changed radically towards the beginning of the 21<sup>st</sup> century when a number of urban ecology studies found that human-created settings provided habitat for many species, and that urban areas have a diverse range of ecosystems, species, and populations (Gilbert 1989; Mark J McDonnell et al. 1997; Grimm et al. 2000; Marzluff, Bowman, and Donnelly 2001).

According to Gaston (2010), research in urban ecology has been accelerated as a result of seven reasons:

1. Majority of the world is now covered with human-dominated ecosystems.
2. A large portion of the Earth and its human population has become urbanized.
3. There is a need to elucidate the connections between urban and rural landscapes.
4. Studies state that interactions with the natural world has significant impacts on people's health and wellbeing.
5. Ecology of urban areas is very different from any other ecosystem.
6. Studying urban ecosystems requires a multidisciplinary approach.
7. Urban development often coincides with areas that support high native species richness and endemism, and its consequences need to be studied.

All of this has led to the realization that urban ecology is extremely relevant to the lives of the urban dwellers as it may aid in the resolution of environmental issues they face. As a result, scientists must not only deal with the general issue of human population growth, but must also understand where that growth is occurring, what its ramifications are, and how to preserve habitats and species of conservation concern in places where human densities are high.

## **1.2 Urban Ecosystem: A 'New type of Environment'**

It may seem odd at first when one applies the term 'ecosystem' to urban areas, but urban ecosystems are ironically the most familiar ecosystems to all. Urban ecosystems are dynamic ecosystems with interactions and behaviors that are comparable to those of natural ecosystems. Yes, there are a multitude of differences between urban ecosystems and other

ecosystems where human influence is less. But just like natural ecosystems, they are a combination of natural and additional man-made elements whose interactions are influenced not only by the natural environment, but also by culture, politics, economics, and social organization. It is an area which is dominated by buildings, roads, sewers and power lines, but it also contains patches of parks, yards, green roadways, canals and unbuilt lots. They may look separate but work together as a single organism.

### **1.2.1 What is Urban?**

Currently about 55.7% of the world's population lives in urban areas (UNCTAD 2020). But what exactly is an urban area? We use this term very loosely without understanding the meaning behind this. What someone might call a small 'city' might be a 'town' for someone or one person's 'megacity' might just be a cluster of many cities from another perspective.

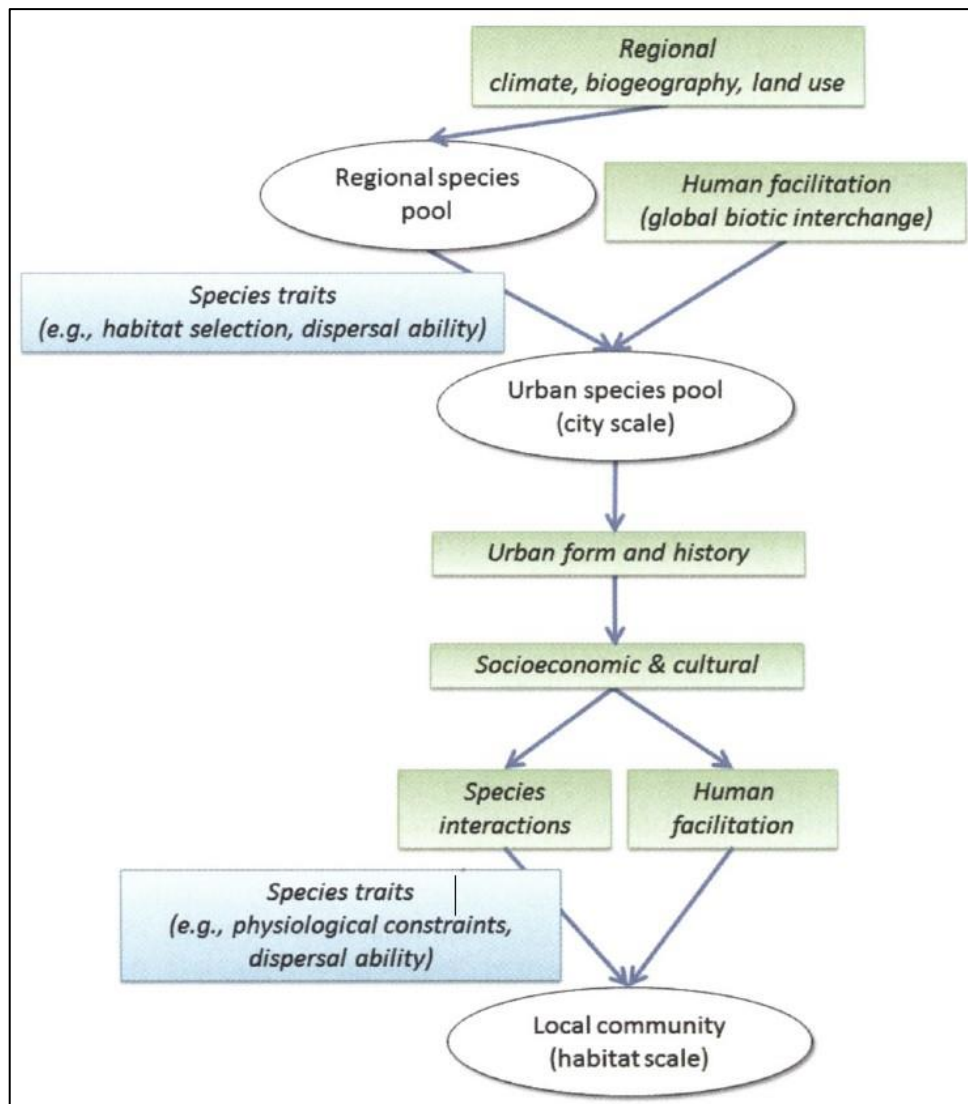
As it just so happens, there is no standard definition of the word 'urban' area. Every country defines it differently and collects data accordingly. For e.g., the Census of India defines an urban area as 'all places with a municipality, corporation, etc., with a minimum population of 5000 and density of population at least 400 persons/km<sup>2</sup> (Provisional Population Totals 2011). On the other hand, USA's definition of urbanized areas is a built-up area with a population of 50000 or more and urban clusters of at least 2,500 and less than 50,000 people (United States Census Bureau 2010). Such disparities in definitions leave comparisons of global statistics near to impossible. Regardless of the criteria, urban areas have expanded dramatically during the last three centuries. This has led to a concentration of a large population in a small fraction of the earth's inhabitable area. In fact Rees (1997) characterizes urban areas as "large concentrations of people and industrial activity that

consume more available energy and material than can be produced, and which produce more wastes than can be assimilated with the relatively small area they occupy”.

In the context of this study, urban areas are defined as both cities and suburbs. The landscape, often known as the "built environment," contains areas where the majority of the land is devoted to man-made structures, such as buildings of all shapes and sizes, lawns and office parks, malls, vacant lots and parking facilities, schools and college campuses.

### **1.2.2 Urbanization**

Urbanization is the process through which towns and cities form and grow as more people begin to live and work in core locations, a phenomena known as population concentration. McDonnell and Pickett (1990) characterize urbanization as “an increase in human habitation, coupled with increased per capita energy and resource consumption and extensive modification of the landscape, creating a system that does not depend principally on local natural resources to persist”. Simply put urbanization refers to the change in size, density, and heterogeneity of cities (Vlahov and Galea 2002). Urbanization can lead to filtering the biological communities at various scales. The effects of settlement patterns, history of the city, urban growth forms, management, human culture and socioeconomics need to be understood. Aronson et al. (2016) studied the various filters that can be influencing the urban biodiversity to understand the ways humans can modulate the community assemblages in urban areas (Figure 1).



**Fig. 1** Community assembly of urban species pools is determined by a series of hierarchical filters (modified from Morin 2011). Green boxes represent the filters hypothesized to be important determinants of species distributions at different scales. White circles represent species pools. Species life history and functional trait filters are represented in blue boxes. Sourced from Aronson et al. (2016).

### 1.2.3 The Grey Sprawl

As urban areas grow, a serious concern is how they expand into the surrounding areas. We would expect cities to grow in a concentric fashion, but this is not true. This expansion is a poorly planned, low density development, which spreads out over large amounts of land in an irregular fashion. As the urban core gets saturated with development, there is a migration of the development towards the fringes of the urban area – undeveloped land – which crowds

the suburbs and rural areas. All of this leads to exploitation of natural habitats, which in turn leads to fragmentation, isolation and degrades the overall quality of the habitat (Adams 2016). The urban sprawl affects all the characteristics of the urban – rural continuum. As one moves towards the urban core, there is a decline in the species richness, number of native species and amount of natural habitat available (McKinney 2008). On the other hand, human induced development is on the rise. This urban sprawl however also gives us different types of habitats. These ‘under urbanization’ areas have high spatial heterogeneity (Savard, Clergeau, and Mennechez 2000). Some studies have shown that these resulting habitats have greater species richness than the surrounding rural areas (Niemelä 1999; Wania, Ingolf, and Klotz 2006).

### **1.3 Urban Habitats**

As mentioned earlier, the urban sprawl along the urban – rural continuum results in various habitats and high spatial heterogeneity. These can be classified into two major categories: the urban grey and the urban green (Figure 2).

#### **1.3.1 Urban Greens**

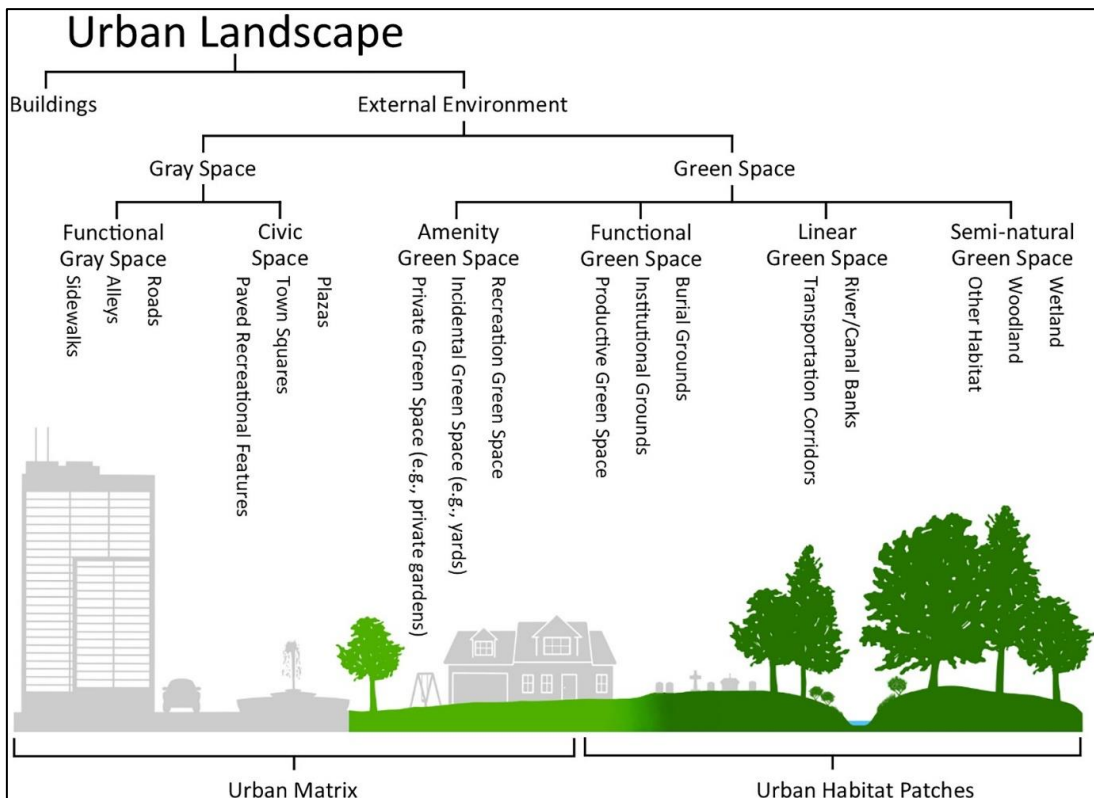
Many mechanisms and definitions exist to classify urban green spaces (hereafter UGS). Some refer to the entire urban green infrastructure that includes all natural, semi-natural and artificial ecological systems within, around and between urban areas (Cilliers et al. 2012). Aronson et al. (2017) defines UGS as “a range of habitats types from remnant patches of native vegetation, urban wastelands (i.e., brownfields, vacant lots), gardens, and yards to highly engineered green infrastructure such as bioswales and green roofs”. It is beyond the scope of the current study to provide a detailed account of the various approaches in defining

UGS. In the context of this study, UGS are defined as – a private or public terrestrial space in urban areas covered with vegetation, which is made available to users.

UGS also provide a multitude of benefits to the urban human population. The presence of green spaces can enhance the health and wellbeing of people living in urban areas (White et al. 2013; Ward et al. 2012; Hartig et al. 2003; Nutsford, Pearson, and Kingham 2013). They also indirectly impact our health by improving the air quality (Dadvand et al. 2015; Nowak, Crane, and Stevens 2006) and mitigating urban heat island effect (Xiao et al. 2018; Park et al. 2017; Bowler et al. 2010; Yu and Hien 2006). They also provide a safe haven and vital habitat for urban wildlife (Baldock et al. 2015; Fuller, Tratalos, and Gaston 2009; Cornelis and Hermy 2004).

### **1.3.2 Urban Grey**

McDonnell and Pickett (1990) make a list of features which are unique to urbanization. These include, dwellings, factories, office buildings, warehouses, roads, pipelines, power lines, railroads, channelized waterways, reservoirs, sewage disposal facilities, dumps and airports. All of these features are part of the ‘built’ or ‘artificial’ environment. This can be said to be the ‘urban grey’. It is also seen that these features become increasing common and their proportions increase as we get closer to the urban core.



**Fig. 2** Diagram of the urban landscape classifications as proposed by Swanwick, Dunnett, and Woolley (2003). Dark green land indicates land cover traditionally considered urban habitat, while light green land indicates green space not traditionally considered habitat. Some overlap exists between these categorizations depending on the city, and the physical structure of the land cover. Gray indicates impervious surfaces and buildings. Sourced from Herrera et al. (2021).

## 1.4 The Urban Matrix

The study of biodiversity at the city level is a new subject that demonstrates how characteristics at this level influences species assemblages. These are strongly dependent on local spatial variation in characteristics such as land-use and land-cover within cities. There are many studies which have looked into landscape-scale urban ecology research from urban edge – to – center gradients (Mark J. McDonnell and Hahs 2008; Niemelä and Kotze 2009), non – linear urban gradients (Hahs and McDonnell 2006; Conole and Kirkpatrick 2011) and also as habitat patch characteristics (Beninde, Veith, and Hochkirch 2015). All the studies mentioned have applied a patch – matrix view of the landscape to understand the underlying biodiversity patterns, where there are patches of habitat embedded in an inhospitable matrix

of non-habitat. This patch – matrix view has been very useful and has resulted in some robust generalizations about the biodiversity in urban areas. But viewing the landscape as binary patches of hospitable and inhospitable is maybe too simplistic.

Initial comparison of urban areas to other terrestrial systems gives us the impression that it fits perfectly with the patch – matrix model because of the sharp and seemingly inhospitable barriers created by built – up surfaces. But the urban matrix however is a spatio – temporal dynamic mosaic of green and grey space (Ramalho and Hobbs 2012; Cadenasso, Pickett, and Schwarz 2007). In fact Prugh et al. (2008) writes that “ the patch/nonpatch dichotomy appears to be a gross over-simplification for many species in fragmented landscapes”.

The urban matrix is extremely heterogeneous. It comprises areas that have high- and low-density buildings, agricultural fields, barren lots, brownfields, linear structures such as roads, rivers, railways, etc. This influences how compact the city is, how it is interspersed with greenery and how the density of buildings is in different areas. This variation across multiple scales give every city its own unique habitat mosaic (Werner 2011).

#### **1.4.1 Defining the urban matrix**

There is no singular definition of the term urban matrix. Some define the urban matrix as everything outside the habitat patches (Er et al. 2005). In other interpretations all urban green spaces are considered as urban matrix, with the remaining near – natural areas in a city defined as patches (Palmer et al. 2008). In the context of the current study the urban matrix is defined as – all the habitat patches in the urban landscape, that lie outside the urban green spaces.

### **1.4.2 Urban matrix matters!**

There is little research which has looked into the biological diversity of the urban matrix. One of the reasons might be that the urban matrix mainly consists of private land and this is not easily accessible for research unlike public spaces. Majority of the urban biodiversity research has focused on the remnant native habitats (Martin, Blossey, and Ellis 2012) and, to some lesser extent, urban parks (Nielsen et al. 2014), other patches of vegetation like allotments, gardens and even brown fields can support a large diversity across taxa (Bonthoux et al. 2014; Goddard, Dougill, and Benton 2010; Morelli et al. 2014; Speak, Mizgajski, and Borysiak 2015).

There is mounting evidence that the urban matrix's relevance in terms of biodiversity in cities has been undervalued until now (Hodgson, French, and Major 2007; Crooks 2002). Some examples are given below, which highlight the role of the matrix in influencing the urban biodiversity. Crooks (2002); Hodgson, French, and Major (2007); Loeb, Post, and Hall (2008) and Evans et al. (2017) studied the penetration of urban fauna into green patches in built – up areas (backyards, gardens, tree belts). They found high penetration by various groups of urban fauna into such spaces. If there was an urban green space surrounded by such spaces, then habitat proportion for these urban fauna will be increased significantly (Werner 2011). In the matrix, areas that are predominantly covered by impervious surfaces can sustain plants and in turn provide resources for other species, for example trees growing along streets and weeds growing on walls and pavements (Ikin et al. 2013; Jim 2014).

Even with mounting evidence regarding the importance of the matrix, the management of the matrix is overlooked. This management is vital because pristine systems will never cover more than a small fraction of the Earth. The human modified land just overwhelmingly

dominates the world's terrestrial ecosystems. Hence as we go into the future it will become more important to manage the urban matrix – including not only the habitats as perceived by humans, but all the extensive areas that surround them. Prugh et al. (2008) emphasize this by saying, “Improving matrix quality may lead to higher conservation returns than manipulating the size and configuration of remnant patches for many of the species that persist in the aftermath of habitat destruction”.

## **1.5 Analyzing the urban matrix**

For analyzing any ecological phenomena, indicators are an integral aspect. Good indicators must be able to synthesize and present current knowledge while also meeting scientific and practical standards. Monitoring of all species would not be practical, hence we choose indicators which are built on the monitoring of some well – known taxa. For the current study birds were chosen as the biodiversity indicator.

Birds are an excellent candidate taxon for monitoring global environmental change since they have been studied extensively over the world (Pereira and Cooper 2006; Bibby 1999). They're easy to spot and recognize, and the census methods are well-developed (Pereira and Cooper 2006; Koskimies 1989). We have a strong understanding of their population biology, behavior, and life history, and they are known to respond to environmental change in predictable ways (Järvinen and Väisänen 1979). They're also numerous and diversified (~10,000 species worldwide), and they're at or near the top of the food chain, making them vulnerable to trophic level shifts.

## **1.6 Aims and Objectives**

In the above context, this study was conducted with the following objectives.

### **1.6.1 Objectives**

1. To determine the features of the avifaunal community in urban matrix of Dehradun.
2. To examine the avifaunal community in the urban matrix relative to the urban green spaces.

### **1.6.2 Questions**

1. What is the richness, abundance, density and composition of the avifaunal community in the urban matrix?
2. What is the richness, density and overlap in the bird communities of the urban green space and urban matrix?

## **STUDY AREA**

## **2.1 Topography**

Dehradun lies between 30°15' – 30°31' N latitude and 77°55' – 78°06' E longitude. It is surrounded by the Lesser Himalayas to the north, the Shiwaliks to the south and is nestled between the River Ganges on the east and the River Yamuna to the west. It lies in the Doon Valley, which is about 100km long and covers an area of 3088 km<sup>2</sup>. Towards the south lies the forests of Rajaji Tiger Reserve and the Shiwalik forest division of Uttar Pradesh. In the north are the reserve forests of the Dehradun and Mussoorie forest divisions. The city shows a gradient in elevation from about 410m at Clement Town to almost 700m at Malsi towards the foothills of the Lesser Himalayas.

## **2.2 Geology**

The bow shaped Doon Valley is one of many latitudinal valleys in the mountainous Himalayan tract. Dehradun is situated on the northern lap of the outer Himalaya. The Doon Valley and is a Quaternary tectonic formation (Kumar Singh et al. 2001; Kumar et al. 2007). The northern slope is steep and dwarfs the southern Shiwalik slopes, but the Shiwalik slopes are steep and densely incised by fluvial action of abundant rainfall before the Holocene (Shukla and Bora 2018). This has resulted in the shift of the channels in the southern valley slope to go eastward towards the Song/Suswa river network or the western Asan river network. These ultimately end up draining into the Ganges and Yamuna respectively.

## **2.3 Climate**

The climate is humid subtropical but varies greatly from tropical to temperate along the altitudinal gradient. Summers in Dehradun are often intense with temperatures reaching 34°C - 38°C. Winters are characterized by foggy and hazy months, with the temperature in

certain parts of the city touching 3°C. The average annual maximum and minimum temperatures recorded are 27.8°C and 13.3°C respectively. Monsoons in the Dehradun are generally during the months of June to September, with July and August being the rainiest. The average annual rainfall is around 2073mm.

## **2.4 Floral diversity**

The forest types present in the study area are mainly Moist Shiwalik Sal Forest, Moist Bhabhar Doon Sal Forest and Dry Shiwalik Sal Forest (Champion and Seth 1968). The major tree species in Dehradun as per Kanjilal (1928) are *Shorea robusta*, *Terminalia bellirica*, *Mallotus philippensis*, *Tectona grandis*, *Cassia fistula*, *Syzygium cumini*, *Bombax ceiba*, etc. Some non-native species such as *Delonix regia*, *Litchi chinensis*, *Melia azedarach*, *Agathis robusta*, and *Jacaranda mimosifolia* are also common along the roads and nallas around the city and suburbs. Ornamental shrubs and twiners like *Hibiscus rosa-sinensis*, *Thevetia peruviana* and *Ipomoea cairica* are present in the residential areas and parks, along hedges and gardens. Low-density residential areas, orchards and backyards usually have fruiting plants such as *Litchi chinensis*, *Mangifera indica*, *Achras sapota*, *Carica papaya* and *Psidium guajava*. Pathways and other walkways are usually planted with ornamental plants like *Lagerstomia speciosa*, *Delonix regia*, *Magnolia champaca*, *Callistemon viminalis*, and *Jacaranda mimosifolia*. Agricultural crops in the city and suburbs include wheat, maize, mustard, French bean, soybean, sugarcane, etc.

## **2.5 Faunal Diversity**

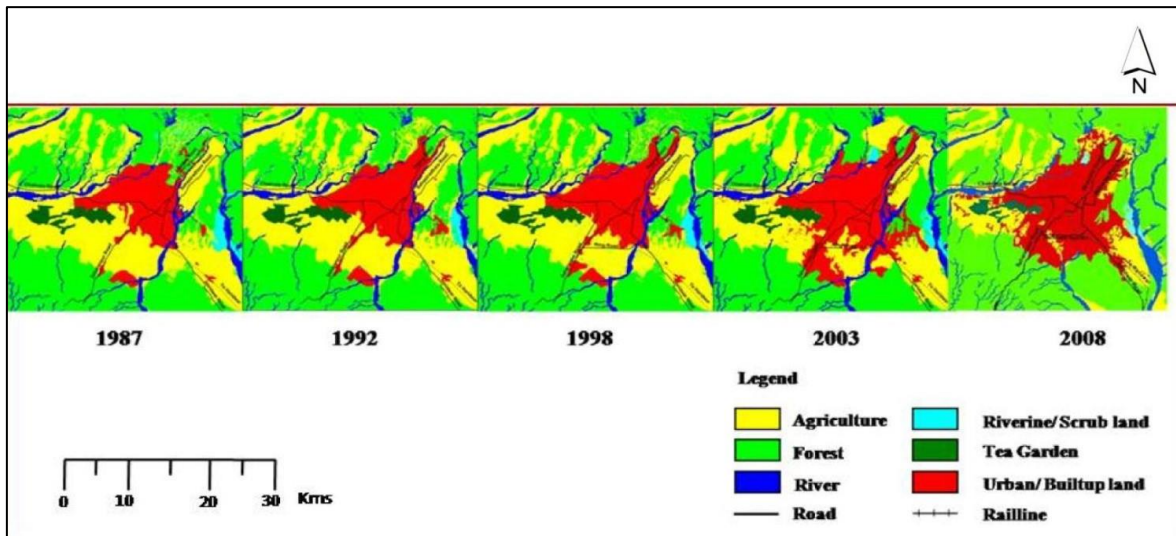
Doon Valley has a unique ecosystem due to its varied physiographic and climatic conditions, leading it to be very rich in its biological diversity. The diversity of woody plants is represented by 674 taxa, 92 families and 368 genera (Negi 2006). The faunal diversity is

about 1700 invertebrates and 700 vertebrate species, belonging to 63 taxa. About 86 species of fish, 20 species of amphibians, 72 species of reptiles, 583 species of birds and 58 species of mammals are found here. Some endangered animal species found here include Bengal Tiger (EN), Indian Elephant (EN), Common Otter (NT), Peter's Tube-nosed Bat (CR), White-rumped Vulture (CR), Pallas's Fish-eagle (EN), Sarus Crane (VU), Tricarinate Hill Turtle (EN), etc.

The geographic location and climate of Dehradun has a big role to play in the avifaunal diversity. About 583 bird species, 84% of avifaunal diversity of Uttarakhand and 43% of the avifaunal diversity of India, are found in the city (eBird 2021). This can be attributed to the many different types of habitats around the city and the various green spaces – Forest Research Institute, Wadia Institute of Himalayan Geology, Indian Military Academy, Wildlife Institute of India, Rashtriya Indian Military College, Uttarakhand Ayurveda University, ONGC Colony and many more.

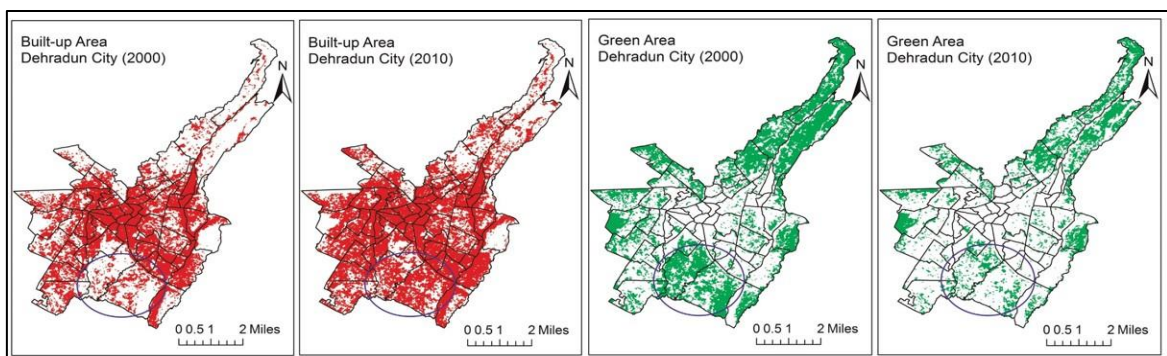
## **2.6 Trends in Urbanization**

Dehradun is classified as a class-I city by the 2011 Census of India. It is the largest urban agglomeration in Uttarakhand's hilly regions. Following the creation of the state of Uttarakhand in the year 2000, it was designated as the capital. As a result, the growth of many sectors in the city skyrocketed. As more jobs and opportunities were available in the region, the population of Dehradun grew dramatically (Census of India 2011). The changes in the land cover around Dehradun became visible as the population grew. There was about 40.96% urban growth in Dehradun between the years 1998-2008 (Gupta 2013)( Figure 3).

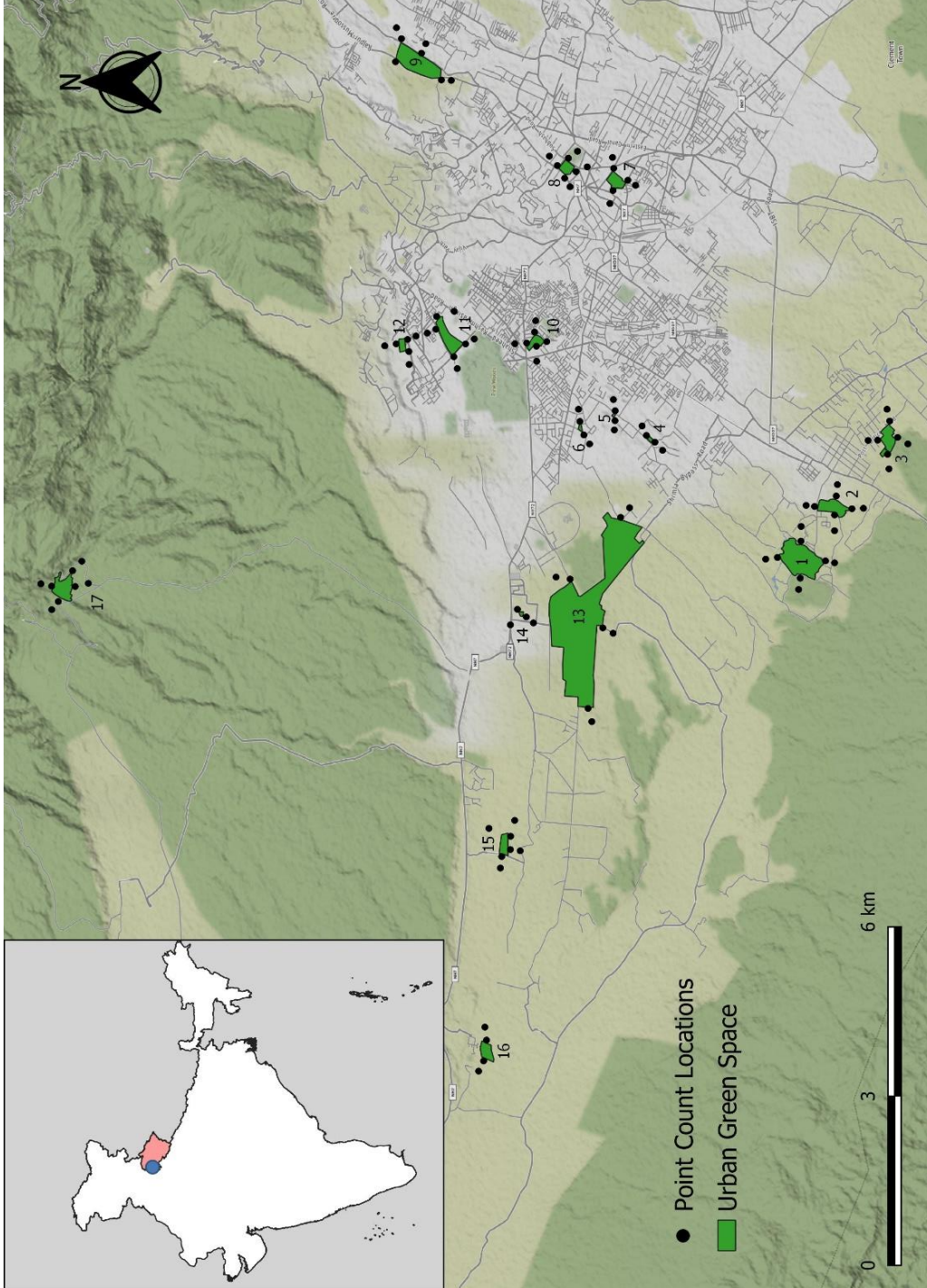


**Fig 3.** Land use Land Cover maps of Dehradun Urban area over a period of two decades. Sourced from (Gupta 2013).

This increase in urban areas has led to the decrease of other land covers like agriculture, forests and open areas. Dutta, Rahman, and Kundu (2015) looked into the growth of Dehradun city and found that the growth had very profound impact on the vegetation cover in the city (Figure 4). This decrease in the vegetation cover is in along the outer boundaries of the city. These places are where there are major highways connecting Dehradun to other major towns. As the population is increasing in Dehradun the urban sprawl is also increasing, leading to the outer boundaries being developed to accommodate the growing city.



**Fig. 4** Built – up and Vegetation cover of Dehradun city in 2000 and 2010. Sourced from Dutta, Rahman, and Kundu (2015).



**Fig. 5** Map of the study area showing the point transects around the urban green spaces in the Doon Valley. The black dots represent the point count locations. The green polygons are the urban green spaces. They are numbered from 1 to 17 and the names are as follows: WII, WII C, GEU, CBI, NP, VV, MKP, GP, NIVH, FRI C, ZSI, TO, TE, MDDA, VIGDH, AWHO and UPES

## **METHODOLOGY**

The goal of this study was to determine the features of the bird community in Dehradun's urban matrix, as well as their relationship to the characteristics of the bird community in urban green areas. To do so, the following three aspects of bird community characteristics were investigated: abundance, species richness, and composition. Bird community characteristics were compared to a variety of ecologically relevant environmental variables in order to better understand the factors affecting the observed patterns. GIS tools were used to quantify the proportional representation of the landcover types in the matrix. Appropriate analytical tools were used to analyze the characteristics and factors influencing the bird community in the urban matrix.

### **3.1 Selection of study area**

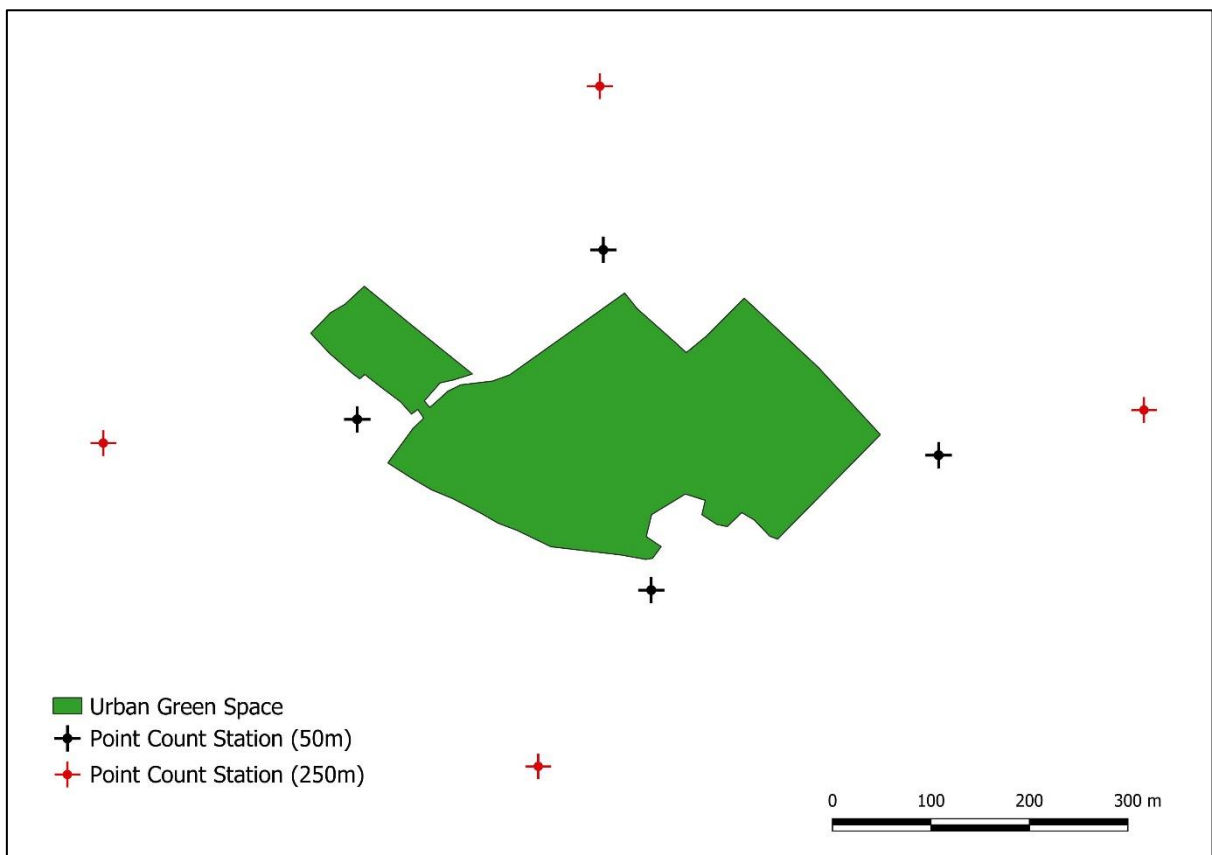
The current study was conducted in the city of Dehradun. This system was selected because the area has a rich bird diversity and has undergone substantial changes in the landscape due to urbanization. Thus, it presents an opportunity to investigate the factors influencing the bird community in the urban matrix.

Over the years, Dehradun has gone through a lot of major changes. After the delineation of the state, political pressure resulted in intense urbanization, due to which agricultural fields and forested areas were converted into built-up areas (Dutta, Rahman, and Kundu 2015). These drastic changes have resulted in the remaining green spaces occurring as small pockets, interspersed in a matrix of the transformed urban landscape comprising of built – up areas, agricultural fields and other land uses in the city. Despite this, Dehradun harbors 43% (583 of 1343) of the avifaunal diversity of India and about 84% (583 of 692) of Uttarakhand (eBird 2021). This makes it vital to understand the contribution of the matrix in maintenance of such a highly diverse bird community. This coupled with the fact that

Kaushik, Tiwari, and Kumari (2020) have previously worked in the urban green spaces around Dehradun provides a good opportunity for the comparison of the bird communities between the urban matrix and urban green spaces.

### 3.2 Study Design

The sampling units were selected around urban green spaces sampled by Kaushik, Tiwari, and Kumari (2020). Variable radius point counts were laid around the urban green space along the cardinal directions at distances of 50m and 250m (Figure 6). A distance of 200m was maintained between each point count (Bibby, Burgess, and Hill 1992). This distance was selected because the urban green spaces were very closely located and could not allow for the point counts to be further apart. A total of 109 point counts were placed across Dehradun based on accessibility of the location of sampling.



**Fig. 6** Diagram representing the study design. The point count stations around each urban green space are situated along the four cardinal directions, maintaining a distance of 50m and 250m from the urban green space.

### 3.3 Field Methods

Field sampling was carried out during the months of March 2021 to April 2021 (breeding season). Variable radius point counts were conducted to sample the bird community. At each point count, no observations were recorded for 3 minutes to allow for acclimatization. This was followed by a 7-minute observation period. Data was collected on the species identity, count of individuals and distance to observer. Distances were recorded using a handheld laser rangefinder (Hawke LRF Pro 400). Species identities of birds which could not be identified on field were photographed and identified later using appropriate field guides (Grimmett, Inskipp, and Inskipp 2016). All point counts were surveyed by only a single observer (JBC) to avoid any observer bias. Bird surveys were carried out from 0600hrs to 0900hrs. All point transects could only be sampled once due to the COVID-19 pandemic restrictions at the time.

### 3.4 Analytical Methods

The community data was tallied in a matrix with rows for point counts and columns for species. The cell value represented the abundance of each species in a point count. This data was used for all subsequent analysis.

To categorize the point counts to a particular habitat, cluster analysis was performed. The data used for this analysis was the percentage of all habitats present around a point count in a 100m radius. These habitats were broadly defined as:

1. **Built-up:** This included all the man-made structures, cemented and paved surfaces like roads and canals.
2. **Green cover:** This included the remnant woodland patches in the city, forest patches, plantations, and tree belts along the roads and backyards.

3. **Open area:** This included the areas where there was short grass and herbs, no tree cover and little to no shrubs (lawns, yards).
4. **Scrubland:** This included the open areas where there was large amount of shrubs and little grass and herb cover.
5. **Agriculture:** This included the agricultural fields which were planted with different crops at the time of sampling.

**Table 1** Range of proportions of habitats in a 100m radius across all point counts.

Sr. No.	Habitat Type	Minimum Proportion (%)	Maximum Proportion (%)
1.	Agriculture	0	78.93
2.	Built – up	0	93.73
3.	Green Cover	0	100
4.	Open Area	0	74.93
5.	Scrubland	0	95.59

The habitats in the 100m radius around the point counts were digitized using the ‘polygon’ tool in Google Earth Pro (v7.3). The digitized habitats were then visited to check the accuracy of the imagery and the digitization. To get the percentage of each habitat in the 100m, each polygon was imported into QGIS Desktop (v3.16.6) and the area for each polygon was calculated in hectares. This was then converted into percentage and used in the clustering algorithm. Landscape Heterogeneity was measured as the Shannon Diversity Index of all the patches of the different habitats in the 100m radius around the point counts.

$k$  – medoid clustering was carried out using the habitat data. The initial number of clusters ( $k$ ) was decided upon by using *a posteriori* information. Bray – Curtis dissimilarity was used to associate each point count to its closest medoid. Internal validation methods were used to check the output of the clustering algorithm and to verify the use of the correct number of clusters. The  $k$  – medoid clustering was computed using function ‘pam’ in package ‘cluster’

(Maechler et al. 2021). The internal validation methods were computed using function 'cIValid' in package 'cIValid' (Brock et al. 2008). These were done in the statistical software 'R' (R Core Team 2021).

Habitat wise density and guild density was calculated by using Conventional Distance Sampling in the software Distance (v7.3) (Thomas et al. 2010). Boxplots of the same were constructed to examine the differences in the habitat wise densities and guild densities across habitats. Overall species richness of the landscape was calculated based on the number of unique species seen across all habitats. Bird species were also classified into foraging guilds based on the food they eat. Overall rank abundance curve was also computed to show the dominance of species in the landscape. Habitat wise species accumulation curves using the rarefaction method were used to compare the richness among the habitats and also to assess the extent to which the bird community within each habitat was sampled. Since the asymptote was not reached in most of the habitats, estimated species richness was calculated using the species richness estimator developed by Chiu et al. (2014). This is based on the information of tripletons and quadruplets to estimate undetected species richness. This estimator is non-parametric and is universally valid for any species abundance distribution. Also rank abundance curves were constructed for each habitat to assess the differential dominance and relative abundance (RA) of different species between the habitats. Estimated species richness was calculated using function 'ChaoSpecies' in package 'SpadeR' (Chao et al. 2016). Species accumulation curves and rank abundance curves were built using the functions 'accumcomp' and 'rankabuncomp' respectively in package 'BiodiversityR' (Kindt and Coe 2005). These were done in the statistical software 'R' (R Core Team 2021).

To illustrate the variations in the bird community composition of the sampling units with the habitat categories, ordination was performed using Non-metric Multidimensional Scaling (NMDS). The ecological distance between two bird communities was calculated using the Bray – Curtis Dissimilarity index. This technique was used to collapse the species data into two dimensions so that the differences in the species composition of the different land cover types could be detected. As this technique relies upon rank orders rather than absolute abundances, it can accommodate nonlinear species responses. Ordination plots were constructed and ellipses were used to demarcate the plots of the same habitats. This was done using function ‘metaMDS’ of the package ‘vegan’ (Oksanen et al. 2020) in the statistical software ‘R’ (R Core Team 2021). Ellipses were constructed using the function ‘ordiellipse’ in the same package (Oksanen et al. 2020).

Linear modelling approaches were employed on the overall species richness and density data with preselected habitat parameters as predictor variables to investigate the relationship between species richness and underlying habitat factors. The proportion of habitats identified within a 100-meter radius of the sampling unit, landscape heterogeneity, distance to nearest and largest forest patches, distance from the UGS and area of UGS were examined as predictive factors at the landscape scale. For the local scale tree richness, tree biomass, tree height, tree density, tree GBH, tree canopy spread, tree canopy cover, shrub richness, shrub volume, shrub density, shrub height and shrub cover were chosen as the predictor variables. In order to see if there was any peaking at intermediate levels, quadratic functions of some variables were also examined as predictors. These were selected based on *a priori* information and hypothesis based on relevant literature (Table 2). Prior to running the analysis, the predictors were scaled so that the result indicated each predictor variable's relative importance.

**Table 2** Hypothesized relationship of predictor variables with species richness and density (landscape level).

<b>Covariate</b>	<b>Hypothesized relationship</b>	<b>Rationale</b>
Proportion of habitats (green cover, scrubland, agriculture, open area)	+ve	The amount of unique habitats present in the urban matrix (apart from built-up) can lead to an increase in the species richness and density (Murgui and Hedblom 2017).
Proportion of built-up	Quadratic	Some studies suggest that species richness is higher in urban areas where human development is low to moderate (Racey and Euler 1982; Jokimaki and Suhonen 1993; Tratalos et al. 2007) and increasing levels of human development leads to decrease in richness (Blair 1996; Emlen 1974; Jokimaki and Suhonen 1993).
Proportion of built – up	-ve	Species richness and density show a decline as the built – up density increases (Gaston 2010; McKinney 2008)
Landscape Heterogeneity	+ve	Many distinctive land uses have resulted in unusually high spatial habitat heterogeneity in urban settings (Savard, Clergeau, and Mennechez 2000; Thompson et al. 2003) and these result in higher species richness (Niemelä 1999).
Distance to nearest forest patch Distance to largest forest patch	+ve	If the habitat patches in the matrix are closer to an natural forested area, generalist species can move about more freely and hence density and richness will show an increase (Adams 2016; Aronson et al. 2014)
Distance from UGS	-ve	As we move more and more towards the urban core, we should see a decrease in the richness and density (Lepczyk et al. 2017).
UGS area	+ve	The size of the UGS is an important factor which determines the density and richness of many taxa in and around the UGS (Goddard, Dougill, and Benton 2010; Aronson et al. 2014; Beninde, Veith, and Hochkirch 2015; Chamberlain et al. 2007).

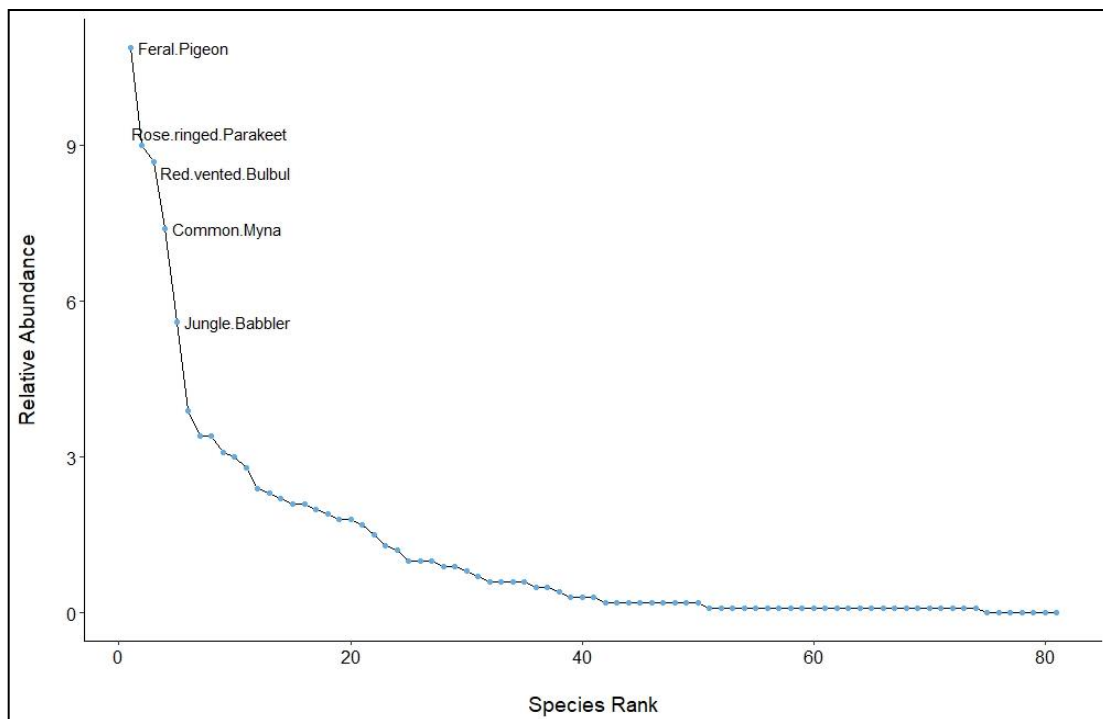
The models were selected based on the information theoretic approach. This was performed by first building a global model with all the covariates. The ecologically sensible variables which that could potentially affect the species richness were identified using a step-wise backward selection method. Model averaging was then performed on models with delta-AIC less than 2.

Comparisons of the species composition, density and richness in the urban matrix and UGS were drawn. This was done by constructing Venn diagrams which captured the differences in the species composition of the urban matrix and UGS. Boxplots of the overall density and richness in the urban matrix and UGS were also plotted to compare the differences. These were done in the statistical software 'R' (R Core Team 2021).

## **RESULTS**

## 4.1 General Overview

A total of 3775 individuals belonging to 81 species (refer to Appendix I for species list) were recorded during the sampling period (breeding season - March 2021 to April 2021). Feral Pigeon (*Columba livia*) (RA: 10.94%), Rose-ringed Parakeet (*Psittacula krameri*) (RA: 9.01%), Red-vented Bulbul (*Pycnonotus cafer*) (RA: 8.72%), Common Myna (*Acridotheres tristis*) (RA: 7.40%) and Jungle Babbler (*Turdoides striata*) (RA: 5.60%) were the most abundant species in the study area (Figure 7). These top five species accounted for 41.67% of the total abundance.

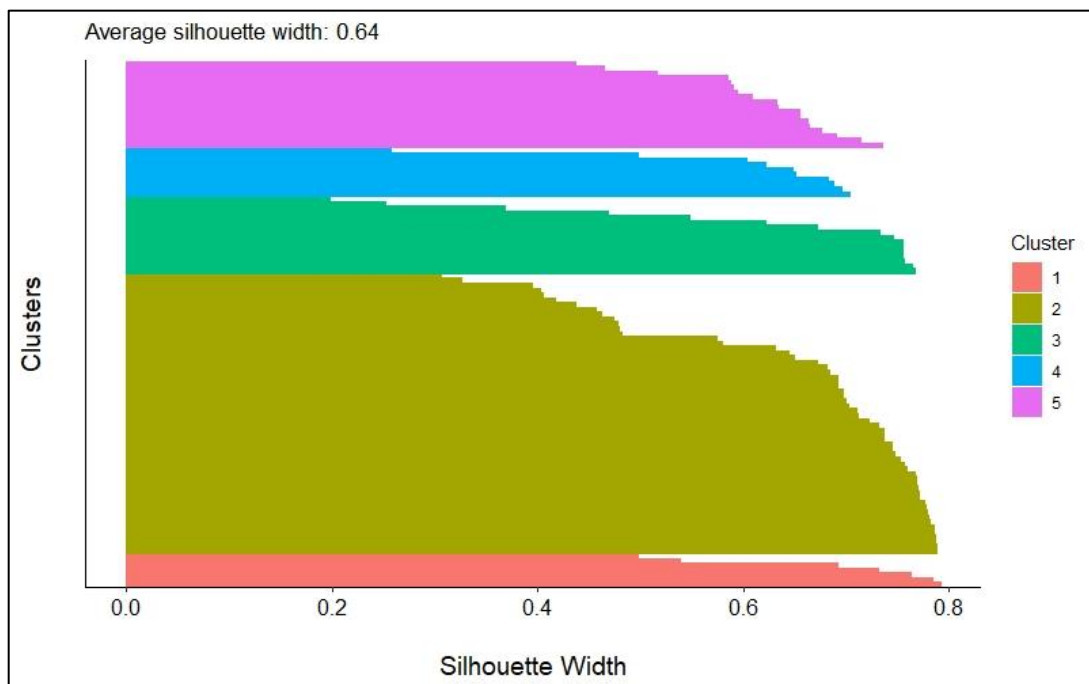


**Fig. 7** Rank Abundance Curve showing the five most abundant species found in the study area during the sampling period.

## 4.2 Classification of sampling units into habitat types

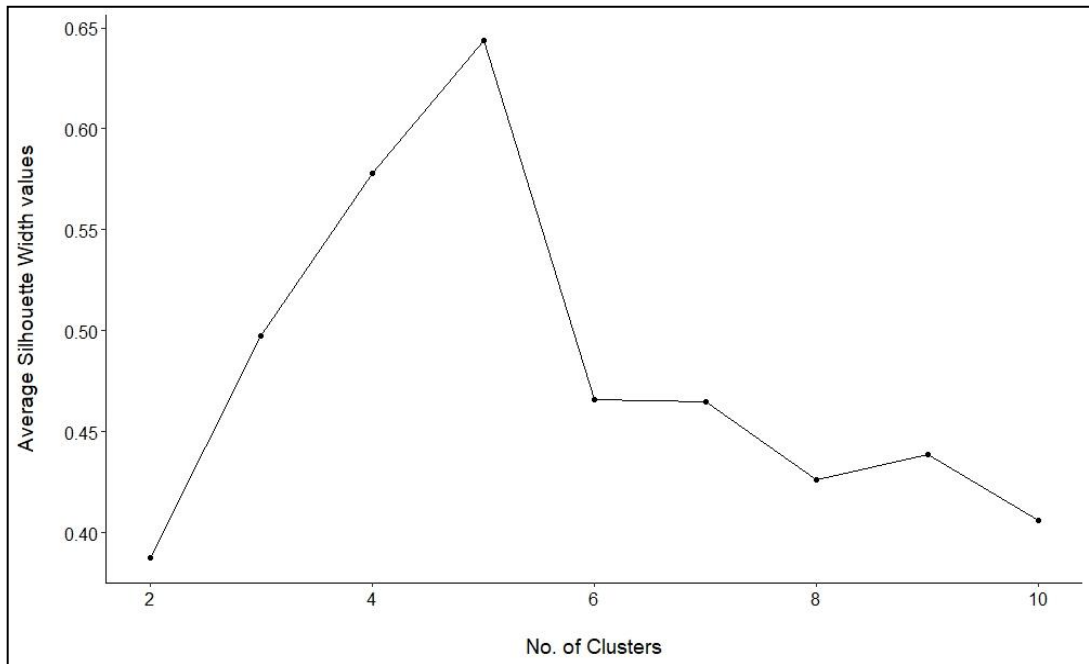
The 109 sampling points resulted in 5 distinct clusters based on the habitat types (Table 3) (For clustering information of individual point counts, please refer to Appendix II.) The resulting clusters were then subjected to internal validation methods.

The silhouette plot (Figure 8) shows the clusters and silhouette value for each sampling unit. Larger silhouette widths in the plot indicate that the sampling unit is well matched to its own cluster and poorly matched to its neighboring clusters. As most sampling units in their respective clusters show high values (closer to +1), the clustering configuration is appropriate.



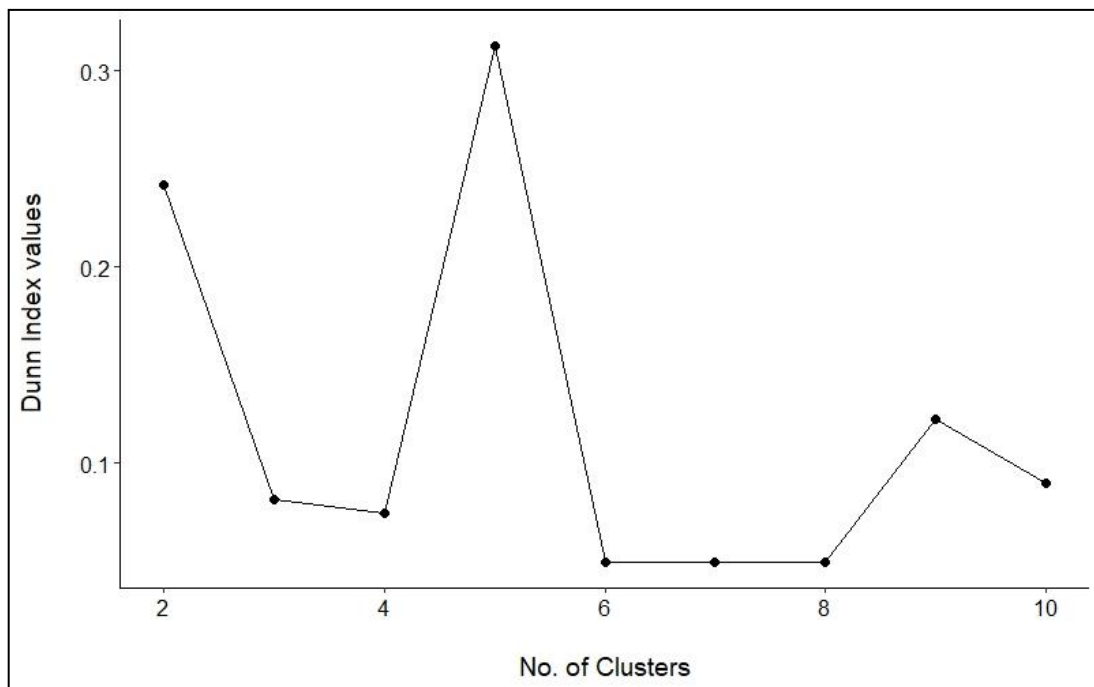
**Fig. 8** Silhouette plot of the cluster analysis showing 5 distinct clusters and their silhouette widths.

The average silhouette width method is indicative of the quality of the clustering. A high average silhouette width indicates a good clustering configuration. As the maximum silhouette width is obtained for a 5-cluster configuration, this is selected as the appropriate number of clusters to represent the data (Figure 9).



**Fig. 9** Plot showing the average silhouette width values across an increasing number of clusters.

The Dunn Index aims to maximize the inter-cluster distances while minimizing the intra-cluster distances. A large value indicates that the clusters are compact and well-separated. As a large value is obtained for a 5-cluster configuration it is selected as the optimal number of clusters (Figure 10).



**Fig. 10** Plot showing the Dunn Index values across an increasing number of clusters.

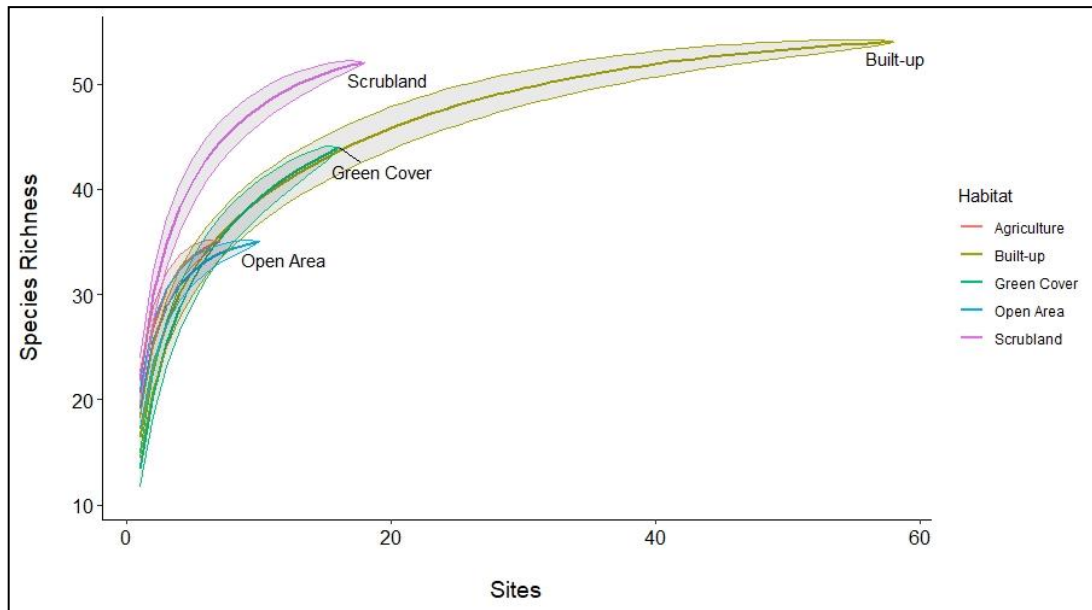
Based on the validation methods, the 5-cluster configuration was selected to be the most appropriate for the data (Table 3).

**Table 3** No. of point count stations in each cluster and its corresponding habitat type.

<b>Cluster</b>	<b>No. of Sampling Units</b>	<b>Habitat Type</b>
1	7	Agriculture
2	58	Built-up
3	16	Green Cover
4	10	Open Area
5	18	Scrubland

### 4.3 Richness

Habitat wise species accumulation curves (Figure 11) using rarefaction method revealed that built-up had the highest species richness (54 species) followed by scrubland (52 species) > green cover (44 species) > open area (35 species) = agriculture (35 species) (Fig. 6). Sampling effort across all the habitat types was not adequate as each of the sites were sampled only once during the sampling period.



**Fig. 11** Species accumulation curves with sites on the x-axis and accumulated habitat wise species richness on the y-axis.

Estimated species richness (Table 4) using Chiu et al. (2014) richness estimator (iChao) showed estimated richness was higher than observed for each of the five habitats and also for the overall landscape.

**Table 4** Estimated species richness across the habitat types within urban matrix using Chiu et al. (2014) richness estimator.

Habitat	Observed Richness	Estimated Richness (iChao)	SE	95% C.I. Lower	95% C.I. Upper	Undetected Species	Undetected Percentage
Agriculture	35	36.78	1.05	35.61	40.22	1.788	4.86
Built – up	54	56.4	0.82	55.49	59.06	2.42	4.29
Green Cover	44	56.39	5.35	49.51	71.89	12.399	21.99
Open Area	35	38.97	1.19	37.66	47.57	3.971	10.19
Scrubland	52	52.73	1.14	52.08	58.46	0.726	1.38
Overall	81	88.40	1.73	86.09	93.26	7.401	8.37

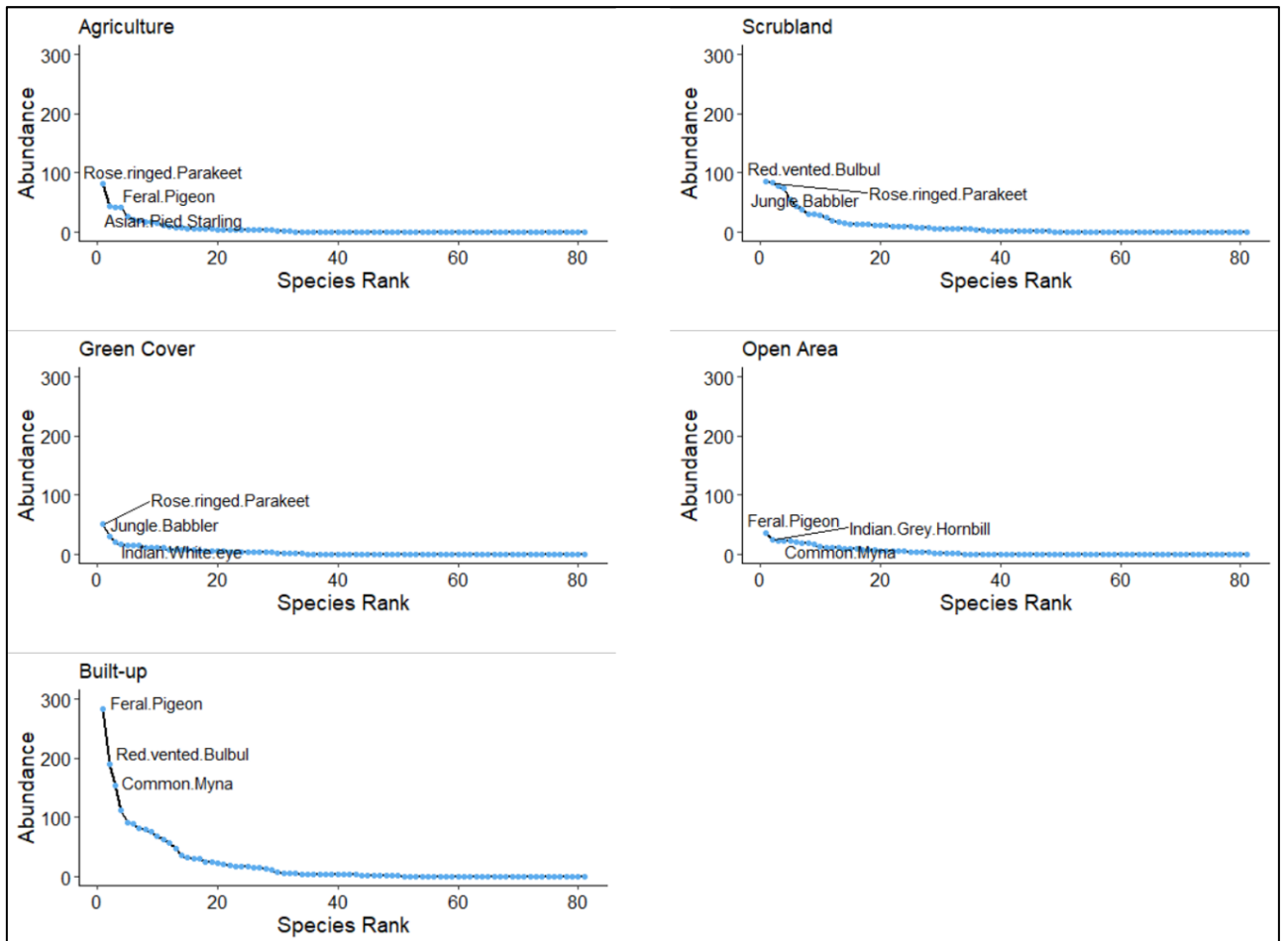
The observed foraging guild richness (Table 5) shows that built – up areas had the maximum richness of frugivorous, insectivorous, nectarivorous and omnivorous birds. Richness of granivorous birds was maximum in agricultural fields. Carnivorous bird richness was same for built – up areas and agriculture.

**Table 5** Foraging guild richness across the habitat types in the study area.

Habitats	Carnivore	Frugivore	Granivore	Insectivore	Nectarivore	Omnivore
Agriculture	1	6	6	8	1	13
Built – up	2	9	4	22	3	15
Green Cover	2	8	3	19	2	10
Open Area	1	5	2	15	1	11
Scrubland	1	7	5	21	2	16

#### 4.4 Abundance

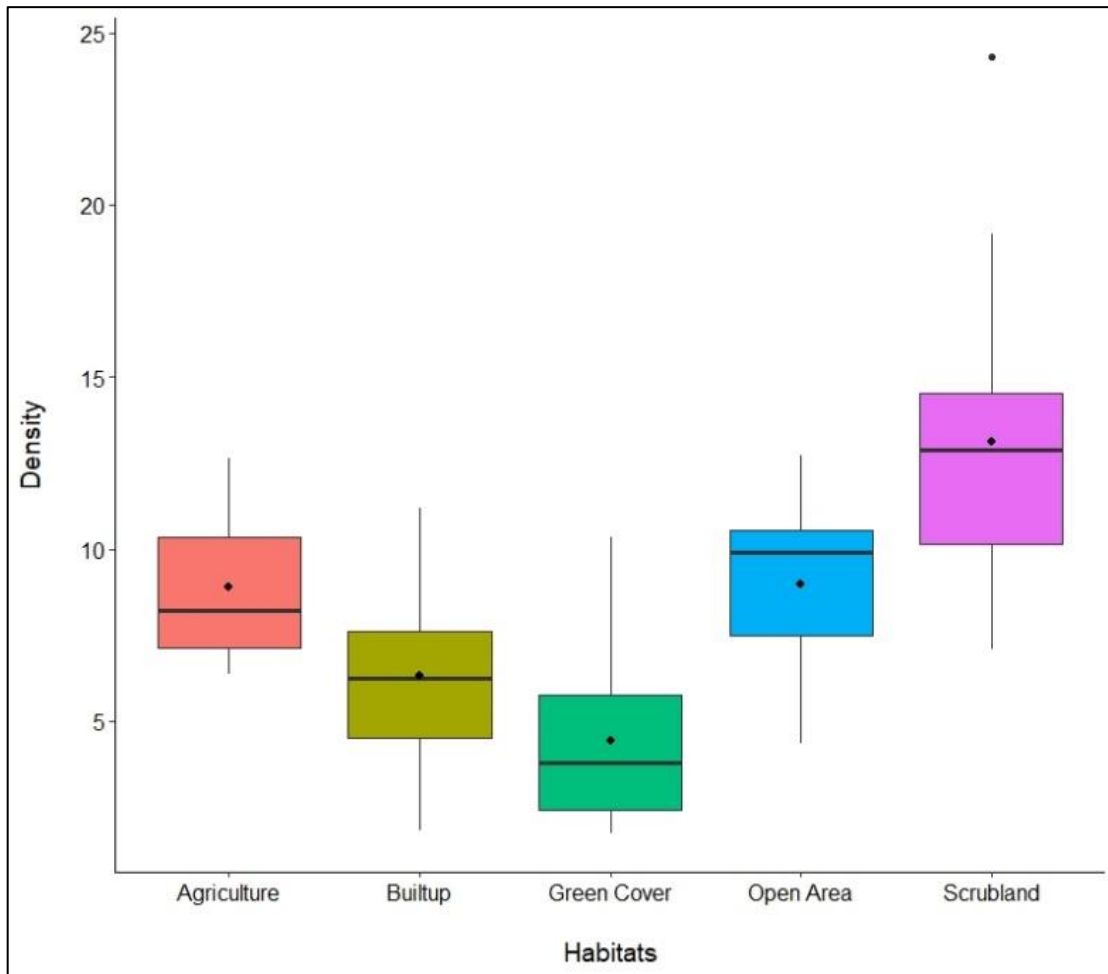
Habitat wise rank abundance curves (Figure 12) showed that Rose-ringed Parakeet (*Psittacula krameri*) showed large values of relative abundance across agriculture, green cover and scrubland (0.19, 0.16, 0.098 respectively). Feral Pigeon (*Columba livia*) was abundant in built-up, open area and agriculture (0.155, 0.103, 0.101 respectively). Red-vented Bulbul (*Pycnonotus cafer*) was most abundant in scrubland followed by built-up (0.104, 0.102 respectively). Common Myna (*Acridotheres tristis*) was more abundant in built-up than open area (0.084, 0.064 respectively). Jungle Babbler (*Turdoides striata*) abundance was more in green cover followed by scrubland (0.094, 0.091 respectively).



**Fig. 12** Rank abundance curves showing the three species with the highest relative abundance values in each of the habitat categories.

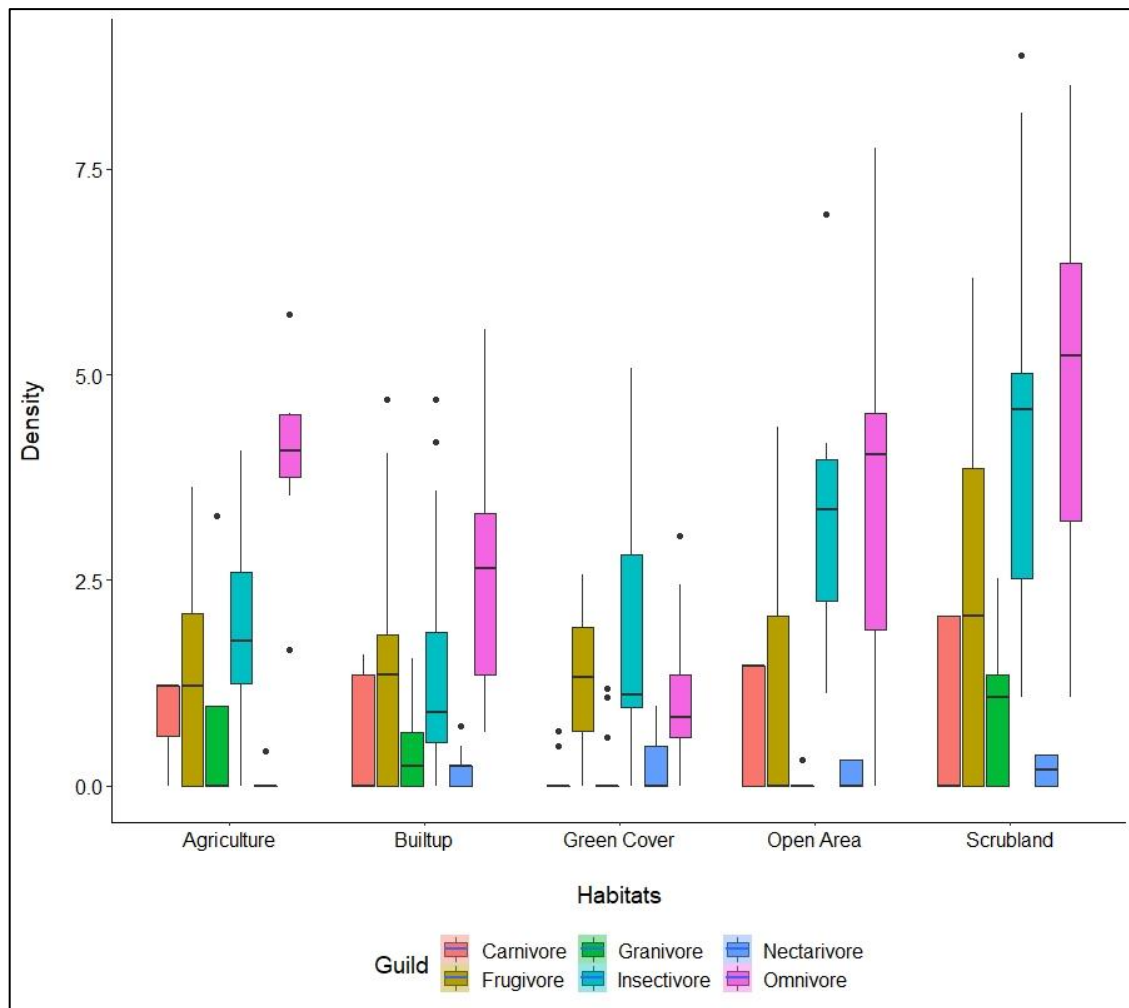
### 4.5 Density

Habitat wise densities of birds in the study area (Figure 13) showed that scrubland had the highest density of birds per hectare ( $13.12_{\text{mean}} \pm 4.35_{\text{SD}}$ ) followed by open area ( $8.97_{\text{mean}} \pm 2.77_{\text{SD}}$ ), agriculture ( $8.89_{\text{mean}} \pm 2.49_{\text{SD}}$ ), built – up ( $6.34_{\text{mean}} \pm 2.28_{\text{SD}}$ ) and green cover ( $4.43_{\text{mean}} \pm 2.39_{\text{SD}}$ ). Refer to Appendix III for the density function graphs.



**Fig. 13** Boxplot showing the habitat wise densities of birds per hectare. The horizontal line within the box represents the median and the black dot within the box represents the mean.

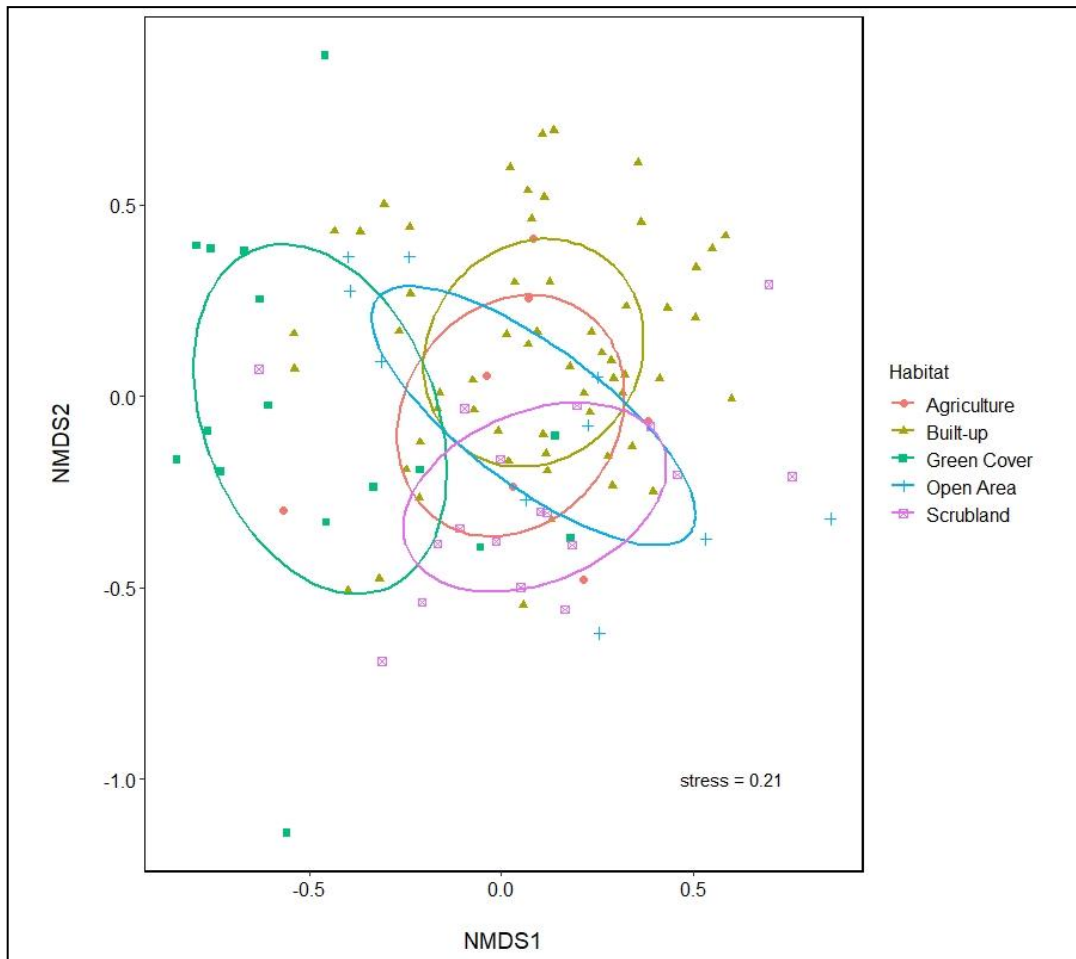
Habitat wise guild density in the study area (Figure 14) showed that scrublands had the highest densities for carnivorous ( $0.91_{\text{mean}} \pm 0.25_{\text{SE}}$ ), frugivorous ( $2.18_{\text{mean}} \pm 0.45_{\text{SE}}$ ), granivorous ( $0.84_{\text{mean}} \pm 0.19_{\text{SE}}$ ), insectivorous ( $4.20_{\text{mean}} \pm 0.54_{\text{SE}}$ ) and omnivorous ( $4.80_{\text{mean}} \pm 0.53_{\text{SE}}$ ) birds. Built – up areas showed the lowest average densities of insectivorous birds ( $1.27_{\text{mean}} \pm 0.15_{\text{SE}}$ ). Nectarivorous birds had the highest density in green cover ( $0.24_{\text{mean}} \pm 0.08_{\text{SE}}$ ).



**Fig. 14** Boxplot showing the habitat wise guild densities of birds per hectare. The horizontal line within the box represents the median.

#### 4.6 Dissimilarity between communities

Ordination was done based on the dissimilarities between the habitats calculated from the abundances of the species shows habitat wise clustering and a great degree of overlap (Figure 15). Habitat wise ellipses over plots of all five habitats show mean spread around the centroid with many outliers. Plots of green cover showed grouping with a low degree of overlap from the other habitats. Plots of built-up, scrubland, agriculture and open area show high degree of overlap among each other and also with some plots of green cover.



**Fig. 15** NMDS ordination showing bird community composition in different habitats. The ellipses are centered at mean MDS values of both axis and the radius is determined by the standard error of the mean at 95% CI. Non-metric fit was 95.5%. (Please refer to Appendix IV for the Stressplot of the NMDS ordination)

#### **4.7 Landscape Scale Drivers of species richness and density**

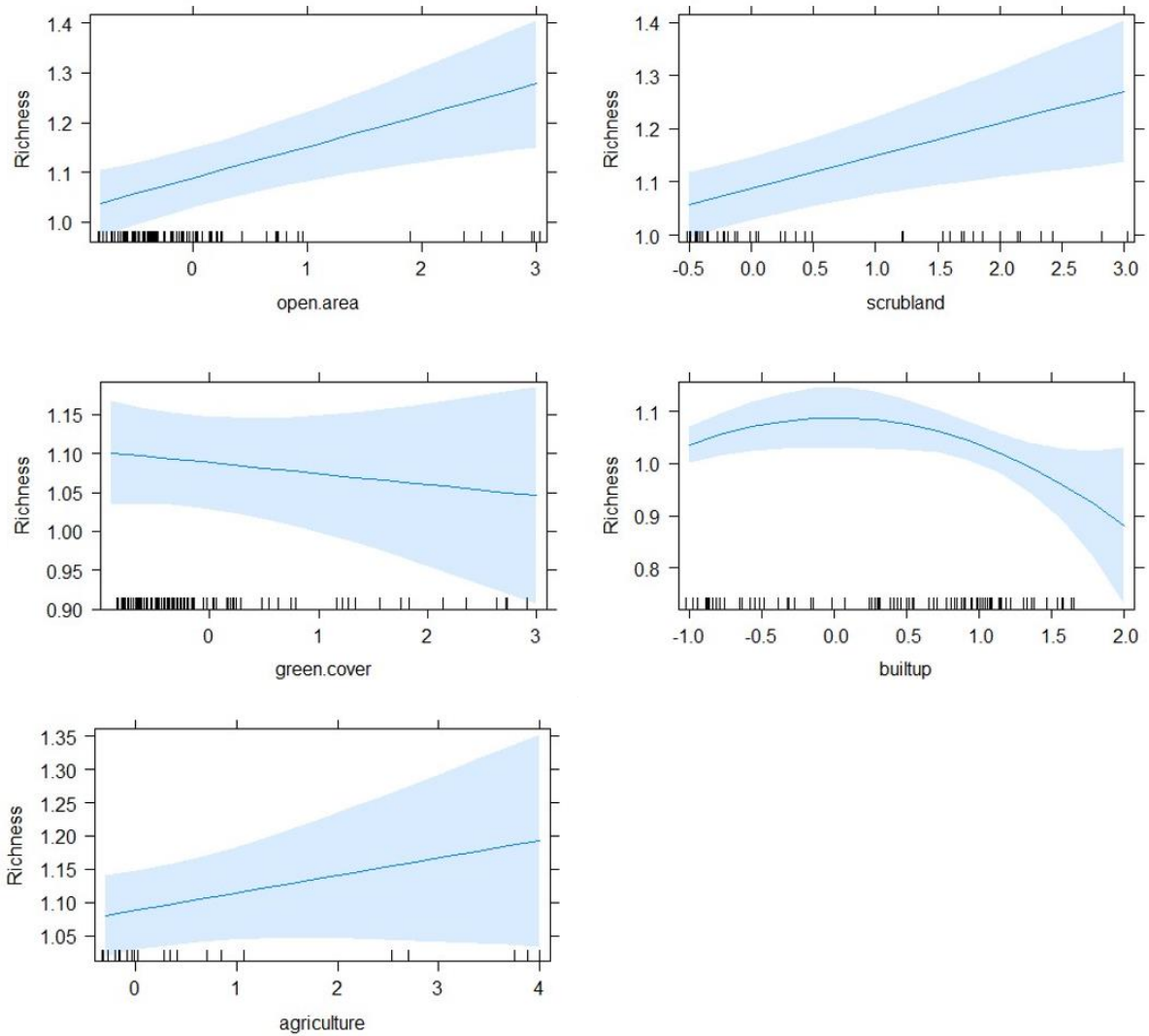
The species richness in the urban matrix was influenced by the proportions of habitats – open area, scrubland and also by the proportion of built – up areas (Table 6). Increasing proportions of open area and scrubland positively influenced the species richness, whereas increasing proportion of built-up showed that the species richness peaked at moderate built – up and then decreased. Agriculture had a positive effect on the species richness and green cover showed a negative effect, but they were statistically not significant (Table 7, Figure 16). Refer to Appendix V for the graphs of the model assumptions.

**Table 6** Comparison of the best fitting models for richness with the global model for landscape level habitat covariates.

<b>Sr. No</b>	<b>Model</b>	<b>df</b>	<b>log Likelihood</b>	<b>AIC</b>	<b>delta AIC</b>
1	~open.area + scrubland + agriculture + I(builtup^2)	6	31.73	-51.45	0
2	~green.cover + open.area + scrubland + agriculture + I(builtup^2)	7	31.98	-49.97	1.48
3	~green.cover + open.area + scrubland + agriculture + I(builtup^2) + Dist_n_fp	11	34.37	-46.73	4.72
4	~green.cover + open.area + scrubland + agriculture + I(builtup^2) + LHI + UGS_area + Dist_n_fp + Dist_1_fp + UGS_dist ( <b>Global Model</b> )	12	34.41	-44.82	6.63

**Table 7** Summary of the averaged model for overall species richness showing variables, coefficient estimates, standard error, associated z – value and p-value for effect of the landscape level habitat features on the bird community richness in the urban matrix.

<b>Averaged model</b>	<b>Variable of the model</b>	<b><math>\beta</math> – estimate</b>	<b>SE</b>	<b>z – value</b>	<b>p – value</b>
~open.area + scrubland + agriculture + green.cover + I(builtup^2)	<i>% open area</i>	<i>0.0663</i>	<i>0.018</i>	<i>3.503</i>	<i>0.000460</i>
	<i>% scrubland</i>	<i>0.0639</i>	<i>0.018</i>	<i>3.383</i>	<i>0.000716</i>
	<i>% agriculture</i>	<i>0.0285</i>	<i>0.018</i>	<i>1.540</i>	<i>0.123556</i>
	<i>% green cover</i>	<i>-0.004</i>	<i>0.013</i>	<i>2.155</i>	<i>0.734202</i>
	<i>% built-up</i>	<i>-0.053</i>	<i>0.024</i>	<i>0.340</i>	<i>0.031138</i>



**Fig. 16** Landscape level habitat correlates of species richness in the urban matrix. The parameters shown are based on the averaged model. The significantly influential variables were proportions of open area, scrubland and built-up. Proportion of agriculture and green cover were not statistically significant.

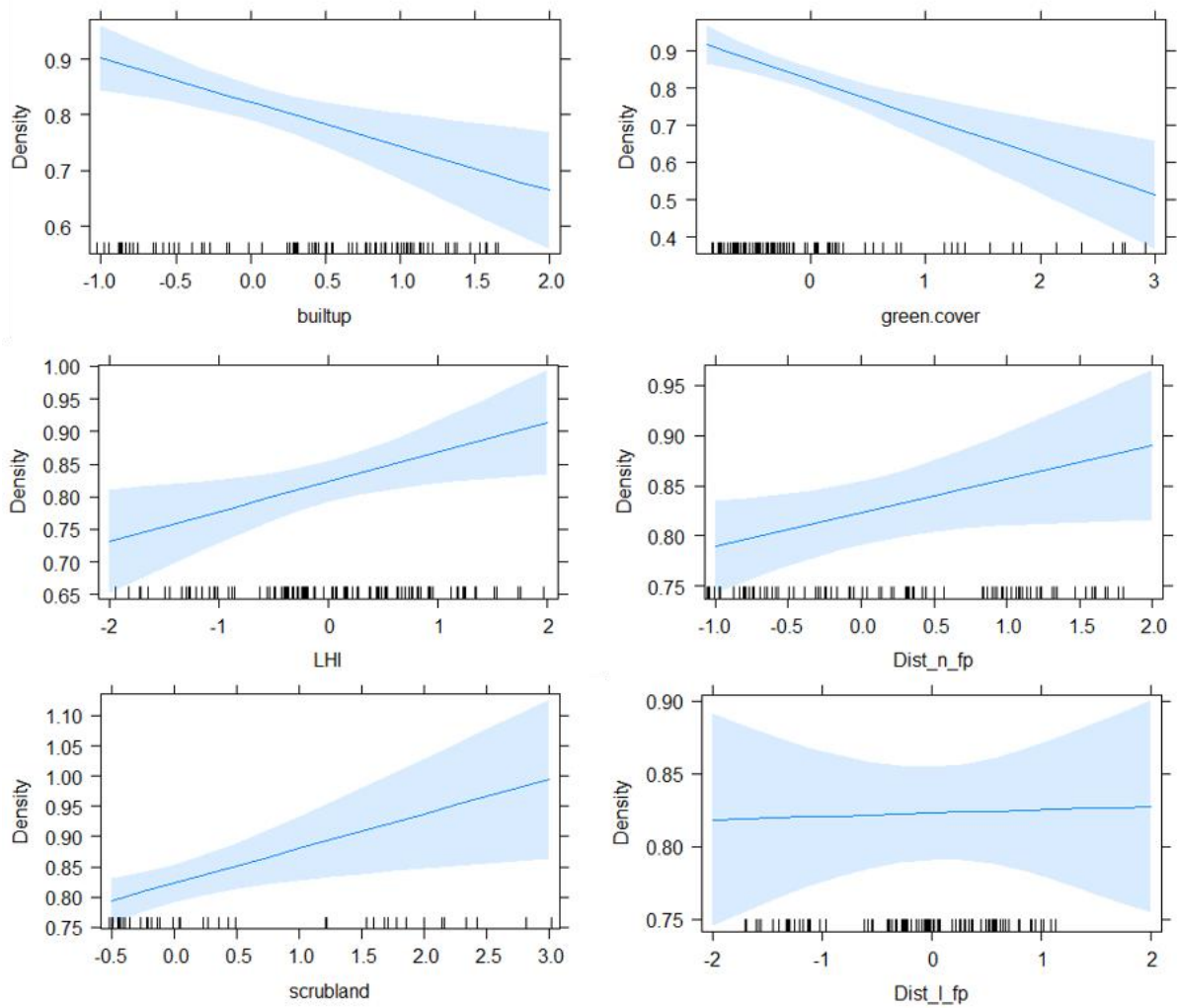
Species density in the urban matrix was influenced by the proportions of habitats – green cover and scrubland, proportion of built – up areas, the landscape heterogeneity (Table 8). Increasing proportion of scrubland had a positive influence on the overall density whereas green cover had a negative influence. Also, as the proportion of built – up areas increased, the overall density decreased. Landscape heterogeneity positively influenced the overall density in the matrix. Distance to the nearest and largest forest patch had a slightly positive influence, but were statistically not significant (Table 9, Figure 17). Refer to Appendix IV for the model assumptions graphs.

**Table 8** Comparison of the models for overall density with the global model for landscape level habitat covariates.

Sr. No	Model	df	log Likelihood	AIC	delta AIC
1	~builtup + green.cover + scrubland + LHI + Dist_n_fp	7	45.06	-76.12	0
2	~builtup + green.cover + scrubland + LHI + Dist_n_fp + Dist_l_fp	8	45.07	-74.14	1.98
3	~builtup + green.cover + scrubland + LHI + UGS_area + Dist_n_fp + Dist_l_fp	9	45.22	-72.44	3.68
4	~builtup + open.area + green.cover + scrubland + agriculture + LHI + UGS_area + Dist_n_fp + Dist_l_fp	10	45.31	-70.61	5.51
5	~builtup + open.area + green.cover + scrubland + agriculture + LHI + UGS_area + Dist_n_fp + Dist_l_fp + UGS_dist ( <b>Global Model</b> )	11	45.45	-68.90	7.22

**Table 9** Summary of the averaged model for overall density showing variables, coefficient estimates, standard error, associated z – value and p-value for effect of the landscape level habitat features on the bird community density in the urban matrix.

Averaged model	Variable of the model	$\beta$ – estimate	SE	z – value	p – value
~builtup + green.cover + scrubland + LHI + Dist_n_fp + Dist_l_fp	% built – up	-0.0796	0.024	3.197	0.00139
	% green cover	-0.1029	0.023	4.339	1.43e <sup>-05</sup>
	% scrubland	0.0572	0.021	2.649	0.00806
	Landscape heterogeneity	0.0457	0.018	2.457	0.01400
	Distance to nearest forest patch	0.0336	0.017	1.957	0.05040
	Distance to largest forest patch	0.0005	0.008	0.065	0.94832



**Fig. 17** Landscape level habitat correlates of overall density in the urban matrix. The parameters shown are based on the averaged model. The significantly influential variables were proportions of built – up areas, green cover, scrubland and landscape heterogeneity. Distance to nearest forest patch and Distance to largest forest patch were not statistically significant.

#### 4.8 Local Scale Drivers of species richness

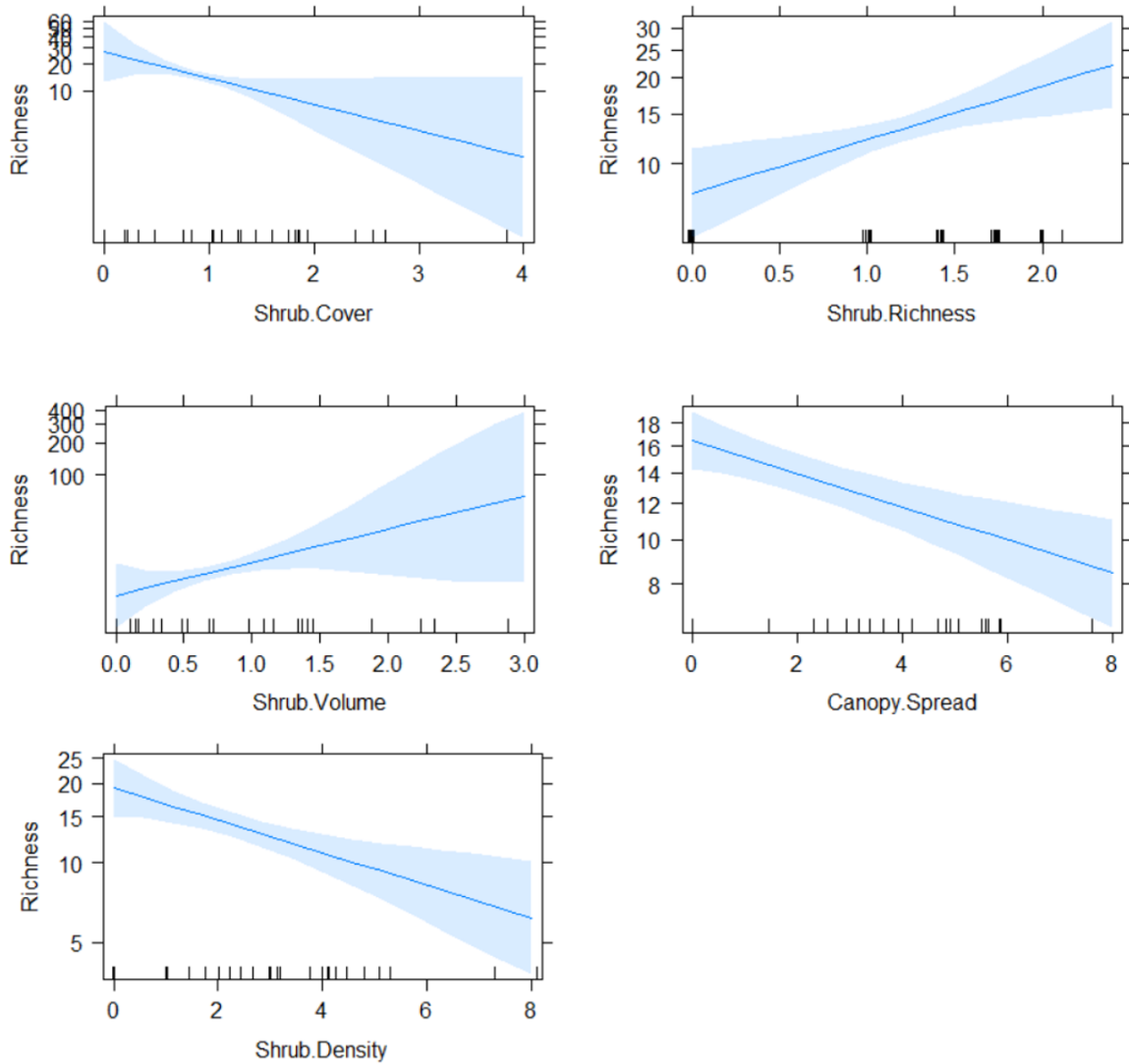
At the local scale, species richness in the urban matrix was influenced by the shrub richness, shrub density and the canopy spread (Table 10). It was seen that as the shrub richness increased the bird species richness also increased. Conversely as the canopy spread and the shrub density increased there was a decrease in the bird species richness. Shrub cover showed a negative effect and the shrub biomass showed a positive effect on the bird species richness but they were not statistically significant (Table 11, Figure 18).

**Table 10** Comparison of the best fitting models for species richness with the global model for local level habitat covariates.

Sr. No	Model	df	log Likelihood	AIC	delta AIC
1	~Shrub.Cover + Shrub.Richness + Shrub.Density + Shrub.Volume + Canopy.Spread	6	-90.33	192.67	0
2	~Tree.Biomass + Shrub.Volume	3	-94.4	194.68	2.01
3	~ Tree.Richness + Tree.Biomass + Tree.Height + Shrub.Cover + Shrub.Richness + Shrub.Density + Shrub.Volume + Canopy.Spread	9	-89.32	196.63	3.96
4	~ Tree.Height + Shrub.Height	3	-95.53	197.07	4.40
5	~ Canopy.Cover + Canopy.Spread + GBH + Shrub.Cover	5	-95.28	200.56	7.89
6	~ Tree.Richness + Tree.Density + Tree.Height + Canopy.Cover + Canopy.Spread + GBH + Shrub.Richness + Shrub.Cover + Shrub.Density + Tree.Biomass + Shrub.Volume + Shrub.Height ( <b>Global Model</b> )	13	-87.70	201.40	8.73
7	~1 ( <b>Null Model</b> )	1	-100.19	202.38	9.71

**Table 11** Summary of the averaged model for overall species richness showing variables, coefficient estimates, standard error, associated z – value and p-value for effect of the local level vegetation features on the bird community richness in the urban matrix.

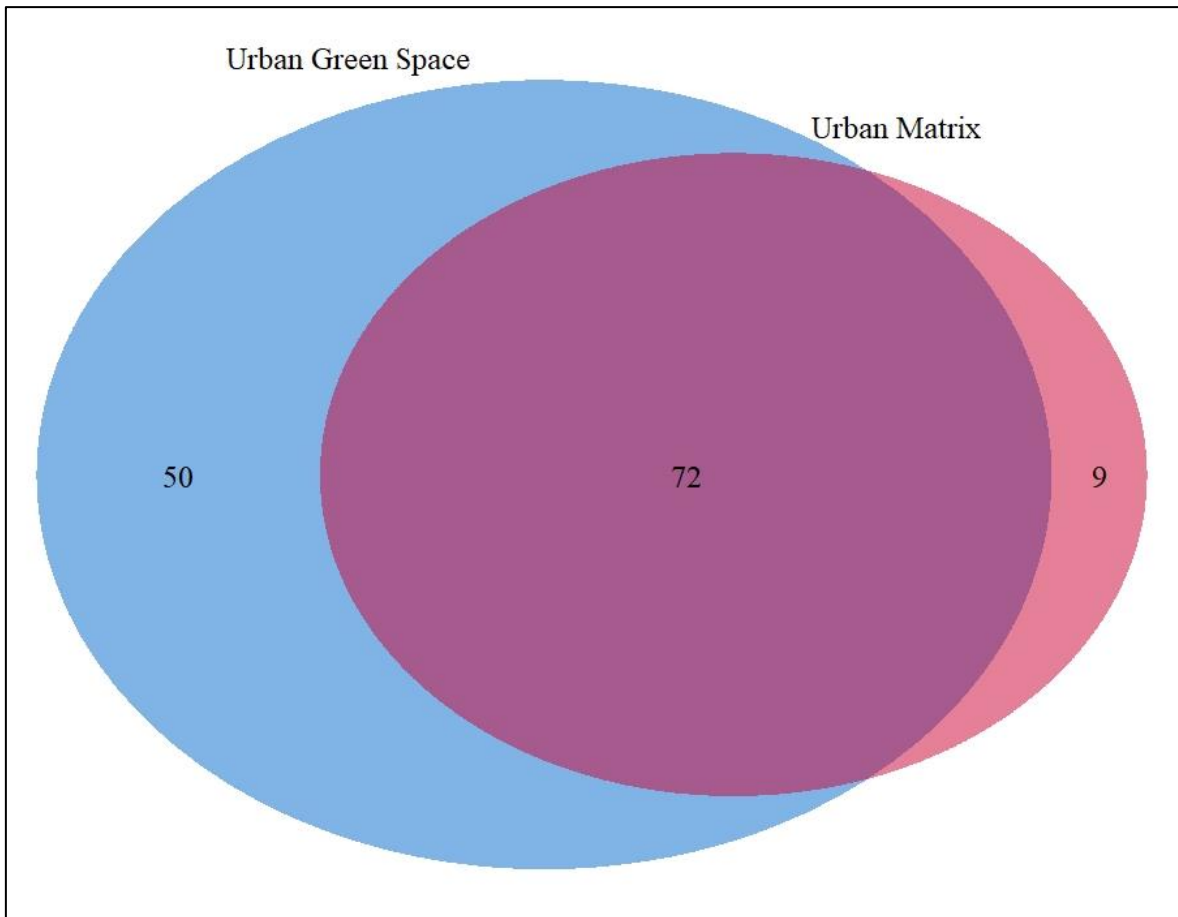
Averaged model	Variable of the model	$\beta$ – estimate	SE	z – value	p – value
~Shrub.Cover + Shrub.Richness + Shrub.Density + Shrub.Biomass + Canopy.Spread	Shrub Cover	-0.6786	0.36	-1.885	0.059
	<i>Shrub Richness</i>	<i>0.4310</i>	<i>0.144</i>	<i>2.986</i>	<i>0.002</i>
	<i>Shrub Density</i>	<i>-0.1416</i>	<i>0.05</i>	<i>-3.109</i>	<i>0.001</i>
	Shrub Biomass	0.7165	0.42	1.688	0.091
	<i>Canopy Spread</i>	<i>-0.0841</i>	<i>0.02</i>	<i>-3.691</i>	<i>0.0002</i>



**Fig. 18** Local scale habitat correlates of species richness in the urban matrix. The parameters shown are based on the best model. The significantly influential variables were Shrub Richness, Shrub Density and Canopy Spread. Shrub Cover and Shrub Volume were not statistically significant

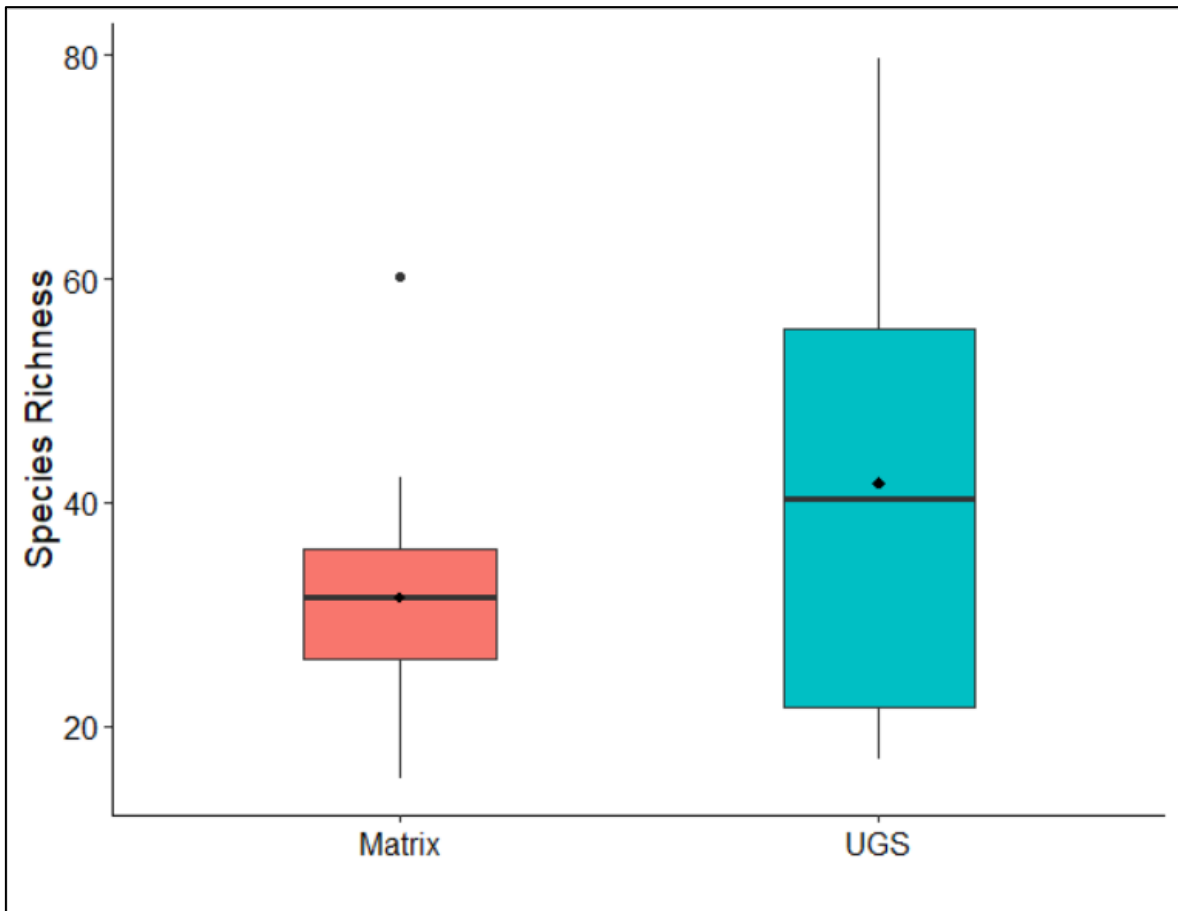
#### 4.9 Comparison of the urban matrix and UGS

The comparison of the species composition in the breeding season, of the urban matrix and UGS revealed that, of the 81 species in the matrix, 72 were also found in the UGS (Figure 19). Unique species belonging to the UGS were 50 in number while those in the urban matrix were 9.



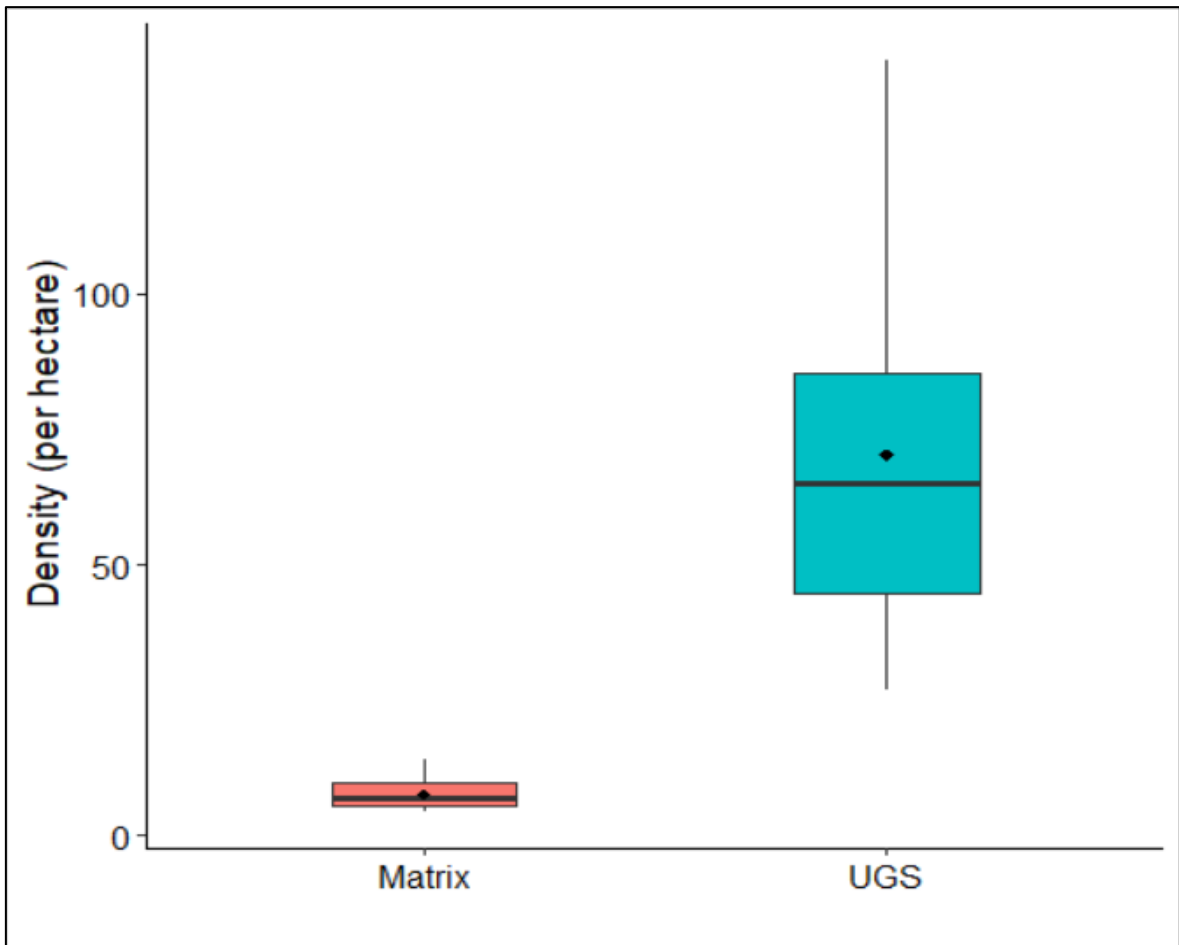
**Fig. 19** Venn diagram showing the species composition in the urban matrix and the UGS. The overlap in the diagram shows the shared species between the two.

The comparison of the overall species richness in the breeding season of the urban matrix and the UGS showed that there was a huge difference between the two (Figure 20). The mean species richness in the urban matrix was  $31.55_{\text{mean}} \pm 10.28_{\text{SD}}$  whereas the mean species richness in the UGS was  $41.76_{\text{mean}} \pm 19.81_{\text{SD}}$ .



**Fig. 20** Boxplot showing the bird species richness in the urban matrix and the UGS. The horizontal line in the box represents the median and the black dot within the box represents the mean.

The overall species density comparison of the urban matrix and the UGS showed that UGS had a higher overall species density (Figure 20). The mean density of birds in the urban matrix was  $7.62_{\text{mean}} \pm 2.57_{\text{SD}}$  whereas the mean density of birds in the UGS was  $70.30_{\text{mean}} \pm 33.61_{\text{SD}}$ .



**Fig. 21** Boxplot showing the bird density in the urban matrix and the UGS. The horizontal line in the box represents the median.

## **DISCUSSION**

The results of the study broadly suggest that the richness, abundance and density of the bird community respond to the habitat characteristics in the urban matrix of Dehradun. A similar pattern was also observed for the guild richness and density. The change in the bird species composition across habitats was not so clear. Analyzing patterns of species richness against environmental variables suggested that the community assemblage in the urban matrix is affected by habitat factors such as proportions of habitats, proportion of built – up and landscape heterogeneity.

### **5.1 Bird community responses to the urban matrix**

The species richness across habitats showed that the estimated species richness was highest in green cover and built – up areas. But the percentage of undetected species was higher in green cover. This can be attributed to the fact that the number of sampling units in this habitat were too low to capture the actual species richness. Another reason would be that there were no temporal replicates, which further limited in adequately sampling the bird community. Most of the species observed were rare species (Lesser Yellownape, Grey-headed Woodpecker, Oriental Pied Hornbill, Long-tailed Minivet, Scarlet Minivet) and therefore the accumulation curve was not saturating. This higher richness estimate is corroborated by other studies which show that forested areas in and around urban areas have the maximum species richness (M. McKinney 2002). The structural heterogeneity and abundance of resources of green cover is expected to be an important factor that influences the bird richness positively (I. Macgregor-fors and Schondube 2011; Sattler et al. 2011; Silva et al. 2015; Ferenc and Fuchs 2013; Schütz and Schulze 2015) and could be another reason for the highest estimated species richness of this habitat. Scrublands showed the next highest estimated species richness and the percentage of undetected species was also very low. These scrub field unlike the green cover are majorly covered with short shrubs and have a relatively

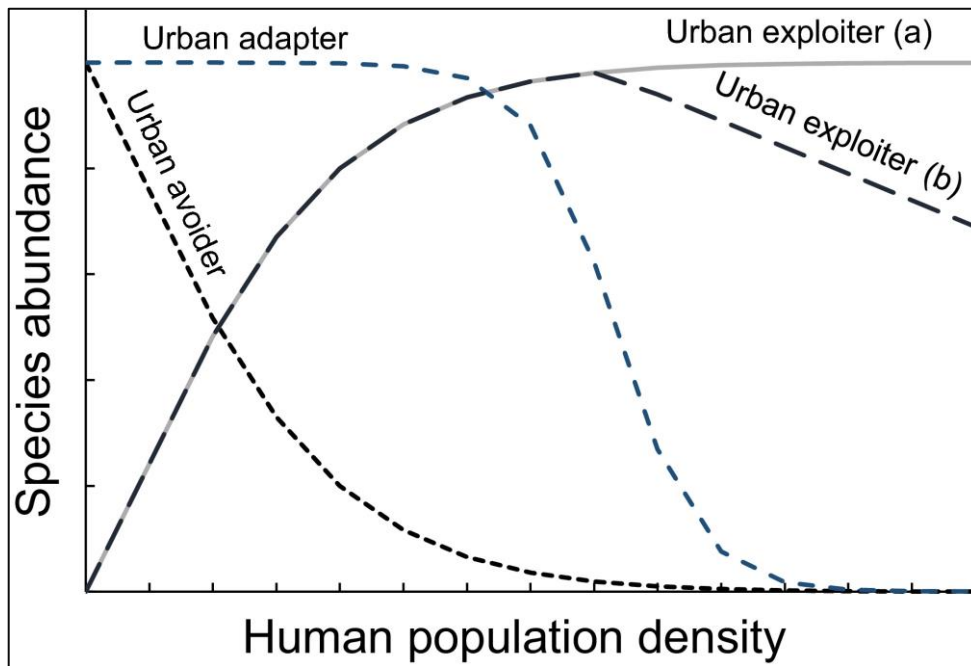
larger open canopy. These vacant and open lots are often seen as discarded and insignificant plots of land in the urban matrix. These lots support more bird species because they can provide food and nesting resources (Leveau, Isla, and Bellocq 2018). Studies have shown that these vacant lots with high scrub densities are essential for birds during the nesting period (Rega-Brodsky and Nilon 2016). Also, these scrubland lots showed some rare species which are not found in built – up areas (Yellow-wattled Lapwing, Indian Thick-knee, Long-tailed Shrike). These birds are also labelled as ‘urban avoiders; and are found in open habitats, grass and scrub lands. Because these habitats are rarer in the urban centres, these species occur in habitats present in the rural land.

The densities of birds in the urban matrix showed that scrublands had the highest density of birds. In these scrubland areas, the abundance of species like Common Myna, Feral Pigeon, Red-vented Bulbul and Rose-ringed Parakeet was high. These species and other flocking species increase in numbers where is food resources available. The field observations of the plant species showed that there were many scrub species which were providing this resource to the bird community. *Lantana*, being invasive in nature, was seen in large numbers across most of the scrub fields. This plant fruits almost all year round and is eaten by many species of birds. Bird abundance and densities will respond to this as studies have shown that there is a positive relation between species density and resource availability (Mills, Dunning, and Bates 1991). Built – up areas had lower densities than other habitat types in the matrix except green cover. As the proportion of built – up increases, spaces and opportunities for foraging and nesting become scarcer. The above-mentioned urban exploiters were definitely more abundant in urban areas than any other habitat type, but the other species became rarer as the intensity of built – up areas increased. The densities of birds in green cover were low and

this can be attributed to the fact that more rare species were seen in this habitat type. These species were seen only once and only few individuals of the same were seen.

The abundance of birds in the urban matrix of Dehradun revealed that Feral Pigeon, Rose-ringed Parakeet, Red-vented Bulbul and Common Myna were most abundant. These urban exploiters (generalists) have a broad environmental tolerance and thus predominant in urban areas (Bonier, Martin, and Wingfield 2007; Croci, Butet, and Clergeau 2008; Blair 1996; Sol et al. 2014; Palacio 2020). The human disturbances in these areas do not affect them much and are able to find resources in these areas to thrive (Gilbert 1989). Other birds such as Indian White-eye, Lesser Yellowname, Oriental Pied Hornbill, etc. were abundant only in certain habitats and are have a much narrow tolerance – specialists – compared to the generalists. These species can be said to be urban avoiders and their abundance and density decreases as the built – up increases (Blair 1996).

Often other fundamental patterns of urban communities such as evenness are not well studied. The communities of green areas in urban areas are not typically dominated by a one or a few species. But the urban communities do show this as a few species can attain high abundance in response to food resources, limited competition and favourable climatic conditions. This is also seen in the current study. Communities found in built – up areas are dominated by some species which account for maximum abundances, whereas the other habitat types like open areas, scrublands and green cover show an even community when compared to built – up areas. This is important to the ecology of urban areas as the communities may show high richness, but the preponderance of a few, densely populated species (urban exploiters) may make the community less resilient to environmental changes (Marzluff and Rodewald 2008)(Figure 21).



**Fig. 22** Generalized response curves of bird species to human population density at the landscape scale. “Urban avoiders” rapidly decline in abundance as population density increases; “urban adapters” are able to tolerate moderate population densities but decline at higher densities; “urban exploiters” benefit from urbanization and increase as human populations increase. Some urban exploiters thrive in highly urbanized areas (urban exploiter type a), whereas others may specialize at moderate levels of urbanization, and decline at high levels (urban exploiter type b). Sourced from Geschke et al. (2018).

The NMDS ordination plots clearly separates the sampling plots in green cover. This is likely due to the presence of forest specialists like woodpeckers, hornbills and woodland raptors. These species require large amounts of green cover and associated floral characteristics to carry out their life functions. Woodpeckers of this region prefer large Sal trees with furrows to forage and nest. Hornbills prefer fruiting trees and trees with cavities for nesting. These habits cannot be found in the built – up areas. The other habitat types found in the study area were no so clearly separated, and hence we can say that the composition of birds across these landscapes is homogeneous. This suggests an important role of urbanization in determining the bird composition in a city (Crocì, Butet, and Clergeau 2008; MacGregor-Fors 2010; Puga-Caballero, MacGregor-Fors, and Ortega-Álvarez 2014). This is also important because

of the arrangement of the species during the breeding season. In the breeding season it is important for the birds to establish territories with not just the nesting requirements, but also food resources. If the urban matrix and by extension the areas with built – up (low to moderate) were not hospitable, then there should not have been such a large degree of overlap. These intermediately disturbed landscapes found near the suburban-rural areas are also important for the dispersal of species in the landscape (Fahrig 2011; Gustafson and Gardner 1996; Hodgson, French, and Major 2007; B. S. Evans et al. 2017) and hence a greater degree of overlap was seen between the habitats.

When the patterns in guild richness were analyzed, it showed that five of the six guilds had the highest species richness in built – up areas. This could be an artefact of the sampling effort, as most of the sampling units were located in built – up areas. The patterns in the guild densities are similar to studies which have studied urbanization impacts on various types of functional guilds. Similar to the current study it was seen that as the proportion of built – up increased, density of insectivorous bird species decreased (Silva, Sepúlveda, and Barbosa 2016). This is because the impervious surfaces increase as we go towards the urban center and the availability of forage and foraging spaces decrease. Also, another contributing factor could be the vegetational composition of the urban centers. The trees and shrubs in highly built – up areas are managed by the city authorities or the people who live there. Usually there is no shrub cover, and if present its mostly exotic and ornamental species. Same is the story with the tree cover. This leads to a cascade wherein the insectivorous species are affected (Devictor et al. 2007; Máthé and Batáry 2015). On the other hand, the numbers of granivores and frugivores may rise in urban areas. City managers and dwellers plant fruiting trees in the suburban areas which can promote the richness of frugivorous species. Indian Grey Hornbill's are usually found in high numbers in these suburban areas

where the presence of fruiting trees is higher. People also have feeders and nest boxes which are utilized by granivorous birds like House Sparrow. This fulfils some of the requirements for these birds to colonize the suburban areas and leads to increased densities.

## **5.2 Landscape scale habitat correlates of species richness and density**

Species richness in the urban matrix was correlated to proportions of open areas and scrublands, and also to the proportion of built – up areas. The former habitats provide opportunities for species to colonize the urban matrix by adding to the landscape heterogeneity of the urban matrix. Negative effects of built – up on species richness have been shown by multiple studies (K. L. Evans, Newson, and Gaston 2009; M. McKinney 2002; M. L. McKinney 2008; Niemelä and Kotze 2009; Emlen 1974; Jokimaki and Suhonen 1993; Blair 1996; Chamberlain et al. 2007). The observed relationship shows that the species richness is peaking at moderate levels of built – up and anthropogenic activities. This is also reported by multiple studies (Tratalos et al. 2007; Racey and Euler 1982; Blair 1996). One explanation for this can be that at low levels of human development, there is still other habitats which birds can utilize, hence these areas show a larger species diversity. As we get closer to the urban core, the human development increases and the habitats decrease in size and number, leading to a decrease in the species diversity. This urban-rural continuum theory is based upon the island biogeography theory and is widely reported by many studies (M. L. McKinney 2008). Also, this peaking of species richness at intermediate levels of urbanization can be said to be correlated to Connell's (1978) intermediate disturbance hypothesis. This theory explains that the peaking occurs because intermediate frequencies of disturbance (urbanization) promotes the coexistence of species by preventing the competitive dominants from excluding other species. This theory then helps in explaining a

pattern and also provides mechanisms for studying changes in species richness along an urban-rural gradient.

Overall densities of birds in the urban matrix was correlated to proportions of green cover and scrubland, proportion of built – up and landscape heterogeneity. Increasing proportions of scrubland showed an overall positive relation with the bird density. Same was the case with the landscape heterogeneity. Just like the richness, habitats in the matrix are crucial to maintain the bird densities by adding to the landscape heterogeneity. As the number of patches of different habitats increase, the number of species and density of species which can occupy these patches increases (Gustafson and Gardner 1996). Even though the barriers in this case are not easily overcome, in low built – up density areas, these are much easily overcome. This helps in dispersal of urban birds to different habitat patches and also to the intact forest patches. The presence of these patches also reduces the biotic homogenization and helps in maintaining the species pool. Green cover on the other hand was negatively correlated. This can be attributed to the fact that even though many species were seen in patches of green cover, their numbers were too low. This might be the case as these green patches in the matrix can be said to be homogeneous both vertically and horizontally. The effect of built – up on the densities has been discussed before and it's pretty clear that the same pattern of decrease was seen in the modelling. Distance to the nearest forest patch and the distance to the largest forest patch had a slight positive effect on the density but overall was not significant. For large birds, the distance to the forest patches may not be a problem, but this is a problem for smaller bird species. As the matrix of certain areas may not be permeable, the movement is restricted. For small birds, the energy required to travel such large distances, predation risk, competition and others are important factors which determine if the bird is capable of dispersal. Another hypothesis can be presence of remnant forest

patches within Dehradun. The city has some large patches of remnant vegetation (Forest Research Institute) which may act like islands of biodiversity which the birds may use. The non-significance of distance to the forest patch can also be because of the fact that the sampling effort was not enough to capture this effect more profoundly.

### **5.3 Local scale habitat correlates of species richness**

Urban areas are highly dynamic systems and the local scale vegetation can have a very significant influence on the bird assemblage (Evans, Newson, and Gaston 2009). Many studies which have looked at the urban green spaces have seen at how the vegetation influences the bird assemblages. Diversity of tree and shrub species was found to be the next most important factor in explaining the breeding bird richness in green spaces (Husté et al. 2006). In this study it was seen that the shrub layer was more important than the tree layer to determine the bird assemblage. Shrub richness showed a highly positive relation with the bird species richness. This can be due to the fact that the shrub layer outside the urban green spaces is not highly managed. This creates an opportunity for many different species to colonise and increase the diversity of the area. These in turn allow for many bird species to use these spaces and contribute to the diversity of the urban areas. In the study by Kaushik, Tiwari, and Kumari (2020) it was seen that the tree layer was important in determining the bird assemblage in the urban green spaces. The shrub layer inside the urban green spaces is heavily managed and controlled, which leads to reduced forage, nesting and other resources which is not the case in the shrub layer of the urban matrix. Shrubs provide birds cover from extreme weather and sunshine, as well as food in the form of insects, seeds and fruits (Daniels and Kirkpatrick 2006). Canopy spread showed a negative relation with the increasing bird species richness. An interesting correlation between the canopy layer and the shrub layer which can have an influence on the bird species richness is that as the canopy

layer becomes thinner, the shrub diversity (richness and density) increases (Metlen and Fiedler 2006; Nagaïke, Kamitani, and Nakashizuka 1999; Schacht, Long, and Malechek 1988; Powell and Bork 2006; Phillips and Waldrop 2008). The light penetrating the floor reduces and hence not many understory species can colonise. Hence as the canopy cover is increasing we are seeing a drop in the bird species richness as there is not a lot of understory shrub cover for the birds to utilise.

#### **5.4 Urban Green Space vs Urban Matrix**

Comparisons of the urban matrix and UGS gave some interesting insights. The density and richness in the UGS in the breeding season was high when compared to the urban matrix. This is in line with studies which have pointed out that UGS act as refugia for urban biodiversity (Aronson et al. 2017; Lepczyk et al. 2017; Beninde, Veith, and Hochkirch 2015; Chamberlain et al. 2009; Thompson et al. 2003; Adams 2016).

Comparison of the species composition of the urban matrix and UGS showed that majority of the species found in the urban matrix were also found in the UGS. The species only found in the UGS are the urban avoiders. These do not thrive in areas of high human disturbance and require a larger proportion of green cover to thrive. Some of these species were Blue-bearded Bee-eater, Pale-footed Bush Warbler, Himalayan Goldenback, Rusty-cheeked Scimitar Babbler and many more. Size and composition of the urban green space also affects the species diversity in urban areas (Dale 2018; Lepczyk et al. 2017; Aronson et al. 2017; 2014).

## 5.5 Understanding urban ecosystem better

Nature is an integral part of urban areas. This nature is being shaped by the city managers and also by the people who live in it to enhance their well – being. A large number of studies have shown that this nature, in the form of urban green spaces can harbor a rich diversity of species, which exceeds the diversity found in the nearby urban matrix habitats (McDonnell and Hahs 2008; M. L. McKinney 2008). These spaces then need to be conserved and many publications have given recommendations to the same effect (Aronson et al. 2017; Lepczyk et al. 2017; Gaston 2010; Gilbert 1989).

The urban matrix however has not received much attention in terms of conservation potential. As seen in the study, the urban matrix does have a significant number of habitats and large proportions of green cover. Studies which have looked in the matrix habitats have found that the matrix is not inhospitable, but holds a good amount of diversity, abundance and species composition (Thompson et al. 2003; I. Macgregor-fors and Schondube 2011; A. I. Macgregor-fors et al. 2018). These matrix habitats are not individual patches, but an intricate web which have connectivity, permeability and movement of species between them (Niemelä 1999).

There needs to be a holistic effort to improve the quality of all existing green infrastructures, in the urban matrix and the urban green spaces. Not only this but the fact that other habitats are of equal importance needs to be understood. Some habitats which are located away from the urban core (suburban) form an interconnected matrix to offer habitat for a wide range of pioneer plants and animals, including threatened species (Breuste 2004) and increase the biological richness. These juxtaposed land covers can support substantial populations of urban adapters. Also, if unbuilt or natural/semi-natural land is retained in close proximity to

these urban and suburban areas, viable populations of tolerant (not greatly) urban avoiders can persist.

As the city is a dynamic ecosystem, a simple uniform strategy will not be sufficient to help conserve the biodiversity, because of the inherent complex response of the biodiversity to urbanization. What most studies try to look at is a combination of multiple approaches like reservation, restoration and reconciliation (Rosenzweig 2004). But it needs to be understood that there is no amount of restoration or reservation that will change the ecology of urban areas to natural areas. There needs to be an understanding that these are novel systems with novel interactions which need to be valued, and that these will have an ecological and evolutionary significance in the future.

## **5.6 Caveats and suggestions for future work**

The biggest caveat is that the sampling effort was not enough to capture the variation across all the habitats equally. This was not a methodological issue but rather a product of the restrictions due to the COVID – 19 pandemic. If more replicates were to be obtained from the sampling units in the urban matrix, the composition and diversity of the bird community could have been observed much better. One of the assumptions of the richness and density was that as the distance to the urban green space increases, the richness and density should have decreased. But this was not found to be significant in the linear modelling approach. This can however be attributed to the fact that either the distance between the point was not enough to show a good relation or the fact that the community in the matrix is homogenous at the landscape scale. To tease this apart, more data is needed at the sampling unit scale and then the linear modelling approaches can be applied to each habitat individually to see how the community of a particular habitat responds to the habitat characteristics. Additional

factors that can influence the bird community characteristics should be studied to better understand the impacts of urbanization. Noise levels in the city and urban predators are some of the factors which studies have found to be influencing the bird community in urban areas (Chace and Walsh 2006; K. L. Evans, Newson, and Gaston 2009; Aronson et al. 2014; Beninde, Veith, and Hochkirch 2015). More intensive data for the vegetational characteristics of the urban matrix is needed to examine their influence on the species composition and diversity Lepczyk et al. (2017) and Beninde, Veith, and Hochkirch (2015) stress on the importance of this local scale vegetation characteristics in shaping the bird assemblage. This study was done during the breeding season and found a large difference in the community characteristics of the urban matrix and urban green spaces. To understand these differences a large-scale study of multiple urban green spaces and the urban matrix, across seasons can be conducted. This can then show the differences of the bird community across seasons and provide much better understanding of the urban matrix. Bird guild characteristics are important in understanding the impacts of urban areas on the bird assemblage. Using different guilds to check the influence of the matrix characteristics can provide valuable insights for the management and conservation value of the urban matrix.

## **REFERENCES**

- Adams, Clark E. *Urban Wildlife Management*. CRC Press, Taylor & Francis Group, 2016. <https://doi.org/10.7589/0090-3558-43.2.321>.
- Aronson, Myla F.J., Christopher A. Lepczyk, Karl L. Evans, Mark A. Goddard, Susannah B. Lerman, J. Scott MacIvor, Charles H. Nilon, and Timothy Vargo. “Biodiversity in the City: Key Challenges for Urban Green Space Management.” *Frontiers in Ecology and the Environment* 15, no. 4 (2017): 189–96. <https://doi.org/10.1002/fee.1480>.
- Aronson, Myla F.J., Frank A. La Sorte, Charles H. Nilon, Madhusudan Katti, Mark A. Goddard, Christopher A. Lepczyk, Paige S. Warren, et al. “A Global Analysis of the Impacts of Urbanization on Bird and Plant Diversity Reveals Key Anthropogenic Drivers.” *Proceedings of the Royal Society B: Biological Sciences* 281, no. 1780 (2014). <https://doi.org/10.1098/rspb.2013.3330>.
- Aronson, Myla F J, Charles H Nilon, Christopher A Lepczyk, S Tommy, Paige S Warren, Sarel S Cilliers, Mark A Goddard, et al. “Hierarchical Filters Determine Community Assembly of Urban Species Pools Published by : Wiley on Behalf of the Ecological Society of America Stable URL : <https://www.jstor.org/stable/44082150> Hierarchical Filters Determine Community Assembly of Urban Spec” 97, no. 11 (2016): 2952–63.
- Baldock, Katherine C R, Mark A Goddard, Damien M Hicks, William E Kunin, Nadine Mitschunas, Lynne M Osgathorpe, Simon G Potts, et al. “Where Is the UK’s Pollinator Biodiversity? The Importance of Urban Areas for Flower-Visiting Insects.” *Proceedings of the Royal Society B: Biological Sciences* 282, no. 1803 (March 22, 2015): 20142849. <https://doi.org/10.1098/rspb.2014.2849>.
- Beninde, Joscha, Michael Veith, and Axel Hochkirch. “Biodiversity in Cities Needs Space: A Meta-Analysis of Factors Determining Intra-Urban Biodiversity Variation.” *Ecology Letters* 18, no. 6 (June 1, 2015): 581–92. <https://doi.org/https://doi.org/10.1111/ele.12427>.
- Bibby, Colin J. “Making the Most of Birds as Environmental Indicators.” *Ostrich* 70, no. 1 (March 1, 1999): 81–88. <https://doi.org/10.1080/00306525.1999.9639752>.
- Bibby, Colin J, Neil D Burgess, and David A Hill. *Bird Census Techniques*. Edited by Colin J Bibby, Neil D Burgess, and David A Hill. Boston: Academic Press, 1992. [https://doi.org/10.1676/0043-5643\(2001\)113\[0468:\]2.0.co;2](https://doi.org/10.1676/0043-5643(2001)113[0468:]2.0.co;2).

- Blair, Robert B. “Land Use and Avian Species Diversity along an Urban Gradient.” *Ecological Applications* 6, no. 2 (1996): 506–19.
- Bonier, Frances, Paul R. Martin, and John C. Wingfield. “Urban Birds Have Broader Environmental Tolerance.” *Biology Letters* 3, no. 6 (2007): 670–73.  
<https://doi.org/10.1098/rsbl.2007.0349>.
- Bonthoux, Sébastien, Marion Brun, Francesca Di Pietro, Sabine Greulich, and Sabine Bouché-Pillon. “How Can Wastelands Promote Biodiversity in Cities? A Review.” *Landscape and Urban Planning* 132 (2014): 79–88.  
<https://doi.org/https://doi.org/10.1016/j.landurbplan.2014.08.010>.
- Bowler, Diana E, Lisette Buyung-Ali, Teri M Knight, and Andrew S Pullin. “Urban Greening to Cool Towns and Cities: A Systematic Review of the Empirical Evidence.” *Landscape and Urban Planning* 97, no. 3 (2010): 147–55.  
<https://doi.org/https://doi.org/10.1016/j.landurbplan.2010.05.006>.
- Boyden, S., S. Millar, K. Newcombe, and B. O’Neill. *The Ecology of a City and Its People. Interdisciplinary Science Reviews*, 1981.
- Breuste, Jürgen. “Decision Making, Planning and Design for the Conservation of Indigenous Vegetation within Urban Development.” *Landscape and Urban Planning* 68 (June 1, 2004): 439–52. [https://doi.org/10.1016/S0169-2046\(03\)00150-6](https://doi.org/10.1016/S0169-2046(03)00150-6).
- Brock, Guy, Vasyl Pihur, Susmita Datta, and Somnath Datta. “CIVValid: An R Package for Cluster Validation.” *Journal of Statistical Software* 25, no. 4 (2008): 1–22.  
<https://www.jstatsoft.org/v25/i04/>.
- Cadenasso, Mary L, Steward T A Pickett, and Kirsten Schwarz. “Spatial Heterogeneity in Urban Ecosystems: Reconceptualizing Land Cover and a Framework for Classification.” *Frontiers in Ecology and the Environment* 5, no. 2 (March 1, 2007): 80–88. [https://doi.org/https://doi.org/10.1890/1540-9295\(2007\)5\[80:SHIUER\]2.0.CO;2](https://doi.org/https://doi.org/10.1890/1540-9295(2007)5[80:SHIUER]2.0.CO;2).
- Census of India. “Dehradun District : Population 2011-2020 Data,” 2011.  
<https://www.census2011.co.in/census/district/578-dehradun.html>.
- Chace, Jameson F, and John J Walsh. “Urban Effects on Native Avifauna: A Review.” *Landscape and Urban Planning* 74, no. 1 (2006): 46–69.  
<https://doi.org/https://doi.org/10.1016/j.landurbplan.2004.08.007>.

- Chamberlain, D. E., A. R. Cannon, M. P. Toms, D. I. Leech, B. J. Hatchwell, and K. J. Gaston. "Avian Productivity in Urban Landscapes: A Review and Meta-Analysis." *Ibis* 151, no. 1 (2009): 1–18. <https://doi.org/10.1111/j.1474-919X.2008.00899.x>.
- Chamberlain, D. E., S. Gough, H. Vaughan, J. A. Vickery, and G. F. Appleton. "Determinants of Bird Species Richness in Public Green Spaces." *Bird Study* 54, no. 1 (2007): 87–97. <https://doi.org/10.1080/00063650709461460>.
- Champion, H.G., and S.K. Seth. "A Revised Survey of Forest Types of India." *Government of India Press*, 1968.
- Chao, Anne, K. H. Ma, T. C. Hsieh, and Chun-Huo Chiu. "SpadeR: Species-Richness Prediction and Diversity Estimation with R," 2016. <https://cran.r-project.org/package=SpadeR>.
- Chiu, Chun Huo, Yi Ting Wang, Bruno A. Walther, and Anne Chao. "An Improved Nonparametric Lower Bound of Species Richness via a Modified Good-Turing Frequency Formula." *Biometrics* 70, no. 3 (2014): 671–82. <https://doi.org/10.1111/biom.12200>.
- Cilliers, Sarel, Juaneé Cilliers, Rina Lubbe, and Stefan Siebert. "Ecosystem Services of Urban Green Spaces in African Countries — Perspectives and Challenges," 2012. <https://doi.org/10.1007/s11252-012-0254-3>.
- Collins, J. P., A. Kinzig, N. B. Grimm, W. F. Fagan, D. Hope, J. Wu, and E. T. Borer. "A New Urban Ecology." *American Scientist* 88, no. 5 (2000): 416–25. <https://doi.org/10.1511/2000.5.416>.
- Connell, Joseph H. "Diversity in Tropical Rain Forests and Coral Reefs." *Science* 199, no. 4335 (March 24, 1978): 1302 LP – 1310. <https://doi.org/10.1126/science.199.4335.1302>.
- Conole, L E, and J B Kirkpatrick. "Functional and Spatial Differentiation of Urban Bird Assemblages at the Landscape Scale." *Landscape and Urban Planning* 100, no. 1 (2011): 11–23. <https://doi.org/https://doi.org/10.1016/j.landurbplan.2010.11.007>.
- Cornelis, Johnny, and Martin Hermy. "Biodiversity Relationships in Urban and Suburban Parks in Flanders." *Landscape and Urban Planning* 69, no. 4 (2004): 385–401. <https://doi.org/https://doi.org/10.1016/j.landurbplan.2003.10.038>.
- Croci, Solène, Alain Butet, and Philippe Clergeau. "Does Urbanization Filter Birds on the Basis of Their Biological Traits?" *Condor* 110, no. 2 (2008): 223–40.

- <https://doi.org/10.1525/cond.2008.8409>.
- Crooks, Kevin R. “Relative Sensitivities of Mammalian Carnivores to Habitat Fragmentation.” *Conservation Biology* 16, no. 2 (April 1, 2002): 488–502. <https://doi.org/https://doi.org/10.1046/j.1523-1739.2002.00386.x>.
- Dadvand, Payam, Ioar Rivas, Xavier Basagaña, Mar Alvarez-Pedrerol, Jason Su, Montserrat De Castro Pascual, Fulvio Amato, et al. “The Association between Greenness and Traffic-Related Air Pollution at Schools.” *Science of The Total Environment* 523 (2015): 59–63. <https://doi.org/https://doi.org/10.1016/j.scitotenv.2015.03.103>.
- Dale, Svein. “Urban Bird Community Composition Influenced by Size of Urban Green Spaces, Presence of Native Forest, and Urbanization.” *Urban Ecosystems* 21, no. 1 (2018): 1–14. <https://doi.org/10.1007/s11252-017-0706-x>.
- Daniels, G D, and J B Kirkpatrick. 2006. “Does Variation in Garden Characteristics Influence the Conservation of Birds in Suburbia?” *Biological Conservation* 133 (3): 326–35. <https://doi.org/https://doi.org/10.1016/j.biocon.2006.06.011>.
- Devictor, Vincent, Romain Julliard, Denis Couvet, Alexandre Lee, and Frédéric Jiguet. “Functional Homogenization Effect of Urbanization on Bird Communities.” *Conservation Biology* 21, no. 3 (2007): 741–51. <https://doi.org/10.1111/j.1523-1739.2007.00671.x>.
- Douglas, Ian. *The Urban Environment*. London: Edward Arnold, 1983.
- Dutta, Dipanwita, Atiqur Rahman, and Arnab Kundu. “Growth of Dehradun City: An Application of Linear Spectral Unmixing (LSU) Technique Using Multi-Temporal Landsat Satellite Data Sets.” *Remote Sensing Applications: Society and Environment* 1 (2015): 98–111. <https://doi.org/10.1016/j.rsase.2015.07.001>.
- eBird. “eBird: An Online Database of Bird Distribution and Abundance [Web Application].” eBird, Cornell Lab of Ornithology, Ithaca, New York, 2021. <http://www.ebird.org>.
- Emlen, John T. “An Urban Bird Community in Tucson, Arizona: Derivation, Structure, Regulation.” *The Condor* 76, no. 2 (April 1, 1974): 184–97. <https://doi.org/10.2307/1366729>.
- Er, Kenneth B H, John L Innes, Kathy Martin, and Brian Klinkenberg. “Forest Loss with Urbanization Predicts Bird Extirpations in Vancouver,” 2005.

- <https://doi.org/10.1016/j.biocon.2005.06.023>.
- Evans, Brian S, A Marm Kilpatrick, Allen H Hurlbert, and Peter P Marra. “Dispersal in the Urban Matrix: Assessing the Influence of Landscape Permeability on the Settlement Patterns of Breeding Songbirds .” *Frontiers in Ecology and Evolution* , 2017. <https://www.frontiersin.org/article/10.3389/fevo.2017.00063>.
- Evans, Karl L., Stuart E. Newson, and Kevin J. Gaston. “Habitat Influences on Urban Avian Assemblages.” *Ibis* 151, no. 1 (2009): 19–39. <https://doi.org/10.1111/j.1474-919X.2008.00898.x>.
- Fahrig, Lenore. “Effect of Spatial Arrangement of Habitat Patches on Local Population Size Author ( s ): Lenore Fahrig and Jyri Paloheimo Published by : Ecological Society of America Stable URL : <Http://Www.Jstor.Org/Stable/1940445> . EFFECT OF SPATIAL ARRANGEMENT OF HABIT.” *Ecology* 69, no. 2 (2011): 468–75.
- Ferenc, Michal, and Roman Fuchs. “How to Improve Urban Greenspace for Woodland Birds : Site and Local-Scale Determinants of Bird Species Richness,” 2013. <https://doi.org/10.1007/s11252-013-0328-x>.
- Fuller, Richard A, Jamie Tratalos, and Kevin J Gaston. “How Many Birds Are There in a City of Half a Million People?” *Diversity and Distributions* 15, no. 2 (March 1, 2009): 328–37. <https://doi.org/https://doi.org/10.1111/j.1472-4642.2008.00537.x>.
- Gaston, Kevin J., ed. *Urban Ecology. Ecological Reviews*. Cambridge: Cambridge University Press, 2010. [https://doi.org/DOI: 10.1017/CBO9780511778483](https://doi.org/DOI:10.1017/CBO9780511778483).
- Geschke, Andrew, Simon James, Andrew F Bennett, and Dale G Nimmo. “Compact Cities or Sprawling Suburbs? Optimising the Distribution of People in Cities to Maximise Species Diversity.” *Journal of Applied Ecology* 55, no. 5 (September 1, 2018): 2320–31. <https://doi.org/https://doi.org/10.1111/1365-2664.13183>.
- Gilbert, O. L. *The Ecology of Urban Habitats*. Chapman & Hall, 1989. <https://doi.org/10.1007/978-94-011-3068-4>.
- Goddard, Mark A, Andrew J Dougill, and Tim G Benton. “Scaling up from Gardens: Biodiversity Conservation in Urban Environments.” *Trends in Ecology & Evolution* 25, no. 2 (2010): 90–98. <https://doi.org/https://doi.org/10.1016/j.tree.2009.07.016>.
- Grimm, Nancy B, J Morgan Grove, Steward T A Pickett, and Charles L Redman. “Integrated Approaches to Long-Term Studies of Urban Ecological Systems” 50,

- no. 7 (2000): 571–84.
- Grimmett, Richard, Carol Inskipp, and Tim Inskipp. *Birds of the Indian Subcontinent*. Bloomsbury Publishing India Pvt. Ltd., 2016.
- Gupta, Kshama. “Unprecedented Growth of Dehradun Urban Area : A Spatio-Temporal Analysis.” *International Journal of Advancement in Remote Sensing, GIS and Geography* 1, no. 2 (2013): 47–56.
- Gustafson, Eric J, and Robert H Gardner. “The Effect of Landscape Heterogeneity on the Probability of Patch Colonization.” *Ecology* 77, no. 1 (January 1, 1996): 94–107. <https://doi.org/https://doi.org/10.2307/2265659>.
- Hahs, Amy K, and Mark J McDonnell. “Selecting Independent Measures to Quantify Melbourne’s Urban–Rural Gradient.” *Landscape and Urban Planning* 78, no. 4 (2006): 435–48. <https://doi.org/https://doi.org/10.1016/j.landurbplan.2005.12.005>.
- Hartig, Terry, Gary W Evans, Larry D Jamner, Deborah S Davis, and Tommy Gärling. “Tracking Restoration in Natural and Urban Field Settings.” *Journal of Environmental Psychology* 23, no. 2 (2003): 109–23. [https://doi.org/https://doi.org/10.1016/S0272-4944\(02\)00109-3](https://doi.org/https://doi.org/10.1016/S0272-4944(02)00109-3).
- Herrera, Daniel J, Sophie M Moore, D T Tyler Flockhart, William J McShea, and Michael V Cove. “Thinking Outside the Park: Recommendations for Camera Trapping Mammal Communities in the Urban Matrix.” *Journal of Urban Ecology* 7, no. 1 (January 22, 2021). <https://doi.org/10.1093/jue/juaa036>.
- Hodgson, Patricia, Kristine French, and Richard E Major. “Avian Movement across Abrupt Ecological Edges: Differential Responses to Housing Density in an Urban Matrix.” *Landscape and Urban Planning* 79, no. 3 (2007): 266–72. <https://doi.org/https://doi.org/10.1016/j.landurbplan.2006.02.012>.
- Ikin, Karen, Emma Knight, David B Lindenmayer, Joern Fischer, and Adrian D Manning. “The Influence of Native versus Exotic Streetscape Vegetation on the Spatial Distribution of Birds in Suburbs and Reserves.” *Diversity and Distributions* 19, no. 3 (March 1, 2013): 294–306. <https://doi.org/https://doi.org/10.1111/j.1472-4642.2012.00937.x>.
- Järvinen, Oili, and Risto A Väisänen. “Changes in Bird Populations as Criteria of Environmental Changes.” *Ecography* 2, no. 2 (April 1, 1979): 75–80. <https://doi.org/https://doi.org/10.1111/j.1600-0587.1979.tb00684.x>.

- Jim, C Y. “Ecology and Conservation of Strangler Figs in Urban Wall Habitats.” *Urban Ecosystems* 17, no. 2 (2014): 405–26. <https://doi.org/10.1007/s11252-013-0322-3>.
- Jokimaki, J., and J. Suhonen. “Effects of Urbanization on the Breeding Bird Species Richness in Finland: A Biogeographical Comparison.” *Ornis Fennica* 70, no. 2 (1993): 71–77.
- Kanjilal, Upendranath. *Forest Flora of the Chakrata, Dehra Dun and Saharanpur Forest Divisions, United Provinces*, 1928.
- Kaushik, Monica, Samakshi Tiwari, and Manisha Kumari. “Habitat Patch Size and Tree Species Richness Shape the Bird Community in Urban Green Spaces of Rapidly Urbanizing Region of India,” 2020. <https://doi.org/https://doi.org/10.1101/2020.10.23.348391>.
- Keeling, Ralph F, Andrew C Manning, Elizabeth M McEvoy, and Stephen R Shertz. “Methods for Measuring Changes in Atmospheric O<sub>2</sub> Concentration and Their Application in Southern Hemisphere Air.” *Journal of Geophysical Research: Atmospheres* 103, no. D3 (February 20, 1998): 3381–97. <https://doi.org/https://doi.org/10.1029/97JD02537>.
- Kindt, R., and R. Coe. *Tree Diversity Analysis. A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies*. World Agroforestry Centre (ICRAF), Nairobi, 2005.
- Koskimies, Pertti. “Birds as a Tool in Environmental Monitoring.” *Annales Zoologici Fennici* 26, no. 3 (July 9, 1989): 153–66. <http://www.jstor.org/stable/23734578>.
- Kumar, Rohtash, N Suresh, Satish J Sangode, and V Kumaravel. “Evolution of the Quaternary Alluvial Fan System in the Himalayan Foreland Basin: Implications for Tectonic and Climatic Decoupling.” *Quaternary International* 159, no. 1 (2007): 6–20. <https://doi.org/https://doi.org/10.1016/j.quaint.2006.08.010>.
- Kumar Singh, A., B. Parkash, R. Mohindra, J. V. Thomas, and A. K. Singhvi. “Quaternary Alluvial Fan Sedimentation in the Dehradun Valley Piggyback Basin, NW Himalaya: Tectonic and Palaeoclimatic Implications.” *Basin Research* 13, no. 4 (2001): 449–71. <https://doi.org/10.1046/j.0950-091X.2001.00160.x>.
- Lepczyk, Christopher A., Myla F.J. Aronson, Karl L. Evans, Mark A. Goddard, Susannah B. Lerman, and J. Scott Macivor. “Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity

- Conservation.” *BioScience* 67, no. 9 (2017): 799–807.  
<https://doi.org/10.1093/biosci/bix079>.
- Leveau, Lucas M, Federico I Isla, and María I Bellocq. “Predicting the Seasonal Dynamics of Bird Communities along an Urban-Rural Gradient Using NDVI.” *Landscape and Urban Planning* 177 (2018): 103–13.  
<https://doi.org/https://doi.org/10.1016/j.landurbplan.2018.04.007>.
- Loeb, Susan C, Christopher J Post, and Steven T Hall. “Relationship between Urbanization and Bat Community Structure in National Parks of the Southeastern U.S.” *Urban Ecosystems* 12, no. 2 (2008): 197. <https://doi.org/10.1007/s11252-008-0075-6>.
- Macgregor-fors, Author Ian, Fernando González-garcía, Carolina Hernández-, Diego Santiago-alarcon, Source The, Wilson Journal, Ian Macgregor-fors, Fernando Gonza, Carolina Herna, and Diego Santiago-. “Where Are the Birds in the Matrix ? Avian Diversity in a Neotropical Landscape Mosaic Biological , Ecological , and Environmental Sciences . 130, no. 1 (2018): 81–93.
- MacGregor-Fors, Ian. “How to Measure the Urban-Wildland Ecotone: Redefining ‘Peri-Urban’ Areas.” *Ecological Research* 25, no. 4 (2010): 883–87.  
<https://doi.org/10.1007/s11284-010-0717-z>.
- Macgregor-fors, Ian, and Jorge E Schondube. “Gray vs . Green Urbanization : Relative Importance of Urban Features for Urban Bird Communities.” *Basic and Applied Ecology* 12, no. 4 (2011): 372–81. <https://doi.org/10.1016/j.baae.2011.04.003>.
- Maechler, M., P. Rousseeuw, A. Struyf, M. Hubert, and K. Hornik. “Cluster: Cluster Analysis Basics and Extensions,” 2021.
- Martin, Laura J, Bernd Blossey, and Erle Ellis. “Mapping Where Ecologists Work: Biases in the Global Distribution of Terrestrial Ecological Observations.” *Frontiers in Ecology and the Environment* 10, no. 4 (May 1, 2012): 195–201.  
<https://doi.org/https://doi.org/10.1890/110154>.
- Marzluff, John M., Reed Bowman, and Roarke Donnelly, eds. *Avian Ecology and Conservation in an Urbanizing World*. Springer Science+Business Media New York, 2001. <https://doi.org/10.1007/978-1-4615-1531-9>.
- Marzluff, John M., and Amanda D. Rodewald. “Conserving Biodiversity in Urbanizing Areas: Nontraditional Views from a Bird’s Perspective.” *Cities and the*

- Environment* 1, no. 2 (2008): 1–27. <https://doi.org/10.15365/cate.1262008>.
- Máthé, Orsolya, and Péter Batáry. “Insectivorous and Open-Cup Nester Bird Species Suffer the Most from Urbanization.” *Bird Study* 62, no. 1 (2015): 78–86. <https://doi.org/10.1080/00063657.2014.1000262>.
- McDonnell, M. J., and S. T. A. Pickett. “Ecosystem Structure and Function along Urban-Rural Gradients : An Unexploited Opportunity for Ecology Urban-Rural Gradients : An Unexploited Opportunity for Ecology.” *Ecology* 71, no. 4 (1990): 1232–37.
- McDonnell, Mark J., and Amy K Hahs. “The Use of Gradient Analysis Studies in Advancing Our Understanding of the Ecology of Urbanizing Landscapes: Current Status and Future Directions.” *Landscape Ecology* 23, no. 10 (2008): 1143–55. <https://doi.org/10.1007/s10980-008-9253-4>.
- McDonnell, Mark J, Steward T A Pickett, Peter Groffman, Patrick Bohlen, Richard V Pouyat, Wayne C Zipperer, Robert W Parmelee, Margaret M Carreiro, and Kimberly Medley. “Ecosystem Processes along an Urban-to-Rural Gradient.” *Urban Ecosystems* 1, no. 1 (1997): 21–36. <https://doi.org/10.1023/A:1014359024275>.
- McKinney, Michael L. “Effects of Urbanization on Species Richness: A Review of Plants and Animals.” *Urban Ecosystems* 11, no. 2 (2008): 161–76. <https://doi.org/10.1007/s11252-007-0045-4>.
- McKinney, ML. “Urbanization, Biodiversity, and Conservation The Impacts of Urbanization on Native Species Are Poorly Studied, but Educating a Highly Urbanized Human Population.” *BioScience* 52, no. 10 (2002): 883–90. <http://bioscience.oxfordjournals.org/content/52/10/883.full>.
- Metlen, Kerry L, and Carl E Fiedler. 2006. “Restoration Treatment Effects on the Understory of Ponderosa Pine/Douglas-Fir Forests in Western Montana, USA.” *Forest Ecology and Management* 222 (1): 355–69. <https://doi.org/https://doi.org/10.1016/j.foreco.2005.10.037>.
- Mills, G. S., J. B. Dunning, and J. M. Bates. “The Relationship between Breeding Bird Density and Vegetation Volume.” *The Wilson Bulletin* 103, no. 3 (1991): 468–79.
- Morelli, Federico, Michał Beim, Leszek Jerzak, Darryl Jones, and Piotr Tryjanowski. “Can Roads, Railways and Related Structures Have Positive Effects on Birds? – A

- Review.” *Transportation Research Part D: Transport and Environment* 30 (2014): 21–31. <https://doi.org/https://doi.org/10.1016/j.trd.2014.05.006>.
- Morin, Peter J. *Community Ecology*. Wiley - Blackwell, 2011.
- Murgui, Enrique, and Marcus Hedblom. “Ecology and Conservation of Birds in Urban Environments.” *Ecology and Conservation of Birds in Urban Environments*, 2017, 1–525. <https://doi.org/10.1007/978-3-319-43314-1>.
- Nagaike, Takuo, Tomohiko Kamitani, and Tohru Nakashizuka. 1999. “The Effect of Shelterwood Logging on the Diversity of Plant Species in a Beech (*Fagus Crenata*) Forest in Japan.” *Forest Ecology and Management* 118 (1): 161–71. [https://doi.org/https://doi.org/10.1016/S0378-1127\(98\)00500-3](https://doi.org/https://doi.org/10.1016/S0378-1127(98)00500-3).
- Negi, P. S. “A Contribution To the Woody Plant Diversity of Doon Valley, Uttaranchal ( North-West Himalaya ).” *The Indian Forester* 132(4), no. April (2006): 429–55.
- Nielsen, Anders Busse, Matilda van den Bosch, Sreetheran Maruthaveeran, and Cecil Konijnendijk van den Bosch. “Species Richness in Urban Parks and Its Drivers: A Review of Empirical Evidence.” *Urban Ecosystems* 17, no. 1 (2014): 305–27. <https://doi.org/10.1007/s11252-013-0316-1>.
- Niemelä, Jari. “Ecology and Urban Planning.” *Biodiversity and Conservation* 8, no. 1 (1999): 119–31. <https://doi.org/10.1023/A:1008817325994>.
- Niemelä, Jari, and D Johan Kotze. “Carabid Beetle Assemblages along Urban to Rural Gradients: A Review.” *Landscape and Urban Planning* 92, no. 2 (2009): 65–71. <https://doi.org/https://doi.org/10.1016/j.landurbplan.2009.05.016>.
- Nowak, David J, Daniel E Crane, and Jack C Stevens. “Air Pollution Removal by Urban Trees and Shrubs in the United States.” *Urban Forestry & Urban Greening* 4, no. 3 (2006): 115–23. <https://doi.org/https://doi.org/10.1016/j.ufug.2006.01.007>.
- Nutsford, D, A L Pearson, and S Kingham. “An Ecological Study Investigating the Association between Access to Urban Green Space and Mental Health.” *Public Health* 127, no. 11 (2013): 1005–11. <https://doi.org/https://doi.org/10.1016/j.puhe.2013.08.016>.
- Oksanen, Jari, F. Guillaume Blanchet, Michael Friendly, Roeland Kindt, Pierre Legendre, Dan McGlenn, Peter R. Minchin, et al. “Vegan: Community Ecology Package,” 2020. <https://cran.r-project.org/package=vegan>.
- Palacio, Facundo Xavier. “Urban Exploiters Have Broader Dietary Niches than Urban

- Avoiders.” *Ibis* 162, no. 1 (January 1, 2020): 42–49.  
<https://doi.org/https://doi.org/10.1111/ibi.12732>.
- Palmer, Grant C, James A Fitzsimons, Mark J Antos, and John G White. “Determinants of Native Avian Richness in Suburban Remnant Vegetation: Implications for Conservation Planning.” *Biological Conservation* 141, no. 9 (2008): 2329–41.  
<https://doi.org/https://doi.org/10.1016/j.biocon.2008.06.025>.
- Park, Jonghoon, Jun-Hyun Kim, Dong Kun Lee, Chae Yeon Park, and Seung Gyu Jeong. “The Influence of Small Green Space Type and Structure at the Street Level on Urban Heat Island Mitigation.” *Urban Forestry & Urban Greening* 21 (2017): 203–12. <https://doi.org/https://doi.org/10.1016/j.ufug.2016.12.005>.
- Pereira, Henrique M, and David H Cooper. “Towards the Global Monitoring of Biodiversity Change.” *Trends in Ecology & Evolution* 21, no. 3 (2006): 123–29.  
<https://doi.org/https://doi.org/10.1016/j.tree.2005.10.015>.
- Phillips, R J, and T A Waldrop. 2008. “Changes in Vegetation Structure and Composition in Response to Fuel Reduction Treatments in the South Carolina Piedmont.” *Forest Ecology and Management* 255 (8): 3107–16.  
<https://doi.org/https://doi.org/10.1016/j.foreco.2007.09.037>.
- Powell, George W, and Edward W Bork. 2006. “Aspen Canopy Removal and Root Trenching Effects on Understory Vegetation.” *Forest Ecology and Management* 230 (1): 79–90. <https://doi.org/https://doi.org/10.1016/j.foreco.2006.04.021>.
- Provisional Population Totals. “Census of India 2011 Urban Agglomerations and Cities,” 2011, 6–10.
- Prugh, Laura R, Karen E Hodges, Anthony R E Sinclair, and Justin S Brashares. “Effect of Habitat Area and Isolation on Fragmented Animal Populations.” *Proceedings of the National Academy of Sciences* 105, no. 52 (December 30, 2008): 20770 LP – 20775. <https://doi.org/10.1073/pnas.0806080105>.
- Puga-Caballero, Aura, Ian MacGregor-Fors, and Rubén Ortega-Álvarez. “Birds at the Urban Fringe: Avian Community Shifts in Different Peri-Urban Ecotones of a Megacity.” *Ecological Research* 29 (July 1, 2014): 619–28.  
<https://doi.org/10.1007/s11284-014-1145-2>.
- R Core Team. “R: A Language and Environment for Statistical Computing.” *R Foundation for Statistical Computing*. Vienna, Austria, 2021. <https://www.r->

project.org/.

- Racey, G D, and D L Euler. "Small Mammal and Habitat Response to Shoreline Cottage Development in Central Ontario." *Canadian Journal of Zoology* 60, no. 5 (May 1, 1982): 865–80. <https://doi.org/10.1139/z82-119>.
- Ramalho, Cristina E, and Richard J Hobbs. "Time for a Change: Dynamic Urban Ecology." *Trends in Ecology & Evolution* 27, no. 3 (2012): 179–88. <https://doi.org/https://doi.org/10.1016/j.tree.2011.10.008>.
- Rees, William E. "Urban Ecosystems : The Human Dimension Urban Ecosystems : The Human Dimension." *Urban Ecosystems* 1, no. March (1997): 63–75. <https://doi.org/10.1023/A>.
- Rega-Brodsky, Christine C, and Charles H Nilon. "Vacant Lots as a Habitat Resource: Nesting Success and Body Condition of Songbirds." *Ecosphere* 7, no. 11 (November 1, 2016): e01578. <https://doi.org/https://doi.org/10.1002/ecs2.1578>.
- Rosenzweig, Michael L. *Win-Win Ecology: How the Earth's Species Can Survive in the Midst of Human Enterprise*. Oxford University Press. Vol. 12, 2004. <https://doi.org/10.1111/j.1061-2971.2004.012201.x>.
- Sattler, Thomas, Simone Fontana, Thomas Sattler, Fabio Bontadina, and Marco Moretti. "How to Manage the Urban Green to Improve Bird Diversity and Community Structure Landscape and Urban Planning How to Manage the Urban Green to Improve Bird Diversity and Community Structure." *Landscape and Urban Planning* 101, no. 3 (2011): 278–85. <https://doi.org/10.1016/j.landurbplan.2011.02.033>.
- Savard, Jean Pierre L., Philippe Clergeau, and Gwenaelle Mennechez. "Biodiversity Concepts and Urban Ecosystems." *Landscape and Urban Planning* 48, no. 3–4 (2000): 131–42. [https://doi.org/10.1016/S0169-2046\(00\)00037-2](https://doi.org/10.1016/S0169-2046(00)00037-2).
- Schacht, Walter H, James N Long, and John C Malechek. 1988. "Above-Ground Production in Cleared and Thinned Stands of Semiarid Tropical Woodland, Brazil." *Forest Ecology and Management* 23 (2): 201–14. [https://doi.org/https://doi.org/10.1016/0378-1127\(88\)90082-5](https://doi.org/https://doi.org/10.1016/0378-1127(88)90082-5).
- Schütz, Claudia, and Christian H. Schulze. "Functional Diversity of Urban Bird Communities: Effects of Landscape Composition, Green Space Area and Vegetation Cover." *Ecology and Evolution* 5, no. 22 (2015): 5230–39.

- <https://doi.org/10.1002/ece3.1778>.
- Shukla, Uma, and Deepender Bora. “The Lower Siwalik Foreland Basin Sedimentation in the Kumaun Himalaya (India): A Transition from Megafan Setting to Incised Valley Fills.” *Journal of Geodynamics* 129 (January 13, 2018).  
<https://doi.org/10.1016/j.jog.2018.01.002>.
- Silva, Carmen Paz, Cristóbal E García, Sergio A Estay, and Olga Barbosa. “Bird Richness and Abundance in Response to Urban Form in a Latin American City : Valdivia , Chile as a Case Study,” 2015, 1–16.  
<https://doi.org/10.1371/journal.pone.0138120>.
- Silva, Carmen Paz, Roger D. Sepúlveda, and Olga Barbosa. “Nonrandom Filtering Effect on Birds: Species and Guilds Response to Urbanization.” *Ecology and Evolution* 6, no. 11 (2016): 3711–20. <https://doi.org/10.1002/ece3.2144>.
- Sol, Daniel, Cesar González-Lagos, Darío Moreira, Joan Maspons, and Oriol Lapiedra. “Urbanisation Tolerance and the Loss of Avian Diversity.” *Ecology Letters* 17, no. 8 (2014): 942–50. <https://doi.org/10.1111/ele.12297>.
- Speak, A F, A Mizgajski, and J Borysiak. “Allotment Gardens and Parks: Provision of Ecosystem Services with an Emphasis on Biodiversity.” *Urban Forestry & Urban Greening* 14, no. 4 (2015): 772–81.  
<https://doi.org/https://doi.org/10.1016/j.ufug.2015.07.007>.
- Swanwick, Carys, Nigel Dunnett, and Helen Woolley. “Nature, Role and Value of Green Space in Towns and Cities: An Overview.” *Built Environment* 29 (June 1, 2003): 94–106. <https://doi.org/10.2148/benv.29.2.94.54467>.
- Thomas, Len, Stephen T Buckland, Eric A Rexstad, Jeff L Laake, Samantha Strindberg, Sharon L Hedley, Jon R B Bishop, Tiago A Marques, and Kenneth P Burnham. “Distance Software: Design and Analysis of Distance Sampling Surveys for Estimating Population Size.” *Journal of Applied Ecology* 47, no. 1 (February 1, 2010): 5–14. <https://doi.org/https://doi.org/10.1111/j.1365-2664.2009.01737.x>.
- Thompson, Ken, Kevin C. Austin, Richard M. Smith, Philip H. Warren, Penny G. Angold, and Kevin J. Gaston. “Urban Domestic Gardens (I): Putting Small-Scale Plant Diversity in Context.” *Journal of Vegetation Science* 14, no. 1 (2003): 71–78.  
<https://doi.org/10.1111/j.1654-1103.2003.tb02129.x>.
- Tratalos, Jamie, Richard A. Fuller, Karl L. Evans, Richard G. Davies, Stuart E. Newson,

- Jeremy J.D. Greenwood, and Kevin J. Gaston. “Bird Densities Are Associated with Household Densities.” *Global Change Biology* 13, no. 8 (2007): 1685–95.  
<https://doi.org/10.1111/j.1365-2486.2007.01390.x>.
- UNCTAD, United Nations Conference on Trade and Development. *2020 Handbook of Statistics*. United Nations Publications, 2020.
- United States Census Bureau. “The Urban and Rural Classification and Urban Area Criteria,” 2010, 1–24.
- Vitousek, Peter M, John D Aber, Robert W Howarth, Gene E Likens, Pamela A Matson, David W Schindler, William H Schlesinger, and David G Tilman. “Human alteration of the global nitrogen cycle: sources and consequences.” *Ecological Applications* 7, no. 3 (August 1, 1997): 737–50.  
[https://doi.org/https://doi.org/10.1890/1051-0761\(1997\)007\[0737:HAOTGN\]2.0.CO;2](https://doi.org/https://doi.org/10.1890/1051-0761(1997)007[0737:HAOTGN]2.0.CO;2).
- Vlahov, David, and Sandro Galea. “Urbanization , Urbanicity , and Health” 79, no. 4 (2002): 1–12.
- Wania, Annett, K Ingolf, and Stefan Klotz. “Plant Richness Patterns in Agricultural and Urban Landscapes in Central Germany — Spatial Gradients of Species Richness” 75 (2006): 97–110. <https://doi.org/10.1016/j.landurbplan.2004.12.006>.
- Ward, Catharine, Jenny Roe, Peter Aspinall, Richard Mitchell, Angela Clow, and David Miller. “Landscape and Urban Planning More Green Space Is Linked to Less Stress in Deprived Communities : Evidence from Salivary Cortisol Patterns.” *Landscape and Urban Planning* 105, no. 3 (2012): 221–29.  
<https://doi.org/10.1016/j.landurbplan.2011.12.015>.
- Werner, Peter. “The Ecology of Urban Areas and Their Functions for Species Diversity.” *Landscape and Ecological Engineering* 7 (2011): 231–40.  
<https://doi.org/10.1007/s11355-011-0153-4>.
- White, Mathew P, Ian Alcock, Benedict W Wheeler, and Michael H Depledge. “Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data.” *Psychological Science* 24, no. 6 (April 23, 2013): 920–28.  
<https://doi.org/10.1177/0956797612464659>.
- Xiao, Xiang Dong, Li Dong, Hainan Yan, Nan Yang, and Yimei Xiong. “The Influence of the Spatial Characteristics of Urban Green Space on the Urban Heat Island

Effect in Suzhou Industrial Park.” *Sustainable Cities and Society* 40 (2018): 428–39. <https://doi.org/https://doi.org/10.1016/j.scs.2018.04.002>.

Yu, Chen, and Wong Nyuk Hien. “Thermal Benefits of City Parks.” *Energy and Buildings* 38, no. 2 (2006): 105–20. <https://doi.org/https://doi.org/10.1016/j.enbuild.2005.04.003>.

## APPENDIX I

### List of Unique Species found in the Study Area

<b>Sr. No.</b>	<b>Species</b>	<b>Scientific Name</b>
1	Ashy Prinia	<i>Prinia socialis</i>
2	Asian Koel	<i>Eudynamys scolopaceus</i>
3	Asian Pied Starling	<i>Gracupica contra</i>
4	Barn Swallow	<i>Hirundo rustica</i>
5	Black Drongo	<i>Dicrurus macrocercus</i>
6	Black Kite	<i>Milvus migrans</i>
7	Black Redstart	<i>Phoenicurus ochruros</i>
8	Black-rumped Flameback	<i>Dinopium benghalense</i>
9	Blue Whistling-thrush	<i>Myophonus caeruleus</i>
10	Brahminy Starling	<i>Sturnia pagodarum</i>
11	Brown-headed Barbet	<i>Megalaima zeylanica</i>
12	Cattle Egret	<i>Bubulcus ibis</i>
13	Chestnut-tailed Starling	<i>Sturnia malabarica</i>
14	Cinereous Tit	<i>Parus major</i>
15	Common Babbler	<i>Turdoides caudatus</i>
16	Common Hawk-Cuckoo	<i>Hierococcyx varius</i>
17	Common Myna	<i>Acridotheres tristis</i>
18	Common Rosefinch	<i>Carpodacus erythrinus</i>
19	Common Tailorbird	<i>Orthotomus sutorius</i>
20	Crimson Sunbird	<i>Aethopyga siparaja</i>
21	Dusky Crag-Martin	<i>Ptyonoprogne concolor</i>
22	Eurasian Hoopoe	<i>Upupa epops</i>
23	Feral Pigeon	<i>Columba livia</i>
24	Greater Coucal	<i>Centropus sinensis</i>
25	Green Bee-eater	<i>Merops orientalis</i>
26	Grey Francolin	<i>Francolinus pondicerianus</i>
27	Grey Treepie	<i>Dendrocitta formosae</i>
28	Grey Wagtail	<i>Motacilla cinerea</i>
29	Grey-breasted Prinia	<i>Prinia hodgsonii</i>
30	Grey-headed Canary-Flycatcher	<i>Culicicapa ceylonensis</i>
31	Grey-headed Woodpecker	<i>Picus canus</i>
32	Hair-crested Drongo	<i>Dicrurus hottentottus</i>
33	Himalayan Bulbul	<i>Pycnonotus leucogenys</i>
34	House Crow	<i>Corvus splendens</i>
35	House Sparrow	<i>Passer domesticus</i>
36	Hume's Warbler	<i>Phylloscopus humei</i>
37	Indian Chat	<i>Oenanthe fusca</i>
38	Indian Golden Oriole	<i>Oriolus oriolus</i>

39	Indian Grey Hornbill	<i>Ocyrceros birostris</i>
40	Indian Peafowl	<i>Pavo cristatus</i>
41	Indian Robin	<i>Saxicoloides fulicata</i>
42	Indian Roller	<i>Coracias benghalensis</i>
43	Indian Silverbill	<i>Euodice malabarica</i>
44	Indian Thick-knee	<i>Burhinus indicus</i>
45	Indian White-eye	<i>Zosterops palpebrosus</i>
46	Jungle Babbler	<i>Turdoides striata</i>
47	Jungle Crow	<i>Corvus macrorhynchos</i>
48	Jungle Myna	<i>Acridotheres fuscus</i>
49	Laughing Dove	<i>Spilopelia senegalensis</i>
50	Lemon-rumped Warbler	<i>Phylloscopus chloronotus</i>
51	Lesser Yellownape	<i>Picus chlorolophus</i>
52	Little Swift	<i>Apus affinis</i>
53	Long-tailed Minivet	<i>Pericrocotus ethologus</i>
54	Long-tailed Shrike	<i>Lanius schach</i>
55	Orange-headed Thrush	<i>Geokichla citrina</i>
56	Oriental Honey-buzzard	<i>Pernis ptilorhynchus</i>
57	Oriental magpie-robin	<i>Copsychus saularis</i>
58	Oriental Pied Hornbill	<i>Anthacoceros albirostris</i>
59	Oriental Turtle Dove	<i>Streptopelia orientalis</i>
60	Paddyfield Pipit	<i>Anthus rufulus</i>
61	Pied Bushchat	<i>Saxicola caprata</i>
62	Plum-headed Parakeet	<i>Psittacula cyanocephala</i>
63	Purple Sunbird	<i>Cinnyris asiaticus</i>
64	Red-vented Bulbul	<i>Pycnonotus cafer</i>
65	Red-wattled Lapwing	<i>Vanellus indicus</i>
66	Red-whiskered Bulbul	<i>Pycnonotus jocosus</i>
67	Rose-ringed Parakeet	<i>Psittacula krameri</i>
68	Rufous Treepie	<i>Dendrocitta vagabunda</i>
69	Scaly Thrush	<i>Zoothera dauma</i>
70	Scaly-breasted Munia	<i>Lonchura punctulata</i>
71	Scarlet Minivet	<i>Pericrocotus speciosus</i>
72	Shikra	<i>Accipiter badius</i>
73	Siberian Stonechat	<i>Saxicola maurus</i>
74	Spotted Dove	<i>Streptopelia chinensis</i>
75	Taiga Flycatcher	<i>Ficedula albicilla</i>
76	White Wagtail	<i>Streptopelia chinensis</i>
77	White-throated Fantail	<i>Rhipidura albicollis</i>
78	White-throated Kingfisher	<i>Halcyon smyrnensis</i>
79	Yellow-eyed Babbler	<i>Chrysomma sinense</i>
80	Yellow-footed Green Pigeon	<i>Treron phoenicopterus</i>
81	Yellow-wattled Lapwing	<i>Vanellus malabaricus</i>

## APPENDIX II

### Clustering Information of all the sampling units in the urban matrix

<b>Point Count Station</b>	<b>Cluster</b>	<b>Habitat</b>
AWHO3	1	Open Area
AWHO4	1	Open Area
GP6	1	Open Area
GP7	1	Open Area
GP8	1	Open Area
TO2	1	Open Area
UPES3	1	Open Area
VIGDH4	1	Open Area
VIGDH6	1	Open Area
VIGDH7	1	Open Area
AWHO7	2	Scrubland
AWHO8	2	Scrubland
TE1	2	Scrubland
TE2	2	Scrubland
TE5	2	Scrubland
TE7	2	Scrubland
TO1	2	Scrubland
TO3	2	Scrubland
TO4	2	Scrubland
UPES1	2	Scrubland
VIGDH1	2	Scrubland
VIGDH2	2	Scrubland
VIGDH3	2	Scrubland
VVPARK2	2	Scrubland
VVPARK4	2	Scrubland
WII C4	2	Scrubland
WII C5	2	Scrubland
WII C6	2	Scrubland
CBI1	3	Built – up
CBI2	3	Built – up
CBI3	3	Built – up
CBI4	3	Built – up
FRI C1	3	Built – up
FRI C3	3	Built – up
FRI C4	3	Built – up
FRI C5	3	Built – up
FRI C6	3	Built – up
FRI C7	3	Built – up
FRI C8	3	Built – up
GEU3	3	Built – up
GEU4	3	Built – up

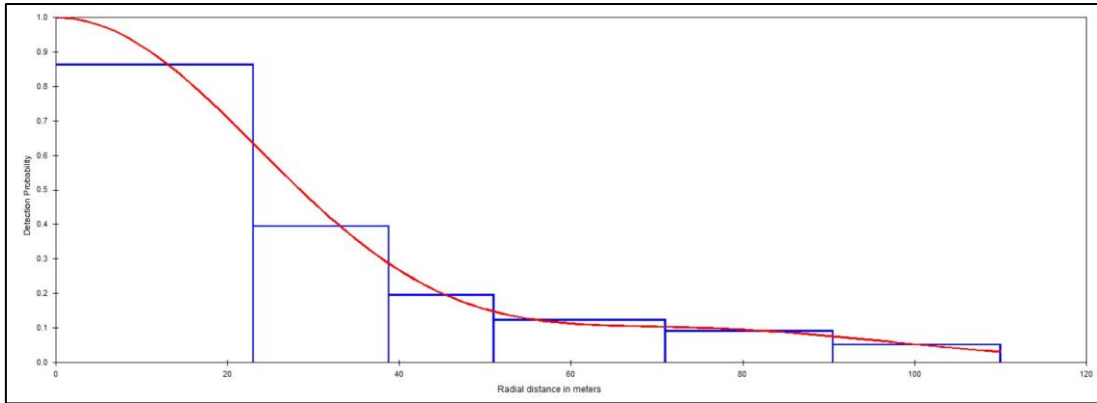
GEU5	3	Built – up
GEU6	3	Built – up
GEU7	3	Built – up
GEU8	3	Built – up
GP1	3	Built – up
GP3	3	Built – up
GP4	3	Built – up
GP5	3	Built – up
MDDA1	3	Built – up
MDDA2	3	Built – up
MDDA3	3	Built – up
MDDA4	3	Built – up
MKP1	3	Built – up
MKP2	3	Built – up
MKP3	3	Built – up
MKP4	3	Built – up
MKP5	3	Built – up
MKP6	3	Built – up
NP1	3	Built – up
NP3	3	Built – up
NP4	3	Built – up
NIVH1	3	Built – up
NIVH2	3	Built – up
NIVH3	3	Built – up
NIVH4	3	Built – up
NIVH7	3	Built – up
NIVH8	3	Built – up
TE8	3	Built – up
TO5	3	Built – up
TO6	3	Built – up
UPES2	3	Built – up
VVPARK1	3	Built – up
VVPARK3	3	Built – up
WII C1	3	Built – up
WII C2	3	Built – up
WII C3	3	Built – up
WII C7	3	Built – up
WII C8	3	Built – up
WII3	3	Built – up
WII5	3	Built – up
WII6	3	Built – up
ZSI1	3	Built – up
ZSI2	3	Built – up
ZSI3	3	Built – up
ZSI5	3	Built – up
GEU1	4	Green Cover

GEU2	4	Green Cover
GP2	4	Green Cover
NP2	4	Green Cover
NIVH5	4	Green Cover
UPES4	4	Green Cover
UPES5	4	Green Cover
UPES6	4	Green Cover
UPES7	4	Green Cover
UPES8	4	Green Cover
WII1	4	Green Cover
WII2	4	Green Cover
ZSI4	4	Green Cover
ZSI6	4	Green Cover
ZSI7	4	Green Cover
ZSI8	4	Green Cover
TE3	5	Agriculture
TE4	5	Agriculture
TE6	5	Agriculture
VIGDH8	5	Agriculture
WII4	5	Agriculture
WII7	5	Agriculture
WII8	5	Agriculture

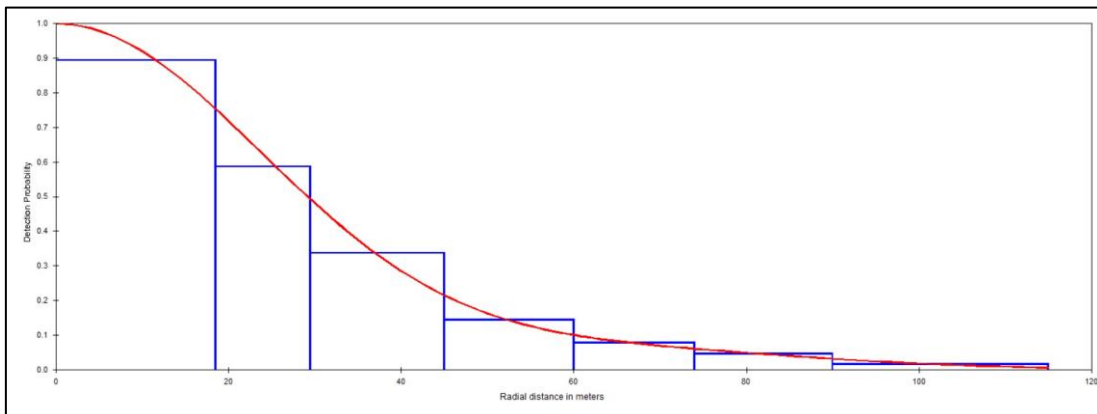
# APPENDIX III

## Detection Probability plots of the habitat wise densities

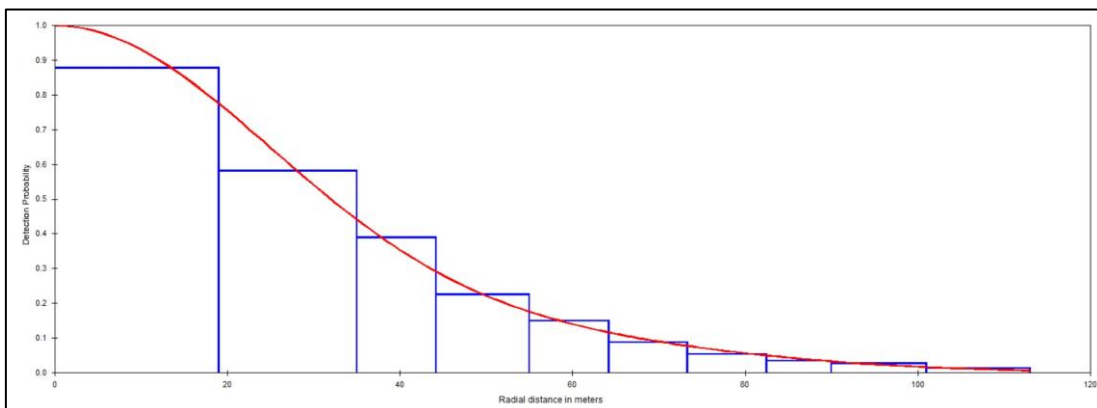
### 1. Agriculture



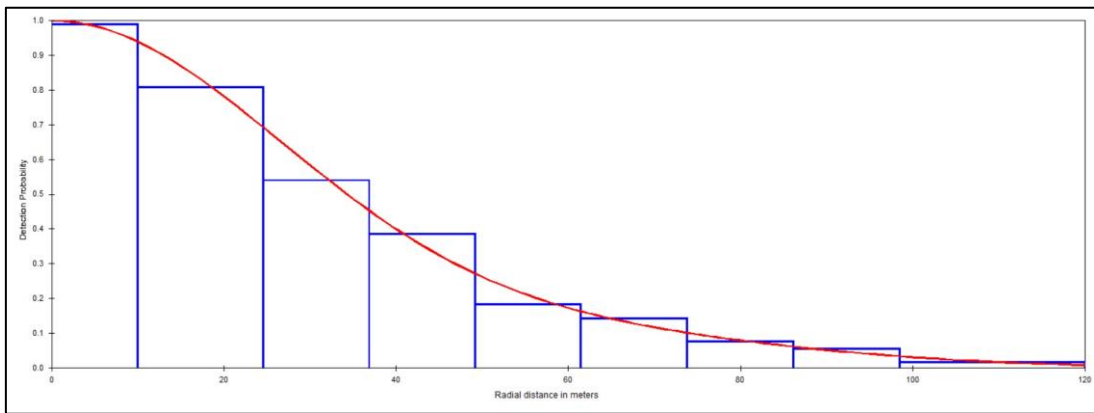
### 2. Built – up



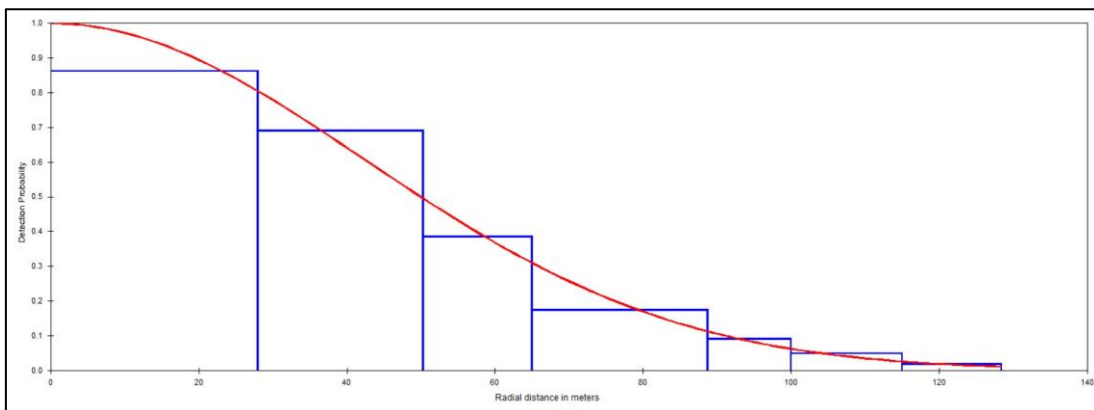
### 3. Green Cover



#### 4. Open Area

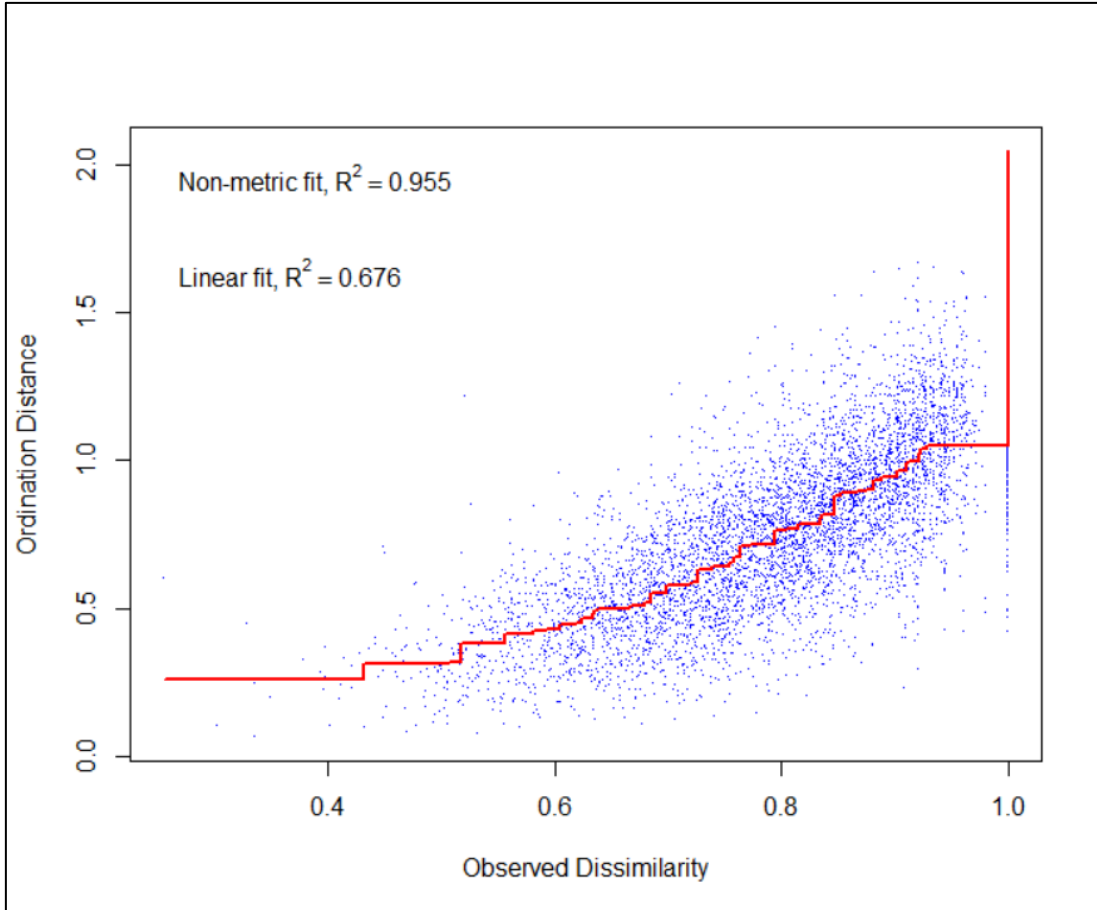


#### 5. Scrubland



# APPENDIX IV

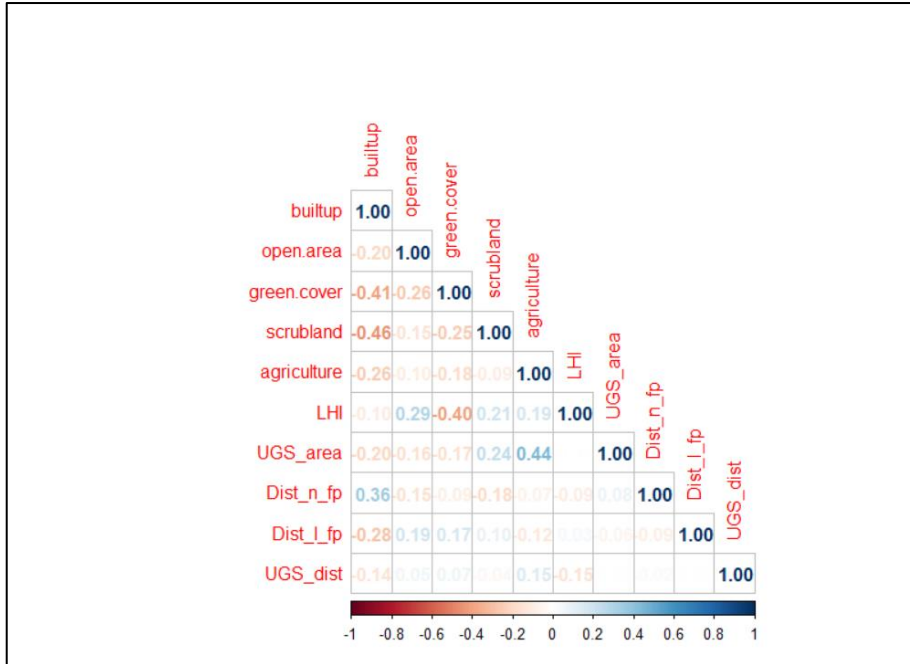
## Stressplot of the NMDS Ordination



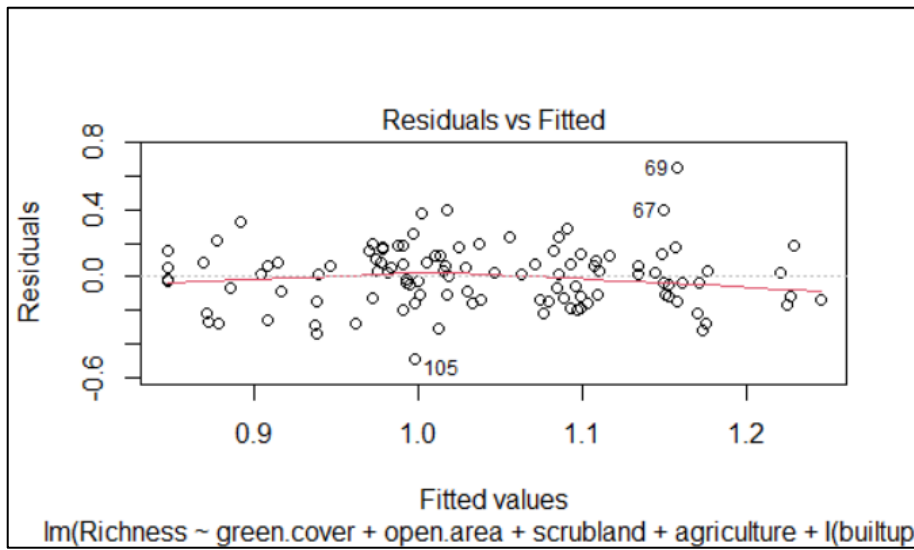
# APPENDIX V

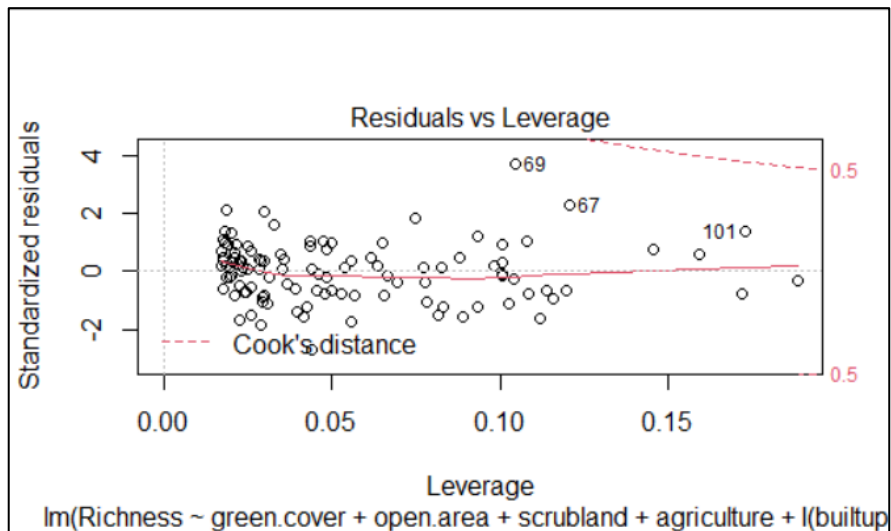
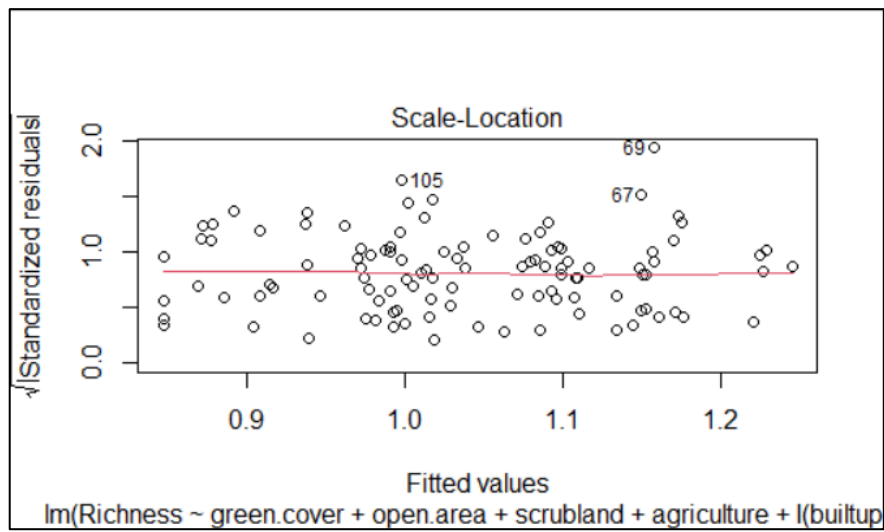
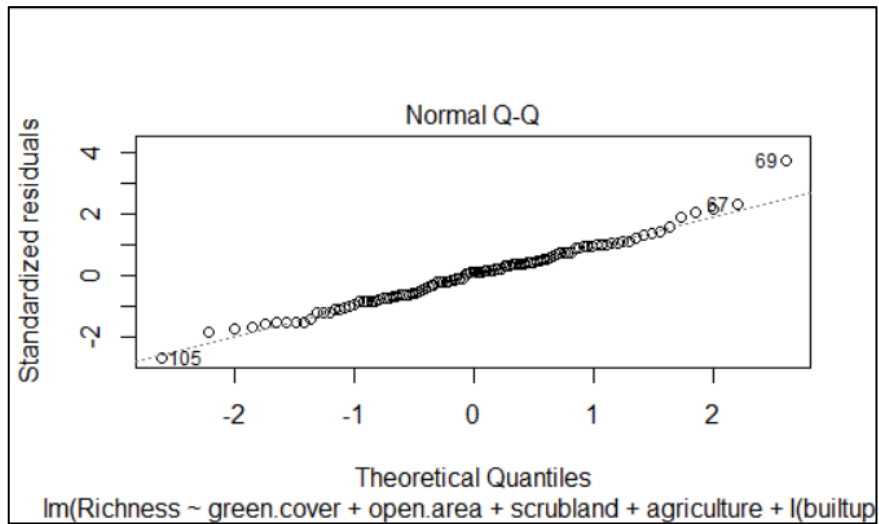
## Correlation plot of the variables and GLM assumption plots of the best models

### 1. Correlation plot of the variables

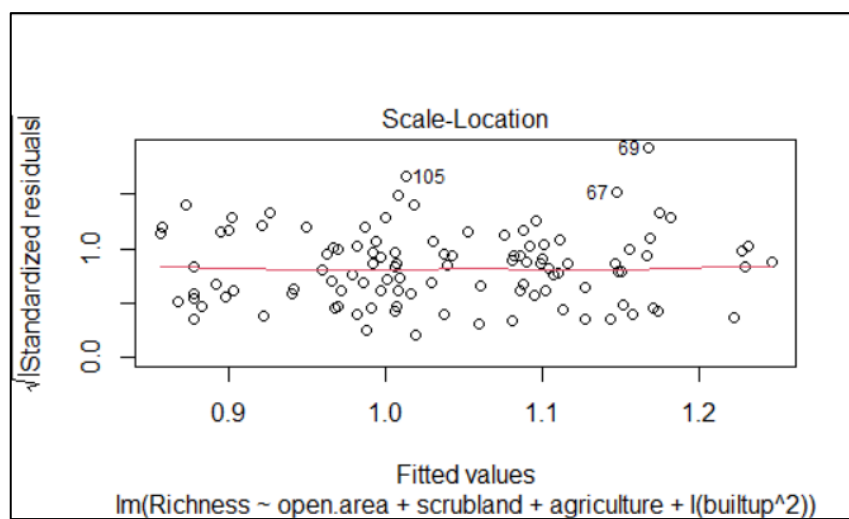
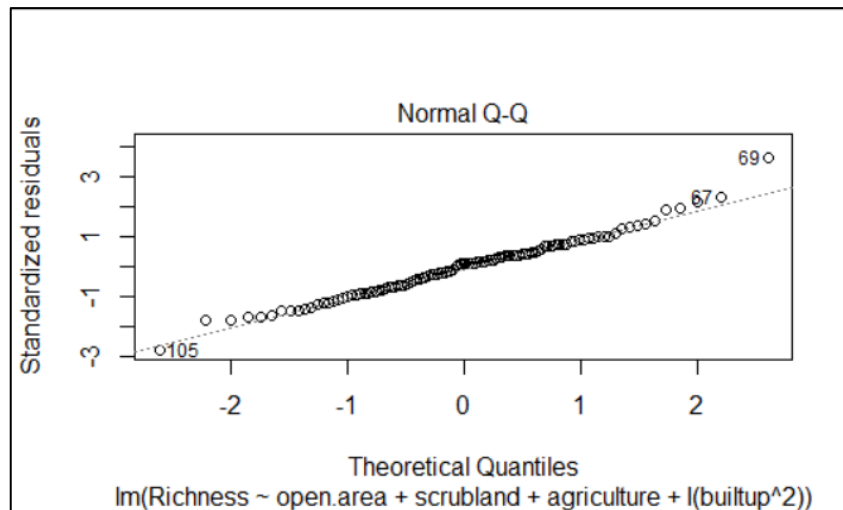
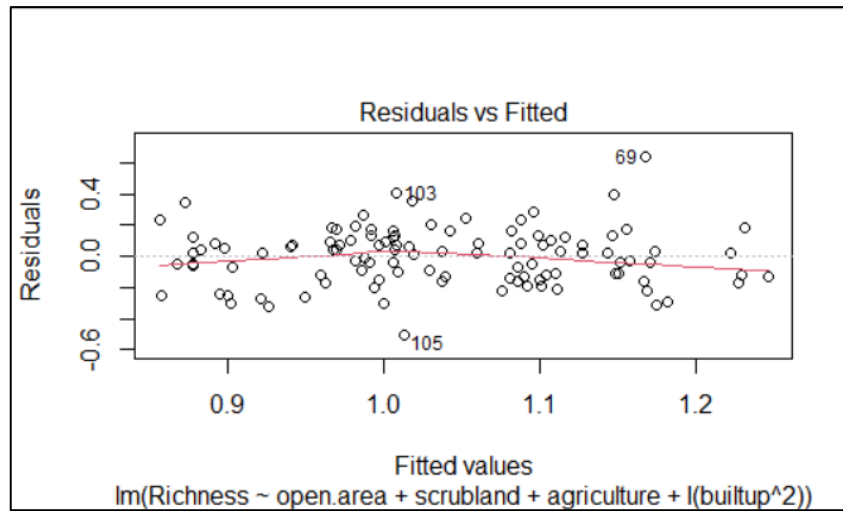


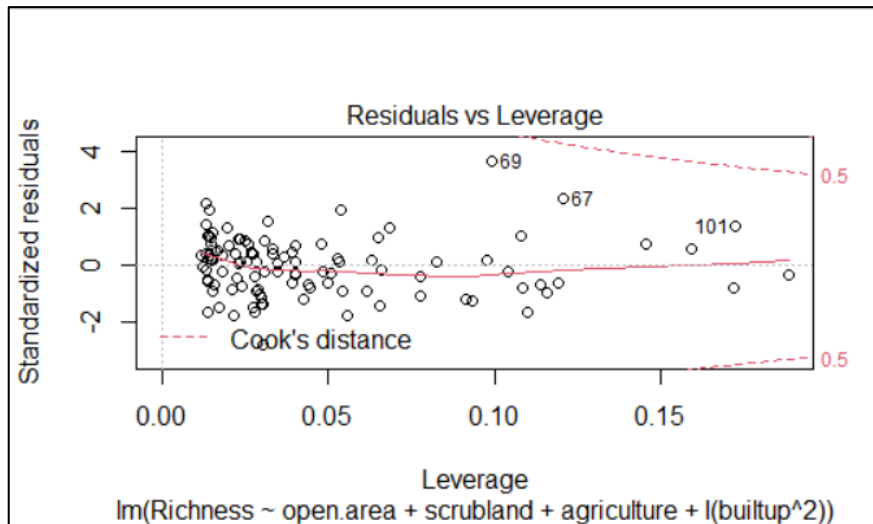
### 2. Normality Assumptions of model 1 of Richness



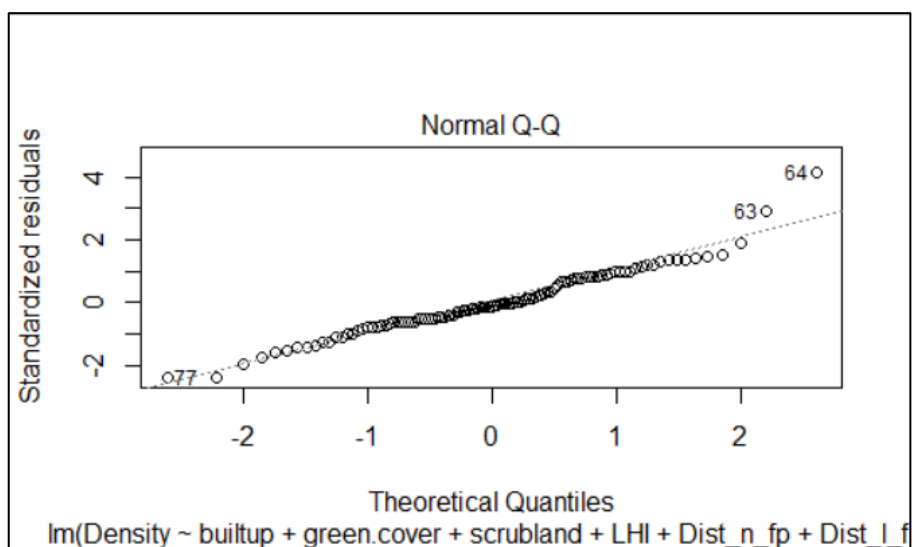
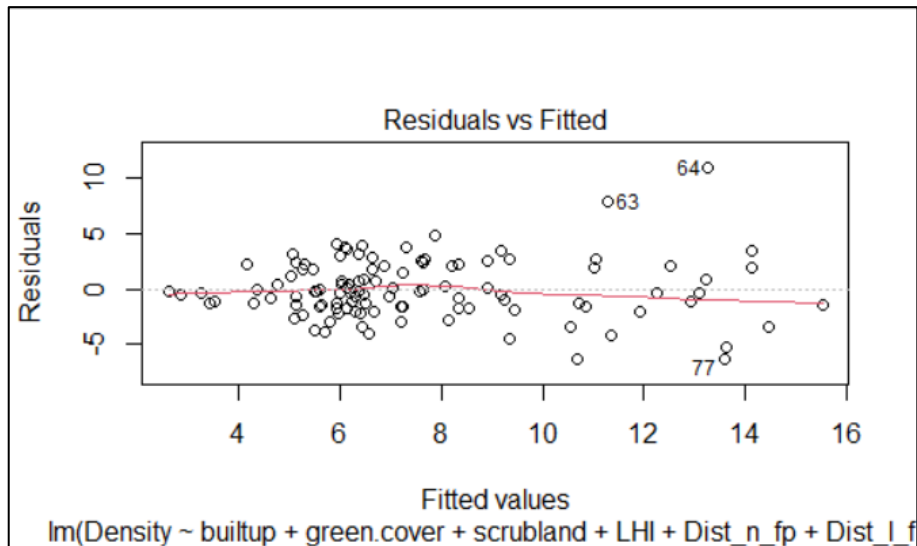


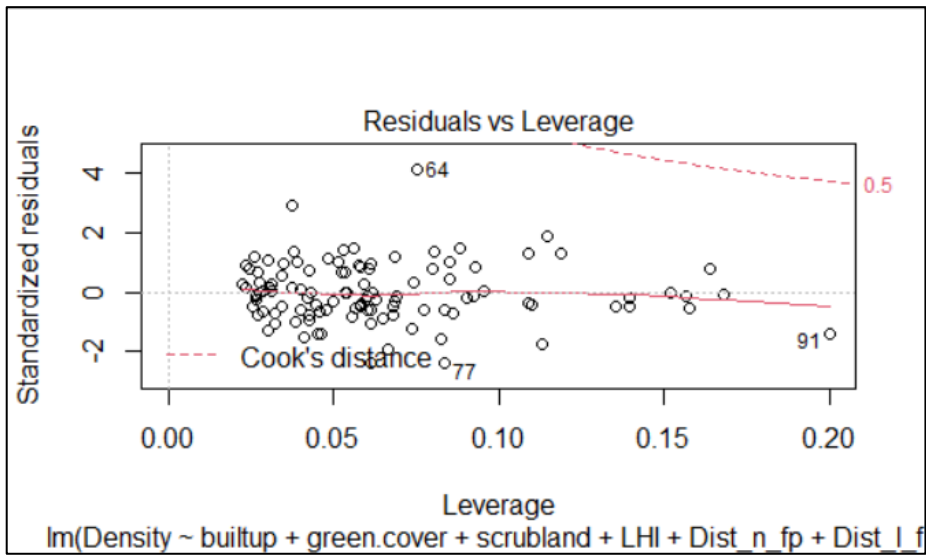
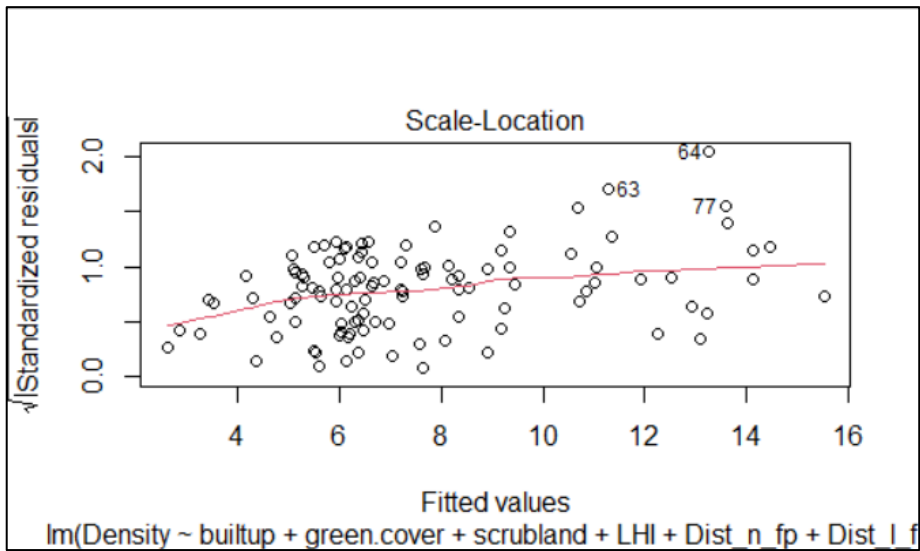
### 3. Normality Assumptions of model 2 of Richness



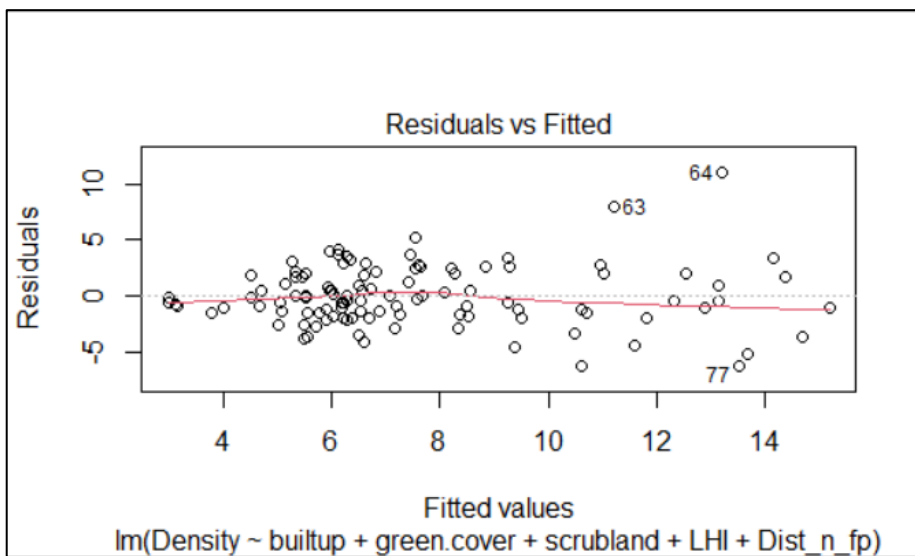


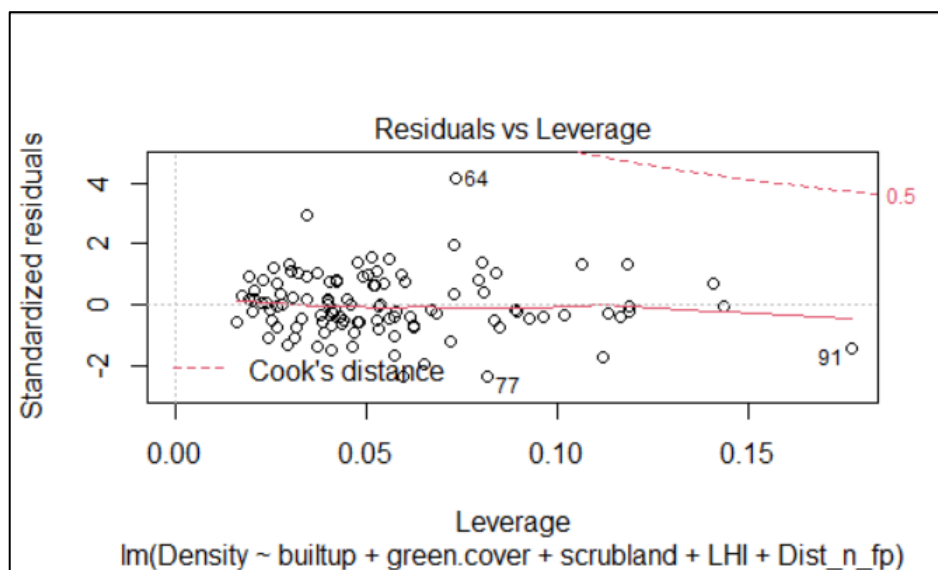
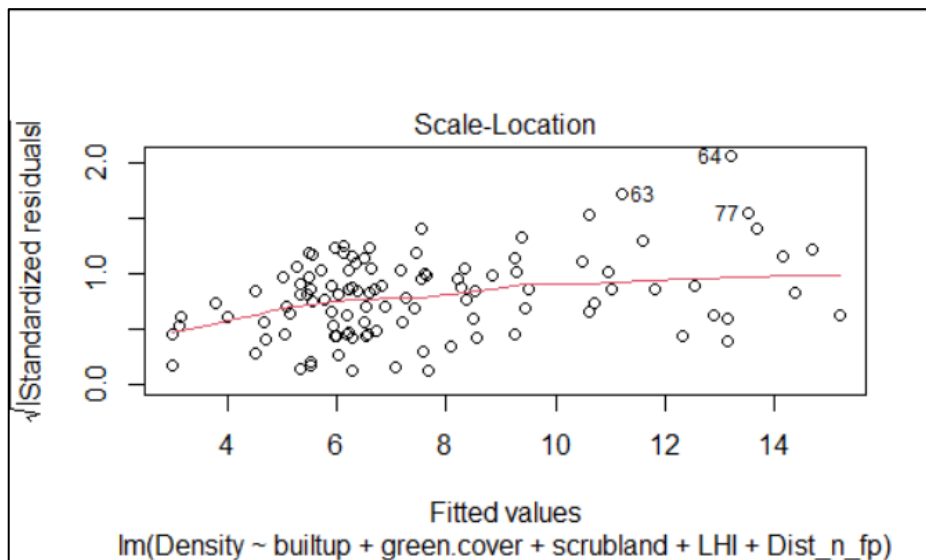
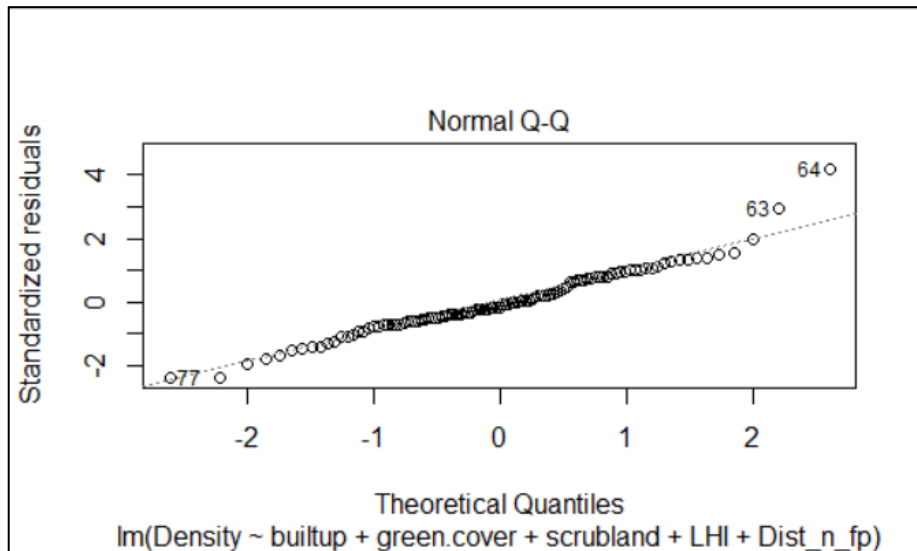
4. Normality Assumptions of model 1 of Density





5. Normality Assumptions of model 2 of Density





6. Normality Assumptions of model of local scale richness

