AVIAN SPECIES SELECTION IN URBAN HABITATS - A STUDY IN COIMBATORE, INDIA

Thesis submitted to the Bharathiar University, Coimbatore

for the award of degree of Doctor of Philosophy in Environmental Sciences

by

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COIMBATORE, 641 108

JUNE 2013

CERTIFICATE

This is to certify that the thesis entitled "**Avian species selection in urban habitats – a study in Coimbatore, India**", submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental science is a record of original research work done by Ms.**Ranjini J.** during the period of 2006-2013 of her study in the Division of Environmental Impact Assessment at Sálim Ali Centre for Ornithology and Natural History, under my supervision and guidance and the thesis has not formed the basis for the award of any Degree/Diploma/Associateship/ Fellowship or other similar title to any candidate of any University.

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DECLARATION

I **Ranjini J.**hereby declare that the thesis entitled **"Avian species selection in urban habitats – a study in Coimbatore, India"**, submitted to the Bharathiar University, in partial fulfilment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental Science is a record of original and independent research work done by me during 2006-2013 under the supervision and guidance of **Dr. P.A.Azeez,** Director andSenior Principal Scientist, Division of Environmental Impact Assessment, Sálim Ali Centre for Ornithology and Natural History, Coimbatore and it has not formed the basis for the award of any Degree/Degree/Diploma/ Associateship/ Fellowship or other similar title to any candidate in any University.

Signature of the Candidate

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I express my sincere gratitude and apologies to all people I might have left out to mention here, which is truly unintentional.

Finally, it is solely my responsibility for any errors or shortages that may persist in this work.

Ranjini

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Ranjini

ABBREVIATIONS

Land use type/Habitat/landscape metrics:

LTHDBA/LTBA	=	High-density building with low-density tree canopy cover
MTHDBA/MTBA	=	High-density building with medium-density tree canopy cover
HTHDBA/HTBA	=	High-density building with high-density tree canopy cover
HTMDBA	=	Medium-density building with high-density tree canopy cover
MTMDBA	=	Medium-density building with medium-density tree canopy cover
LTMDBA	=	Medium-density building with low-density tree canopy cover
HTLDBA	=	Low-density building with high-density tree canopy cover
MTLDBA	=	Low-density building with medium-density tree canopy cover
LTLDBA	=	Low-density building with low-density tree canopy cover
VLDBA	=	Area with very less density of building
Village	=	MTLDBA+LTLDBA
Rural	=	HTLDBA

Land use Land cover:

Wet	=	Wetland
OA	=	Open ground with bushes / dispersed trees/agricultural areas
T	=	Tree canopy cover
Road	=	Tarred road (trd) + Un-tarred road (utrd)
TBL	=	Tiled building
PBL	=	Plastered/concrete building

Statistical analysis:

MDS	=	Multi-dimensional scaling
MCA	=	Multiple Correspondence Analysis (MCA)
AIC	=	Akaike Information Criterion
df	=	degrees of freedom

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SUMMARY

INTRODUCTION

Survival of a species is closely associated with changing habitats. We studied this in the context of urbanization that brings massive changes in the landscape. The study is contextual in view of high rates of conversion of natural landscapes into urban areas. With the ascent of urbanization, many species disappear while some species become abundant. The present study investigated avian species and their distribution along a rural-urban gradient of the Coimbatore city - a fast growing city in Tamil Nadu, India. The study was taken up to explore the factors that affect the distribution of avian species across an urbanisation gradient and to identify survival strategies adopted by avian species in urban areas.

The thesis encompassed the work carried out during 2007-2010 in the urban to rural landscape of the Coimbatore city and its environs. As the first step of the study, a gradient of urbanization was identified through the Coimbatore city, its suburbs and rural areas, based on landscape metrics and a set of land use / land cover variables that were used a measure of urbanization. Second, the bird community distribution along the gradient was studied and the non-linear relationship with urbanization was explained. To shed more light into factors underlying species distribution pattern, the life-history traits of species seen along the gradient was analysed. Finally the activities and substrate use of the species was examined, to see how species survive in such resource limited and challenging urban environment.

METHODS

To find an urbanization gradient two approaches were selected 1) Linear distance from the city centre and 2) land use types across the urban rural landscape. The former was carried out in a study plot, 7m wide and 13m long area, which was further classified of 18 grids. The land use types were

quantified using satellite imageries freely available in Goole earth software. In the land use based study to find the gradient, the land use types were identified along the urban to rural stretch and several plots of 75m x 75m laid in each land use types to quantify land use land cover (LULC) within each land use type. The urbanization gradient was identifiedbased on the land use types and (LULC.

The bird community distribution across an urbanization gradient was studied using point counts in plots of 35m x 35m size. During surveys, details such as species, number, nest, habitat and activity were recorded at each site. The life-history traits of species were collated from published literatures. The species that were strictly terrestrial and resident were only considered for the present study. Nocturnal, wetland and migratory species were omitted from further analysis.

The distribution of species along the urban-rural gradient was documented by estimating species richness, turnover rate, and densities along the gradient. The species were classified into three groups based on their sensitivity to urbanization as i) urban sensitive (US), ii) urban adapter (UA), and iii) urban exploiter (UE), essentially based on their distribution along the urban to rural gradient. The UE types were seen in higher frequencies in the city, and US the least. The factors associated with the dispersal of the species were deduced by appropriate statistical techniques such as non-linear regression.

In order, to see if certain taxa are better selected in urban areas, the proportion of the species falling under same family was compared between natural and urban populations. To understand the basis of species selection in urban areas, life-history traits of each species were examined. As a first step, the species were classified based on their life-history traits using Multiple Correspondence Analysis (MCA).

I hypothesise that species might adopt certain strategies in order to adjust to the changing settings in urban areas. To see the response of the species to the human manipulated habitat, I recorded nest substrate use, type of activity (foraging, breeding, agonistic, flying and resting) and timing of the breeding. I also collated details such as body weight and brain variables.

RESULTS

The study of species distribution along rural to urban gradient shed some light on how species are being filtered during the process of urbanization. The richness and turnover rate declined as the urbanization levels reached high. The abundances of few species, belonging to the group UE increased, while the diversity of US was high at lower levels of urbanization. Among UE, certain species showed peak distribution towards rural, whereas certain species were restricted mostly to areas with higher levels of urbanization. For instance, Rock pigeon and Black kite were high at locations with high urbanization, whereas, species such as House sparrow, Common myna and Asian koel peaked in numbers at lower urbanization levels. Crow showed consistent density across the urbanization gradient, except in villages.

The decrease in the number of UA and US was correlated to the decreasing natural areas with the ascent of urbanization, whereas increase in UE was correlated to certain other species-specific factors. The House sparrow population showed correlation with the availability of anthropogenic food; while, Asian koel and Common myna were associated with medium levels of urbanization with natural areas. Crow and Black kite population did not correlate with any parameters that were considered. The density of Rock pigeon was correlated negatively with the presence of natural areas and positively with multi-storied buildings. The number of nests of UE species also correlated with their population densities, except in the case of Rock pigeon.

The results show that the correlation of distribution of species within a family between natural and urban community was not significantly different. Thus, it could be deemed that life-history traits would have a major role in the selection of species to urban areas. The Multiple Correspondence Analyses on life-history traits, distinguished species based on habitat, nest type, nest substrate and body weight. The stepwise regression on the life-history traits show that 'habitat' was the major factor that determined survival of species in urban areas.

The nest substrate use in bird species in urban area revealed the use of analogues of microhabitats such as rocky cliffs, in urban areas by the species. The platform and cavity nesters occupied artificial structures such as buildings or open wells, whereas platform-cup nesters even used cell phone masts. The activity patterns show that certain species were active throughout the day, while others rested during hot hours. It was seen that most species in urban areas were breeding all through the year.

The body weight of species belonging to the UE group varied widely; House sparrow had lowest body weight and Black kite the highest. The brain variables other than functional telencephalon ratio were not significantly different from the non-urban group, while its ratio was significantly higher in UE species. However, the ratio of functional telencephalon varied significantly within the UE group.

DISCUSSIONS

This study shows that life-history traits play significant role in species selection in urban area. The UE species were distinguished from other species based on traits such as body weight, habitat, nest substrate and nest type. However, habitat turned out to be the crucial factor in deciding bird species survival in urban areas. The species hailing from a challenging/competitive situation, in this case 'open' habitat, frequented urban areas.

The declining species richness and turnover rate coupled with increasing densities of a few select species indicate biotic homogenization. The main factor associated would be lack of appropriate vegetation to support species in the city. Crow was the only species that did not show any trend of decline or rise in population. It did not show any correlation with the habitat parameters as well. Looking at the counts, crow was present in most of the point-count sites and their frequency was mostly 2-3. This could be due to the 'social networking' strategy with which they spread across in space to scan for food availability. House sparrow on the other hand was present mostly in villages where tiled buildings and availability of anthropogenic food was higher. House sparrows were rare in urban Coimbatore, similar to the trend across the world. Common Myna, a common species in many cities, was rather less in urban Coimbatore. However, their roosting population remained high in the city. Rock pigeon was also relatively less in Coimbatore than in other major cities such as Mumbai. Their population was related to the presence of plastered buildings, or buildings with open ledges and window sills. While the modern buildings lack them, in the older parts of the city many old buildings were still present. These buildings offer nesting and roosting sites for species such as Rock pigeon. Black kite was present mostly in higher urbanised locations, mostly where tree cover ranges from medium to high, markets and solid waste dumping.

The study found that species adopt certain survival strategies aided by their life-history traits. The study on nest substrates reveal that they found analogues of their original habitat features in the artificial structures. These species (UE) also broaden their breeding period all through the year, probably because of food availability. The main high light of the activity levels and substrate use in select birds that survive in urban areas is that, there was decrease use of buildings during the 'hot' hours. This could be to avoid heat emanating from concrete buildings during these 'hot' hours. The location of the study, in a tropical city could have a greater effect for this result. The study concludes with a hypothesis that the role of cognitive capacities for survival in urban areas for species that face limitation could be a necessity. The functional telencephalon ratio of urban species supports this hypothesis. However, the present study is not enough to substantiate this, as we are yet to understand whether behavioural strategies require higher cognition.

CONCLUSIONS

The study shows that species were filtered across urbanization gradient based on their life-history traits. However, the species that frequented urban areas also differed in their response to urbanization levels. They adopted several strategies to survive in urban areas, which in part were influenced by their life-history traits that were favoured in urban areas. The requirement of higher cognitive capacity to formulate survival strategies is not yet clear, as it is yet to understand whether behavioural strategies they adopt in urban areas require higher level of cognition.

CHAPTER 1

GENERAL INTRODUCTION

1.1 BACKGROUND

Urbanization is an incessant course that transform uninhabited wild lands into a range of settlement densities and patterns from widely spaced agricultural and recreational homesteads to the concrete and steel heart of a large metropolitan area (Marzluff et al., 2001). This range in settlement density and pattern is often referred to collectively as a gradient of urbanization (McDonnell et al., 1993). Urbanization alters both structure and function of a landscape leading to a monotonous composition of habitat - combinations of man-made forms such as roads, buildings, and other structures needed by human populations, which are developed to the detriment of the natural environment, throughout the world (McKinney, 2006; Clergeau et al., 2001; Savard et al., 2000). In addition, urbanization induces disturbances due to human activity (Fernández-Juricic and Schroeder, 2003), heat islands (Voogt and Oke, 2003), environmental pollution (Fenger, 1999), and noise pollution (Slabbekoorn et al., 2007).

Around two-thirds of land mass is occupied by urban areas and it is rapidly increasing, taking over more and more wild and forested lands. It is expected that by 2050 a major proportion of the total land mass will be under urban conglomerations. Urban areas differ in the intensity of urbanization, affected by factors such as the city structure (structural), age (temporal), geographical location (spatial) and GDP (Gross domestic product; economic). In addition, the rate of spread of urbanization to the neighbouring areas, along the perimeter of the city, is also a main factor; this phenomenon is called urban sprawl.

Unplanned and rapid urbanization is a common phenomenon in the case of developing countries, which results in 'dualism' - characteristics of third world cities. In the scenario of 'dualism', one observes co-existence of extremes, poor and rich, skilled and unskilled, traditionalism and modernism. This is mainly a resultant of rapid influx of rural people to cities i.e., human migration. This is expected to reflect in the urban geography that is explicitly depicted in the housing / built-up structure, where one can see squatter settlements (non-conventional type) or widely known as 'slum', built by the urban poor, in the midst of conventional buildings / apartments. The migration of people from rural areas in search of employment results in the formation of local shanties or 'bazaars'.

Other than the obvious social and economic issues, unplanned urbanization creates two types of ecological challenges, 1) depletion of wilder / forested lands and 2) urban areas becoming more and more urbanized, more or less depriving opportunity for other life forms, other than human being to survive. The condition worsens in developing countries as 'urban sprawl' wipe away agricultural areas and forests. The relocation of people, especially farmers from rural areas seeking employment, results in vacant rural or agricultural lands left vacant and uncultivated. They would trade their productive 'vacant' farm / land for a life in city. The rural land / farms are then subject to conversion for urbanising developmental activities. This is a common scenario in developing countries, where 'real estate' plays a crucial role in land use / land cover changes.

The ecological effects of urbanization are fragmentation, isolation, and loss of natural habitat patches, as well as creation of new habitats (Loram et al., 2007; Melles et al., 2003; Marzluff and Ewing, 2001). This is the leading cause of biological diversity loss worldwide (Vitousek et al., 1997). As a result, the majority of the earth's human population will likely be living in a state of "biological poverty" by the year 2030. Biological poverty occurs when urban citizens experience below-average levels of native species diversity on a daily basis (Turner et al., 2004).

Until recently, majority studies in urban areas were restricted to those related to socio-economic or urban planning, although studies of birds in urban areas have fairly long history. Conventionally, studies regarding conservation of species and ecosystems were restricted to natural habitats, as urban areas were not viewed as an ecosystem. As a result urban areas has been ignored through many decades of ecological research (Miller and Hobbs, 2002; Collins et al., 2000). However, there are many species that survive in urban areas utilising the existing vegetation patches present either as remnant patches or man-made vegetation such as road-side greeneries (Sebastian and Azeez, 2013) or lawns; few wild species that has learned to associate with human beings also survive in urban areas known as synanthropic species, apart from the domesticated species such as dogs, cats and few birds. Thus, urban areas also hold wild life, and there exists an ecosystem, though very different from the natural environment. This was the point when many ecologists started realising urban areas as an 'ecosystem', and many studies started coming up in this field.

Considering the wide spread urbanization, which is gradually occupying majority space in the globe, since the early 1990s a concept emerging that accepted the potential of urban areas as an 'ecosystem' and the importance of conserving species thriving in this ecosystem (McKinney, 2002; Miller and Hobbs, 2002; Grimm et al., 2000; Rebele, 1994; McDonnell and Pickett, 1990). With this emerging concept, urban environments are being realised as valuable habitat that, with proper management, has the potential to support diverse communities (Shochat et al., 2010b). During the last decade urban ecosystems have therefore become one of the ecological challenges in conservation, restoration, and reconciliation ecology (Miller and Hobbs, 2002; Rosenzweig, 2003).

Studies have found that as urbanization alters the habitat several species fail to survive, while certain species are able to or certain others learn to utilise the available resources in the altered habitat. This selection leads to lower diversity and increase in the abundances of some species in urban areas as reported by many studies (Rodewald and Shustack, 2008; Chace and Walsh, 2006;

Marzluff, 2001; Emlen, 1974). Hence, it is important to investigate associated changes in species diversity and community similarity in urban areas (Newmark, 2006; Marzluff, 2005).

Currently, ecologists are trying to understand the drivers of urban bird population dynamics and community structure (Shochat et al., 2010b), which is still in the stage of infancy. Birds are often used as a biological model because they are good ecological indicators and are easily observable (Clergeau et al., 2001). The study of urban effects on birds has increased steadily since Pitelka (1942) characterized how the coastal avifauna of California responded to suburbanization and recreational development. Knowledge of the patterns of urban bird populations and communities started emerging in the 1970s (Emlen, 1974). There were some long-term studies (Luniak and Mulsow, 1988; Bezzel, 1985; Walcott, 1974; Batten, 1972), which documented avifaunal change at a site that became increasingly urbanized over more than a century. The study of Blackbirds over a period of 150 years by Luniak and Mulsow (1988) documented increasing density of Blackbirds in response to urbanization.

Urban research with the recent concept of 'bio-ecological approach' Grove and Burch (1997) examined the changes in natural processes and conditions that occur along the rural-urban gradient and restoration of natural processes within areas disturbed by humans (Givoni, 1991). The initial studies show that total and native species richness decline at high levels of development (Porneluzi and Faaborg, 1999; Blair, 1996; Hoover et al., 1995; Friesen et al., 1995). The results of many recent studies indicate that as development intensifies, bird communities become increasingly homogenized (McKinney and Lockwood, 1999). Much recent work by avian ecologists has focused on community-level correlation studies; but unless the processes that generate bird-community patterns are identified, efforts to influence policy and planning will be largely ineffectual (Hostetler, 2001). Blair (2001) and Reale and Blair (2005) did some notable studies on bird ecology along an urban to rural gradient.

A review of the publications of research done on birds in urban areas for more than 20 years (Marzluff et al., 2001), found that studies of birds in tropical urban settings are especially lacking except for a few studies (Kentish et al., 1995; Green et al., 1989; Munyenyembe et al., 1989; Ruszczyk et al., 1987; Jones, 1981; Shcuyler Fonaroff, 1974). In India, studies on birds in urban areas are scanty. Nevertheless, the concerns on the wide spread decline of House sparrows impacted the ornithology research in urban areas of India. There were studies from different parts of India to understand the declining population of House sparrow (Singh et al. (2013) in Jammu, Dhanya (2011) in Tamil Nadu, Bhattacharya et al. (2010) in West Bengal, Balakrishnan et al. (2011) in Kerala, Dhanya and Azeez (2010) in Andhra Pradesh, Ghosh et al. (2010), Bhattacharya et al., 2010 in West Bengal, Khera et al. (2010) in Delhi, Rajasekhar and Venkadesha (2008) in Bangalore, Goyal (2005) in Haridwar, Kumudanathan (1983) in Hyderabad).

The studies on birds along urban-rural gradient are rare in India. Dhanya (2011) studied the ecology of House sparrow along an urban to rural gradient of the Coimbatore city, Tamil Nadu. (Menon et al., 2014) conducted bird distribution studies along a rural to urban gradient in Thiruchirapally, Tamil Nadu. Several studies have attempted to describe bird community patterns in urban areas (Chace and Walsh, 2006). However, the mechanisms underlying the community patterns are not properly addressed (Shochat et al., 2006). The present work studied community patterns and explored the underlying mechanism by taking birds as a model organism. Birds (Class: Aves) were chosen considering the presence of large number of species in the urban habitat. Class Aves is also one of the diverse taxa in terms of life-history traits. The objective of the present study was to 1) find suitable urbanization gradient for ecological study in Coimbatore, 2) explore the bird community structure and distribution along the urbanization gradient and 3) understand the strategies adopted by bird species to survive in urban areas.

Community pattern along an urbanization gradient is the basis for conservation of wild life, commons and natural vegetation in urban areas. Urban space offers potential site to study survival strategies in a changing landscape. Urbanization gradient provide a series of finer scales of changes in urbanization that could be well utilised for such studies. The focus of this introductory study was to see how species composition changed across the gradient of urbanization in Coimbatore city, interpreting the results on the basis their life-history traits. In order to get a clear picture of how certain species survive in resource limited urban area, their essential activities in urban area was examined based on certain hypothesis.

1.2 STRUCTURE OF THE THESIS

The thesis is divided into five chapters, including the General Introduction. A consolidated summary is given before Chapter 1. The Chapter 1, 'General Introduction' explains the background, significance, objectives and major findings and outcome of the study. This chapter briefs about urbanization and its consequences, its effect on biota and current works on avifauna of the urban areas. An abstract, brief introduction, detailed method, results and discussion is given under each technical chapter. The second chapter briefs about the study area and explains the methods that tested to explore a gradient of urbanization in the Coimbatore city. In this chapter, the distribution of land-use land-cover of the study areas is given. The third chapter looks at the factors underlying the distribution of bird species along an urban to rural gradient of the Coimbatore city. The species richness, density, turnover rate and the factors associated with the distribution are discussed. In the fourth chapter, the life-history traits and strategy adopted by different bird species in urban areas were analysed. Fifth chapter is General Conclusion where the relevance of the findings of the present study and suggestions for future research are discussed. References and appendices sections are given at the end.

CHAPTER 2

FINDING A GRADIENT OF URBANIZATION IN THE COIMBATORE CITY, INDIA

2.1 ABSTRACT

Studies along an urbanization gradient are expected help solving many puzzles in ecological studies. This study was conceived to identify a suitable gradient of urbanization in the Coimbatore city to conduct bird distribution studies. Taking consideration of previous studies, two methods were applied to find a gradient of urbanization; a) a gradient based on linear distance from the city centre and b) a gradient based on land use land cover types (LULC) / landscape metrics in the urban-rural landscape continuum. The result show that urbanization in the Coimbatore city did not follow urban-rural distance gradient, whereas a gradient based on landscape metrics, arranged according to low-high intensity of urbanization was found to be a better 'fit' as a 'gradient'. This gradient was a measure of landscape metrics in an urban-rural landscape in association with physical variables

2.2 INTRODUCTION

Environmental changes associated with increasing urbanization have been significant since the middle of the last century. Examining the impact of urbanization gives an opportunity to better understand the ecological process and address contemporary issues in environment (McDonnell and Pickett, 1990). Understanding the relationship between the spatial pattern of urbanization and ecological processes is the basis of urban ecology (Breuste et al., 1998; Loucks, 1994; Sukopp, 1998, 1990), which could be best described by studying the ecological systems along an urban to rural gradient (McDonnell et al., 1993).

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2.2 Introduction

Environmental changes associated with increasing urbanization have been significant since the middle of the last century. Examining the impact of urbanization gives an opportunity to better understand the ecological process and address contemporary issues in environment (McDonnell and Pickett, 1990). Understanding the relationship between the spatial pattern of urbanization and ecological processes is the basis of urban ecology (Breuste et al., 1998; Loucks, 1994; Sukopp, 1998, 1990), which could be best described by studying the ecological systems along an urban to rural gradient (McDonnell et al., 1993).

An urban-rural gradient presents a gradient of urbanization / human activities inherent in the process of urbanization, where at one end urbanization is at its maximum intensity (i.e., city) in the local context and at the other end urbanization is at the minimal level (i.e., rural / village). Using an approach based on the gradient of change, the spatial heterogeneity in the urban landscape is compared to that in relatively more gradual ecotone in environments with minimal human activity. Urban to rural gradients are applied widely in ecology that span from microbial ecology to watershed management. Recent studies show its application in studying vegetation (McDonnell et al., 1997; Medley et al., 1995), bird diversity (Blair, 1999; Clergeau et al., 1998) and watershed integrity (Harding et al., 1999).

Two approaches have been used in the gradient studies; i) distance from the city centre and ii) land use types / landscape metrics along urban-rural landscape. The assumption of distance gradient analysis is that exposure to urban disturbance changes predictably with distance from the urban core. Whereas in the latter approach, one quantifies the range of land use type / habitat observed while travelling from rural area to a city, where the city is the ultimate form of urbanization. However, overview of the city morphology (the type of city and growth pattern) is inevitable in choosing the right gradient. An over simplification without considering the variations in the urban development growth patterns (planned or unplanned), could cause gradient analysis to fail to satisfactorily reflect the distribution or change in the natural components such as undomesticated animals.

The morphology and evolution of cities have been extensively studied by geographers, economists, and social scientists for centuries (von Thünen (1825) and Burgess (1925), Hoyt (1939), Harris and Ullman (1945), Lösch (1954) and Christaller, (1966). Three classic theories of urban morphology are a) the concentric zone theory - urban pattern as concentric rings of different land use types with a central business district in the middle, (Burgess (1925), b) the sector theory - concentric zone pattern modified by transportation networks (Hoyt (1939), and c) the multiple nuclei theory - patchy urban pattern formed by multiple centres of specialized land use activities. Predominantly the first two are seen in situation where in a city has developed with some semblance of planning, while the third one largely would have formed under the process of natural expansion.

There are some recent notable studies that tried to find and identify a gradient in urban to rural landscape and quantify the changes. Luck and Wu, (2002) studied the landscape pattern dynamics along an urban-rural gradient with the help of gradient analysis using landscape metrics for the Phoenix metropolitan area (Arizona, USA). Hahs and McDonnell, (2006) quantified an urban-rural gradient for Melbourne city using a combination of landscape metrics, demographic and physical variables.

While such studies are very rare in developing nations, one such notable study is that of du Toit and Cilliers (2011) conducted in a South African city. The growth pattern of cities in developing nations (third world nations) stand out from the rest and remain barely explored. Dualism is the characteristics of third world cities, where one observes co-existence of extremes such as poor and rich, skilled and unskilled, traditionalism and modernism. This condition - dualism, is mainly a resultant of rapid influx of rural to urban human migration. This is also reflected in the urban geography that is explicitly reflected in the housing / built-up structure, where one can see squatter settlements (non-conventional type) or widely known as 'slum', constructed by the urban poor, in the midst of conventional buildings / apartments. The migration of people from rural areas in search of employment results in the formation of local 'bazaars' (market) – characteristics of third world cities. Hence, to sample a third world city one has to take into account all these aspects. du Toit and Cilliers (2011) following Hahs and McDonnell (2006), confirmed the effectiveness of landscape metrics in association with demographic and physical variables in quantifying urban rural gradient of Klerksdorp, a South African city.

Concurrent with the previous studies, the present study tested both linear gradient from the distance from city centre and also tested landscape metrics in association with physical variables to find an urbanization gradient. The study was conducted in Coimbatore city in the state of Tamil Nadu, India that has a recent history of spurt in development. Moreover, the span of the urban-rural gradient was spread within a distance of 13Km, which show the significance of this area for such studies. The motive of this study was to find a gradient of urbanization to study bird community pattern in Coimbatore. More specifically, this study was intended to address the following questions:

1. Which approach reflected the best gradient of urbanization in the case of Coimbatore city – distance from the city or land use type changes along the urban-rural landscape?
2. How did different land use type change across distance from the city centre?

The land use land cover distribution across the urban rural landscape was compared between the linear distance gradient from the city centre and land use land cover within the urban-rural landscape arranged according to the increasing degree of urbanization.

2.3 METHODS

The study was conducted in two steps – first a distance gradient was selected from urban core to rural area, and land use land cover details were analysed.

2.3.1 STUDY AREA

The present study was conducted in the urban to rural gradient of the Coimbatore city. The Anaikatty reserve forest is situated in the rural end of the gradient (see description in 2.3.1.3). The typical location provides an ideal urban-rural gradient that span within 13Km long and 7Km wide, with one end (west) Anaikatty reserve forest in the Western Ghats (Figure 2. 1) biodiversity hotspot, and on the other end, a major junction on the Madras-Palghat broad gauge section and the National highway (NH-47) that runs through the city centre.

2.3.1.1 THE COIMBATORE CITY

The city is the headquarters of the Coimbatore district and is the third largest city in Tamil Nadu. It has been home to a variety of industries, such as automotive and textiles, for the past several decades and has seen the emergence of new industries, like healthcare and information technology in recent decades. The investment climate in Coimbatore is ranked fourth among Indian cities by the Confederation of Indian Industry.

The Coimbatore city is situated between 10^0 57' and 11^0 North and 76^0 56' and 77^0 01' East. It has an average elevation of 442 meters above mean sea level. The extent of the city is 105.6 km^2. Of this, developed area constitutes 52% while, the rest are agricultural, unused and wastelands. Several streams that originates in the Vellingiri and Siruvani hills of the Western Ghats joins together to form the river Noyyal that flows through the Coimbatore city. About 28 wetlands present in the urban Coimbatore are fed by the river Noyyal. A large extend of the agricultural land is also irrigated by the Noyyal river system.

The climate condition is moderate and weather is uniformly salubrious owing to its proximity to the continuous stretch of hills covered with thick forests and the cool breeze blowing through the Palghat gap (35Km wide gap in the Western Ghats) during monsoon. The average maximum and minimum temperature are 39.6°C and 17.3°C. The average rainfall per annum is 494. 90mm.

The city is well connected by rail, road and air. The domestic airport in the city links with all major cities of the country. Coimbatore is the third most populated city of the state of Tamil Nadu and seventeenth most populated in India. The population has grown from 0.47 lakhs in 1911 to 9.3 lakhs by the year 2001 (Census report, 2001) with an average annual growth rate of 2.7% and an average decadal growth rate of 27.34%. The availability of power, clubbed with raw materials for textile processing, from 1935 has led to the establishment of many industries thereby resulting in a nearly 52% increase in population during 1941-1951.

2.3.1.2 THE ANAIKATTY RESERVE FOREST

Situated in the Coimbatore forest division of Tamil Nadu state, in southern India, Anaikatty reserve forest ($76^0 39'$ to $76^0 50'$E and $11^0 0'$ to $11^0 31'$N, 140Km^2) is placed at the foothills of the Nilgiri Biosphere Reserve in an altitude range of 560–1600 m A.S.L. It mainly consists of southern tropical dry mixed deciduous forest according to Champion and Seth's (1968) classification of Indian forests. This region is recognized as one of the eight 'hottest hotspots' of biological diversity in the world (Myers et al., 2000) and among the 200 globally most important ecoregions (Olson and Dinerstien, 1998). The reserve is surrounded by the Palghat Forest division of the Kerala state in the west, agricultural plains in the east, Palghat gap in the south and Sathyamangalam and Nilgiri Forest Divisions in the north. The climate of the area is semi-arid as it is located in the rain shadow region of the Western Ghats. However, for the Western Ghats Coimbatore is characterised by seasonal streams and waterfalls. The region falls in the watershed of the River Bhavani. The average rainfall was 668 mm per year and maximum temperature varied from 29 to 37^0C for a period of 1996–2006 (Nirmala 2013).

From Anaikatty forests, 194 species of birds belonging to 45 families and 17 orders were identified. Passeriformes are 55% of the birds, of which 36 species of bird species falls under the family Muscicapidae. Anaikatty hills is significant with 6 endemic species to Western Ghats, and 2 species endemic to Peninsular India, also 6 least concerned, 3 near threatened and one vulnerable species.

2.3.1.3 HISTORICAL REFERENCE

Historical reference dates back to 1200 AD. Earlier ruled by Chera dynasty, the city developed as a strategic town during the reign of Nayakas of Madurai. The Mysore ruler Tipu Sultan conceded the town to British colonialists in 1799, who subsequently promoted Coimbatore as military transit town between Palghat in the west and Gazal Hatty in the north. Towards 1879, the city has started to emerge as an administrative and industrial town on its own merit. In the year 1866, Coimbatore was constituted as the Municipal Town with an area of 10.88 sq. Km., and in the same year, the Madras - Podanur rail link passing through Erode was opened, improving connectivity to the region.

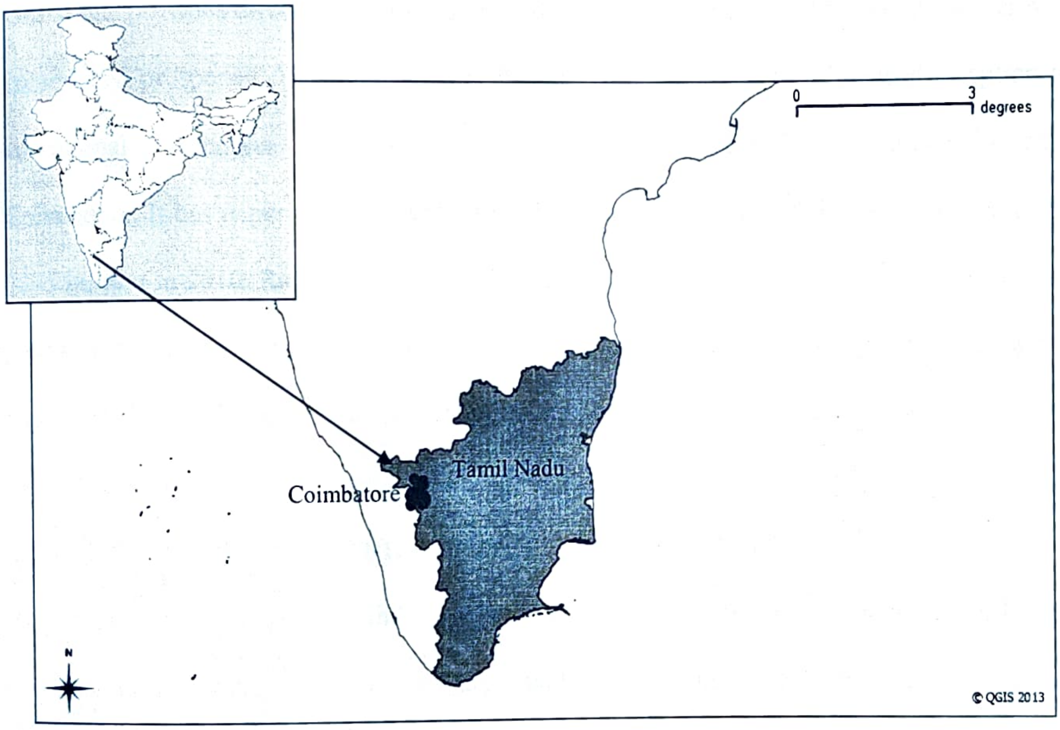


FIGURE 2. 1 MAP SHOWING LOCATION OF THE STUDY AREA
The India map is given in the inset (not to scale) pointing Coimbatore in Tamil Nadu. The sampling location in Coimbatore is given as black points.

The Coimbatore City and its environs have been rapidly burgeoning since 1932, after electric power from the Pykara hydroelectric power station became available to Coimbatore. Successful cotton crops, blooming in the characteristic black cotton soil, provided primary drive for flourishing textile industry. Consequent, cotton ginning, spinning and textiles mills are the backbone of the industrial growth of Coimbatore. The boom in textile industry flagged way for emergence of a number of auxiliary and allied industries, subsequently converting the city into a major industrial hub in south India. The Coimbatore Corporation was upgraded from special grade municipality to corporation in the year 1981, expanding the area to 105.60sq.kms. The Coimbatore city is located at a distance of

500km from Madras. It witnessed rapid industrial development beginning in 1960s. Geographical position of the city (located in the immediate eastern side of the Palghat gap across the Western Ghats) that provides direct access for traders from west coast (Harriss et al., 1990) further boosted its commercial prosperity. The rapid growth in industry and commerce influenced inception of many educational institutions, especially engineering and technical training institutes in and around Coimbatore. It has experienced growth in the healthcare industry, which was estimated to be worth $375 million in 2010. Rapid urbanization in the main city caused the development of many smaller towns like Tirupur, Sathyamangalam and Karur around it. Increasingly, even villages around Coimbatore are taking on urban characteristics similar to many other areas in India.

2.3.2 SELECTING THE GRADIENT, STUDY LOCATIONS AND SAMPLING

The motive of the study is to find a gradient of urbanization intensity to conduct bird distribution studies. As majority of studies revealed that distance not necessarily reflect a gradient of urbanization intensity, the present study also considered land use land cover (LULC) details, as a parallel method to find the gradient of urbanization intensity. Therefore, this study was carried out at two levels i) along the urban-rural gradient on a distance scale from urban core and ii) land use land cover type in the urban to rural land scape of Coimbatore city.

2.3.2.1 METHOD 1. URBANIZATION GRADIENT BASED ON LAND USE TYPE DISTRIBUTION ALONG THE DISTANCE GRADIENT FROM THE CITY CENTRE

To conduct the study along the urban to rural gradient, study plot was chosen in such a way, so as to test the assumption of linear gradient that urbanization intensity decreases with increasing distance from the urban core. The centre of the city was identified as town hall, which once used to be the centre of urbanization. Anaikatty reserve forest, it was regarded as rural area that fell around 13 Km away from the city centre.

In order to demarcate the study area along the urban-rural gradient, a grid was placed along the urban-rural stretch of the Coimbatore city. The city centre was considered as distance '0'. The 13Km stretch from the city centre to the rural end was conveniently divided into five vertical distance classes at intervals of 2.8Km. In order, to consider the horizontal spread of the city, 3.6Km width was taken towards either side of the city centre. It was divided into two equal horizontal distance classes at 1.8 Km interval. The vertical distance classification were 0-2.6, 2.6-5.2, 5.2-7.8, 7.8-10.4, 10.4-13 (Km) and horizontal classification were 0-1.8, 1.8-3.6 (Km) forming 18 grids of 2.6Kmx1.8Km, covering an area of 84.24Km^2 in total. Thence, the area demarcated consisted of 10 distance classification (Table 2.1, Figure 2.2). The grids were numbered starting from right hand side of urban end as 1 to 18 in sequence for convenience. It has 5 rows of which first four rows contain four grids and last row contain only two (as rest of the area in that row was forest) and four columns. The four columns, running along stretch the urban-rural. The distance classification of study area selected along urban to rural gradient of the Coimbatore city gradient consisted of four transects that fell within two distance gradients (Table 2.1). The land use types were quantified in each transects and compared based on the distance from the city centre.

TABLE 2.1 THE DISTANCE CLASSIFICATION OF THE STUDY AREA SELECTED ALONG URBAN TO RURAL GRADIENT OF THE COIMBATORE CITY

	Distance class		Grid No. in respective transects			
	Horizontal (Km)	Verical (Km)				
Distance Gradient 1	0-1.8	0-2.6	Transect 2	2	Transect 3	3
		2.6-5.2		6		7
		5.2-7.8		10		11
		7.8-10.4		14		15
		10.4-13		18		--
Distance Gradient 2	1.8-3.6	0-2.6	Transect 1	1	Transect 4	4
		2.6-5.2		5		8
		5.2-7.8		9		12
		7.8-10.4		13		16
		10.4-13		17		--

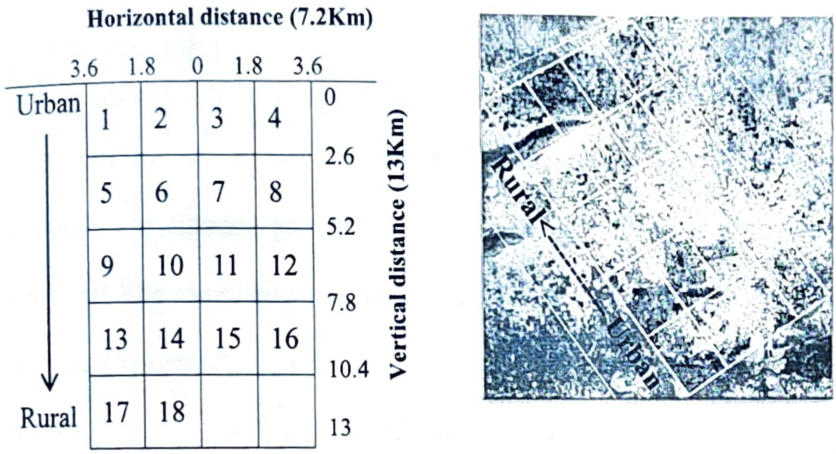


FIGURE 2. 2 SAMPLING ALONG AN URBAN-RURAL LANDSCAPE

Eighteen grids were laid along urban to rural landscape with horizontal (top) and vertical (right hand side) distance specified. The distances are given in Kilometre.

Quantification of land use

Using satellite imageries, major land uses were identified along the rural-urban gradient and adjacent places of the Coimbatore city such as Wetland, OA (open ground / bushes / dispersed trees), Tree cover and Built-up areas. Built-up areas were further divided as MTHDBA, LTHDBA, HTHDBA, LTMDBA, MTMDBA, HDMTBA, VLDBA, LTLDBA, MTLDBA, HTLDBA (where the letters H, M, L = High, Medium, Low; T=Tree, D=dense, BA=Building area, V=very). This classification was based on qualitative (visual) estimation of the density of buildings, open ground / bushes / dispersed trees, and tree cover within the built-up area. This was also supplemented with the aid of satellite imageries (uploaded during 2011) freely available at Google earth software version 4.2. However, for the purpose of bird surveys, the land use type such as LTLDBA and LTLDBA were clubbed to form land use type called Village, and HTLDBA was called Rural.

To find the area, land uses were digitized with the aid of the satellite imageries available in the Google Earth open access software and saved as KML files. These KML files were then uploaded into the open access software GE Path (ver. 1.4.1.) to get the area under each land use.

2.3.2.2 METHOD 2. SAMPLING BASED ON LAND USE LAND COVER IN URBAN TO RURAL LANDSCAPE OF THE COIMBATORE CITY

The hypothesis of the study was that the urban rural gradient of cities in developing countries might not follow a distance gradient. In such case, land use could be used as a measure of gradient selection. The sampling was extended beyond the span of urban-rural distance gradient to conduct this study (Figure 2. 3). The motive behind this sampling was to cover more area within the span of the Coimbatore city and its rural areas. As a preliminary step, the area sampled was initially identified based on qualitative land use / land cover as described in method (1). Further, samples of 75mx75m plots were laid to describe land use at a finer scale (Table 2.2). The land-uses were type of built-up area (tiled / terraced / multi-storied), tree canopy cover, open ground/bushes/dispersed trees / agricultural (as majority agriculture was seasonal in Coimbatore), wetland and road (tarred / un-tarred). However, for detailed analysis, building types were reduced to TBL and PBL, and tarred and un-tarred road were merged to Road. The method used to quantify land uses were same as that of method 1 using open access software Google Earth to digitise the extent of the land use, save the KML file and then find its area using GE path. The method was repeated in each quadrat.

TABLE 2.2 AREA OF LAND USE TYPES SAMPLED

Land use type	No. of plots	Area sampled (m^2)
Rural	6	30807.4
Village	25	129985.69
VLDBA	16	80334.76
HTMDBA	3	15071.07
MTMDBA	38	191135.16
LTMDBA	20	100907.22
HTHDBA	6	30160.86
MTHDBA	32	160640.9
LTHDBA	20	100433.58
Total	166	839476.64

2.3.3 DATA ANALYSIS

Method 1. The area of land use types were plotted in a pie diagram as percentage cover LULC types across the urban rural landscape. The quantified land use types in each transect was tabulated and compared.

Method 2. The areas of LULC/physical variables collected using 75m x 75m (0.56Ha) size plots. Such 166 random plots were laid in the study area. All the point counts in one land use type/habitat was pooled together and the value of LULC was projected as density/unit area (m^2). The density was calculated following the equation given below.

$$Density = Area\ under\ the\ specific\ land\ use\ \div Total\ area\ sampled$$

Then, linear regression of the trend of LULC variables across urban-rural gradient was done. After finding the correlation between habitat variables, auto-correlated variables were removed before carrying out stepwise regression. Stepwise regression was done to find the significant LULC variable across the urban-rural gradient. Cluster analysis was done to find similarity between the land use types. It was complimented by multi-dimensional analysis (*MDS* -Proxcal) plot that gives the dimensions of variation. In order to get a gradient of urbanization, *MDS* -Proxcal analysis was carried out based on the significant LULC variable (results of stepwise regression), where land use types were re-arranged according to the intensity of the significant LULC variable. To support this, an excel graph showing the simple linear regression results of natural area and artificial area along the re-arranged urbanization gradient was plotted. All analysis were done using SPSS version 16.0 and MS Excel version 10.00.

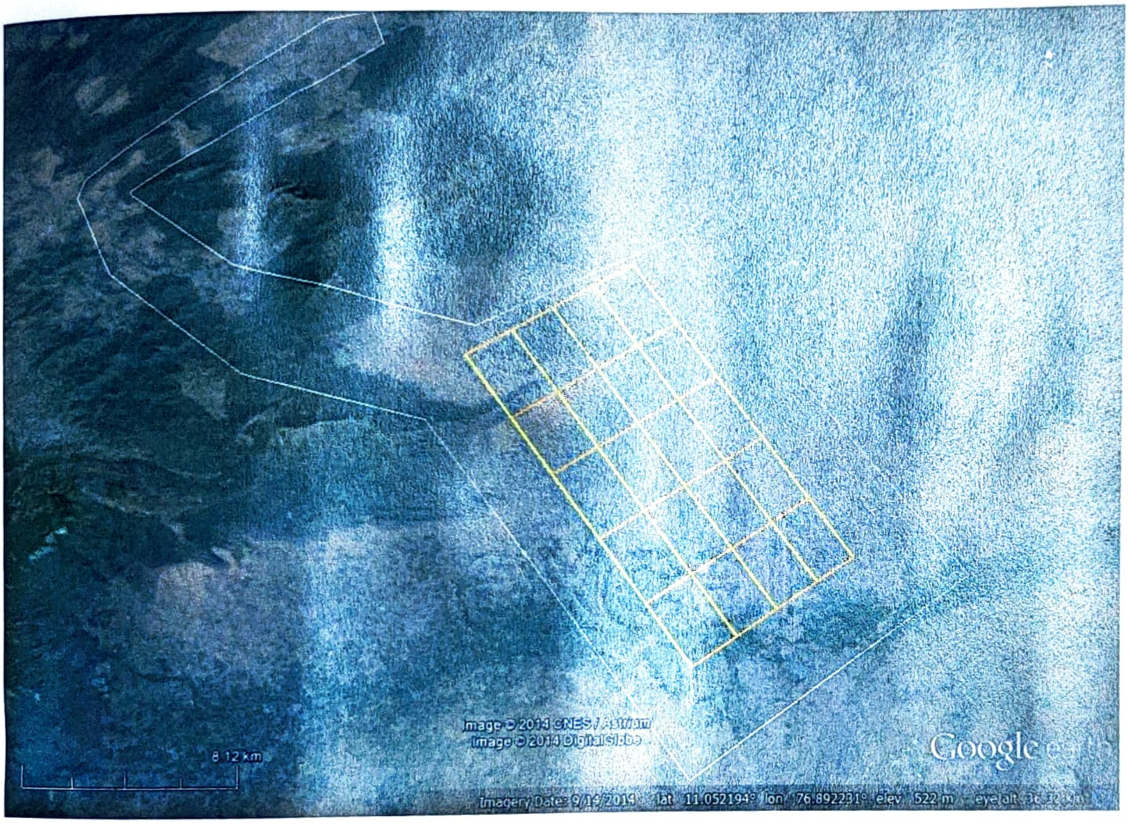


FIGURE 2. 3 SAMPLING AREA IN COIMBATORE CITY TO RURAL LANDSCAPE

The border drawn, inclusive of the grid were selected for sampling land use land cover variables.

2.4 Results

The result of the work done to find a gradient of urbanization levels in the Coimbatore city are presented here. The study was conducted at two levels - 1) Urban-rural gradient and 2) Land use type.

2.4.1 Identification of LULC types

In the study area, nine habitat types were identified along rural-urban landscape based on the building density and tree canopy cover such as Rural, Village, VLDBA, HTMDBA, MTMDBA, LTMDBA, HTHDBA, MTHDBA and LTHDBA (Figure 2.4, Figure 2.5).

Low-density built-up areas:

Rural area was located in the forest fringes with dispersed tribal hamlets, temples or institute campus. It was hence characterised by large proportion of Tree (0.74$\pm$0.36) and least proportions of OA (0.19$\pm$0.31) and built-up structures (TBL, 0.17$\pm$0.04).

Village comprise of a commercial centre that coexist with residential areas, and in general has a temple. Adjacent to it follows agricultural areas / brick industries. The result of this study show that in village, 46% area was occupied by OA (0.46$\pm$0.18), followed by 28% Tree (0.28$\pm$ 0.14, df=25), and 20% built-up areas such as Road, TBL and PBL (5%, 7% and 8% respectively). Wet (0.02$\pm$0.06) occupied very small proportion of the general village space.

Not farther from village, but not comparable to rural, VLDBA stands out as a distinct land use. It comprised of mainly residential areas dispersed in open vegetation. VLDBA had higher proportion of land under open areas with bushes and dispersed trees (OA) (44%, 0.44$\pm$0.19), followed by 27% of Tree (0.28$\pm$0.14, df=25), and 26% of built-up areas such as Road, TBL and PBL (5%, 8% and 13% respectively). Wet (0.004$\pm$0.01) occupied very small proportion.

Medium-density built-up areas:

In the case of MTMDBA, OA (0.27$\pm$ 0.21) considerably reduced whereas buildings increased to 35%, retaining Tree (0.25$\pm$ 0.12). Wetland was absent.

In LTMDBA the areas under Tree (0.13$\pm$ 0.06) reduced to almost half the area compared to previous habitats, whereas building area was high upto to 43% from 35% in the former types. However, land under OA (0.24$\pm$ 0.21) retained. Roads (Tarred, 0.13$\pm$ 0.12 and un-tarred, 0.04$\pm$ 0.04) showed slight increase than previous habitat.

High-density built-up areas:

In MTHDBA, OA (0.06± 0.09) significantly lower than the previous habitats. However, the land under Tree (0.20± 0.14) increased; the area under buildings also increased slightly (48%). Road increased to 18%. Wet was present in least proportion.

In LTHDBA the area under Tree reduced to half that of that in MTHDBA, Road and buildings showed slight increase from MTHDBA. Multi-storeyed buildings were present in least proportions and also limited to very few sites (15%, p=.003). Wetland was present in least proportions.

HTHDBA is actually a small patch in the high-density built-up area. In HTHDBA, Trees and OA was high, with considerable decrease in the proportion of buildings. However, multi-storey buildings showed increase (4%). This is a well-planned area of the city with parks, racecourses and affluent residential areas.

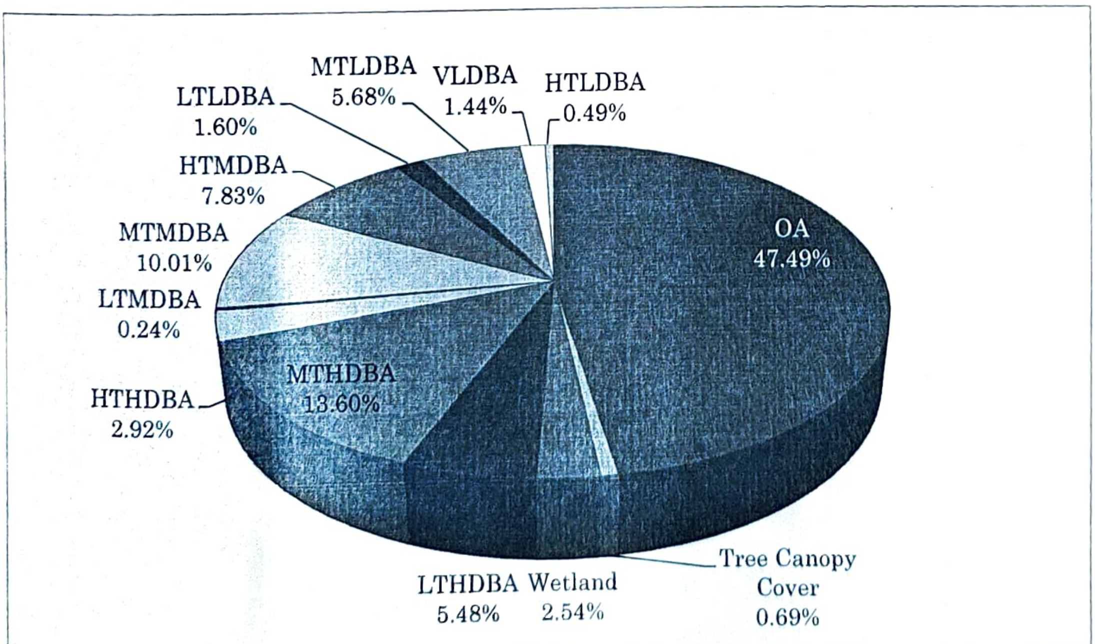


FIGURE 2. 4 LAND USE LAND COVER IN THE URBAN TO RURAL LANDSCAPE OF COIMBATORE CITY

The data presented here is the quantification of the demarcated area (13Km x 7Km) along urban to rural gradient of the Coimbatore city. The figure represents proportion of different land-use types seen along the gradient.

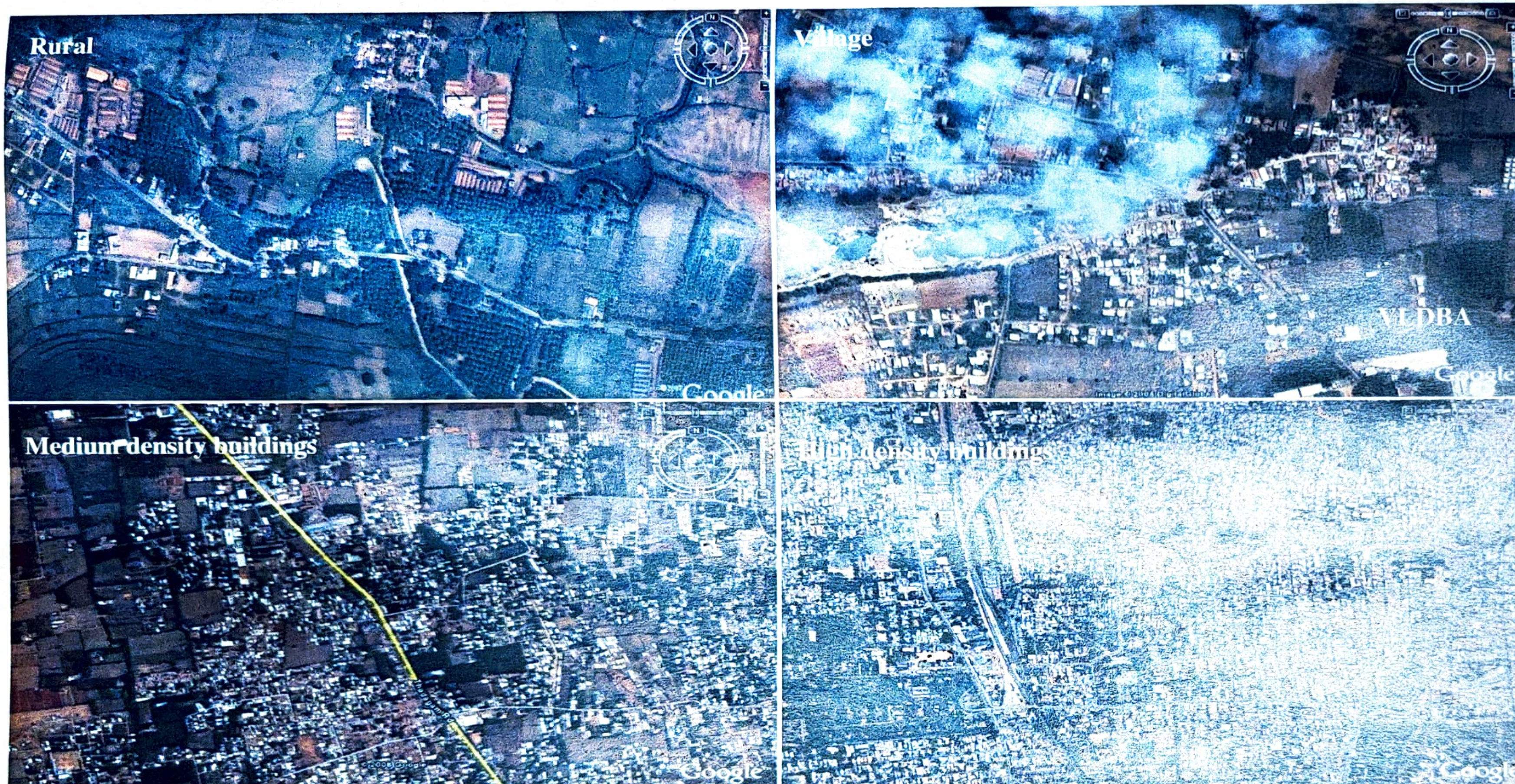


FIGURE 2.1LAND USE LAND COVER TYPES ACROSS RURAL TO URBAN LANDSCAPE OF THE COIMBATORE CITY
Abbrev. VLDBA – area under very low density building

TABLE 2.3 DISTRIBUTION OF LAND USE TYPE WITH THE DISTANCE FROM THE CITY CENTRE OF COIMBATORE

Four transects were laid across urban to rural gradient, incorporating both horizontal and vertical distance. The land use distribution within these fixed distance frames were studied and depicted here. The colour and number in the cells indicate the density (m^2) of land use land cover.

Grid No.	T	Wet	OA	HTLDBA	MTLDBA	LTLDBA	VLDBA	HTMDBA	MTMDBA	LTMDBA	HTHDBA	MTHDBA	LTHDBA
Transect 1													
1	0.00	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.24
9	0.00	0.01	0.17	0.00	0.00	0.00	0.00	0.17	0.64	0.00	0.00	0.01	0.00
13	0.00	0.00	0.57	0.00	0.00	0.05	0.01	0.01	0.23	0.05	0.03	0.00	0.05
17	0.00	0.00	0.73	0.00	0.19	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
Transect 2													
2	0.02	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.40
6	0.04	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.93	0.01
10	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.13	0.00	0.07
14	0.00	0.00	0.74	0.00	0.02	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	0.00	0.00	0.97	0.00	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Transect 3													
3	0.13	0.26	0.18	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	0.11
7	0.00	0.09	0.40	0.00	0.00	0.00	0.20	0.00	0.12	0.00	0.00	0.10	0.09
11	0.00	0.00	0.00	0.04	0.52	0.00	0.00	0.21	0.10	0.00	0.00	0.01	0.11
15	0.00	0.00	0.90	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Transect 4													
4	0.00	0.01	0.76	0.00	0.00	0.00	0.01	0.00	0.23	0.00	0.00	0.00	0.00
8	0.00	0.12	0.60	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.03	0.04
12	0.00	0.00	0.39	0.03	0.00	0.00	0.00	0.50	0.04	0.00	0.00	0.00	0.03
16	0.00	0.00	0.90	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Abbrev. LTHDBA=high-density building with low-density tree cover, MTHDBA= high-density building with medium-density tree cover, HTHDBA= high-density building with high-density tree cover; HTMDBA= Medium-density building with high-density tree cover, MTMDBA= Medium-density building with medium-density tree cover, LTMDBA= Low-density building with low-density tree cover; VLDBA= area with very less density of buildings, T= Tree canopy cover, OA= open area with scrub/dispersed tree/agriculture, Wet= Wetland

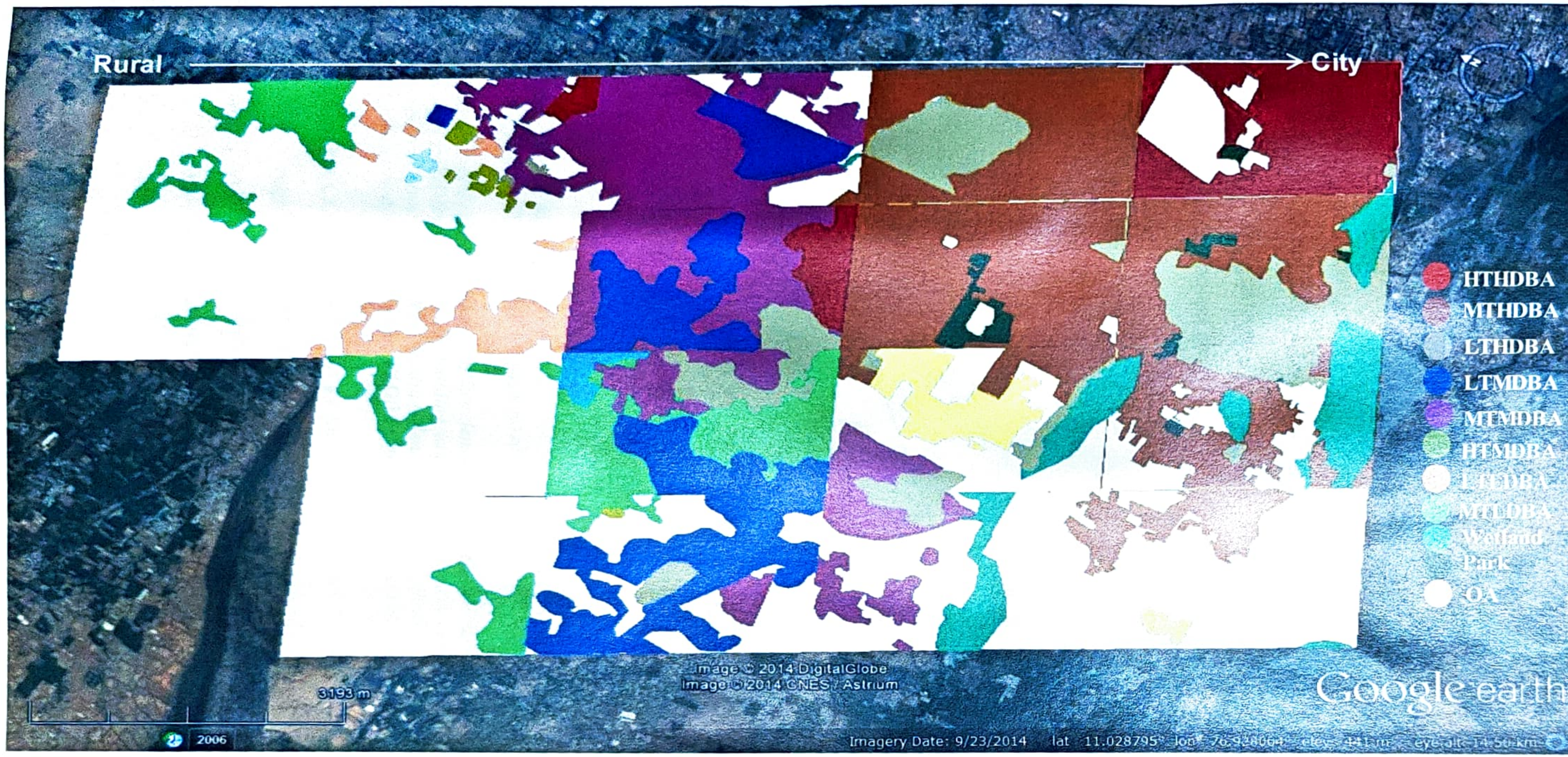


FIGURE 2. 6 THE DISTRIBUTION OF LAND USE TYPES ALONG DISTANCE GRADIENT OF THE COIMBATORE CITY

Abbrev. LTHDBA=high-density building with low-density tree cover, MTHDBA= high-density building with medium-density tree cover, HTHDBA= high-density building with high-density tree cover; HTMDBA= Medium-density building with high-density tree cover, MTMDBA= Medium-density building with medium-density tree cover, LTMDBA= Low-density building with low-density tree cover; VLDBA= area with very less density of buildings, T= Tree canopy cover, OA= open area with scrub/dispersed tree/agriculture, Wet= Wetland

2.4.2 URBANIZATION GRADIENT BASED ON LAND USE TYPE

The land use types were arranged in an ascending order of urbanization intensity (density of artificial area/built-up structures, Figure 2.7). The land use type that showed lower artificial area in the gradient (Figure 2.7) such as HTMDBA and HTHDBA compared to village and VLDBA was not re-arranged, considering distance from the city and presence of terraced / plastered buildings. OA did not showed a linear (R^2=0.34) decrease as the gradient progressed, even though not highly significant. Hence, this was gradient was chosen as it represented all LULC variables, which could be a better choice for an ecological study.

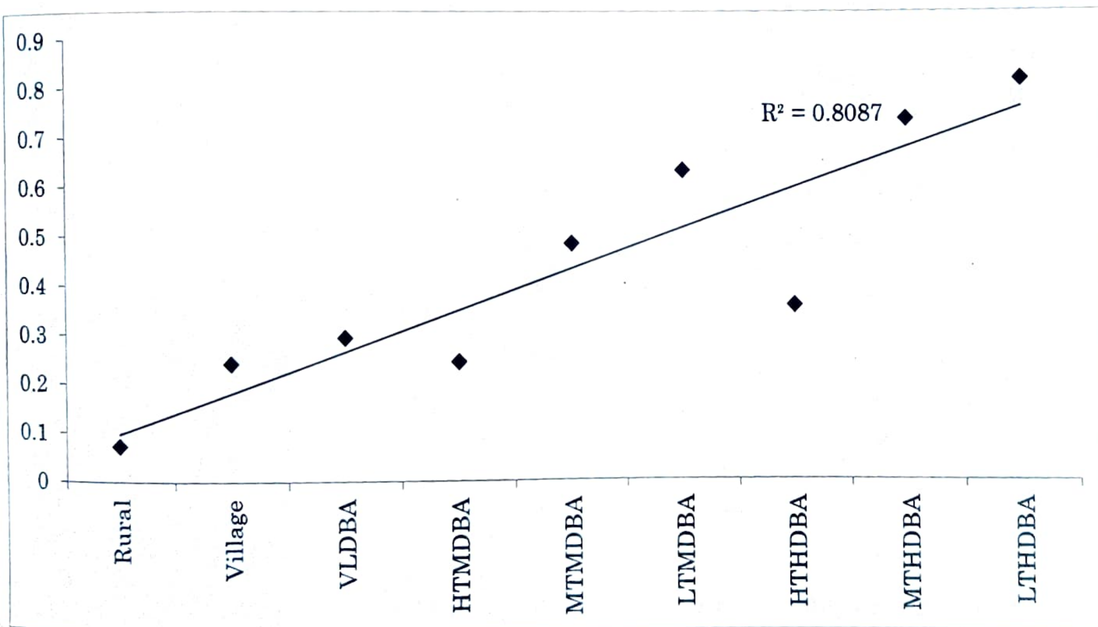


FIGURE 2.7 GRADIENT ALIGNED IN ACCORDANCE TO THE PROPORTION OF ARTIFICIAL AREA WITHIN THE LAND USE TYPES SEEN IN THE URBAN-RURAL LANDSCAPE OF COIMBATORE CITY

Abbrev. LTHDBA=high-density building with low-density tree cover, MTHDBA= high-density building with medium-density tree cover, HTHDBA= high-density building with high-density tree cover; HTMDBA= Medium-density building with high-density tree cover, MTMDBA= Medium-density building with medium-density tree cover, LTMDBA= Low-density building with low-density tree cover; VLDBA= area with very less density of buildings

2.4.2.1 TREND OF LAND USE TYPE ACROSS THE GRADIENT

The simple linear regression done on the density of land-use land-cover (LULC) variables of nine land use / habitat types revealed following results (Figure 2.8). The land cover under built-up areas such as PBL (R^2=0.84) and Road (R^2=0.61, df=8) increased towards higher urban grades. Natural areas under Tree canopy cover (T, R^2=0.39, df=8) and OA (R^2 =0.34, df=8) significantly declined with urbanization intensity. TBL and Wetland did not show a significant trend. Tree canopy cover

(T) negatively correlated to built-up structures such as Road, TBL and PBL. Road was correlated to PBL, and OA and Wet did not show correlation with any variables (Table 2.3). The step-wise regression analysis with land use type as dependant variable shows PBL as the significant LULC variable along the urbanization gradient (Table 2.4).

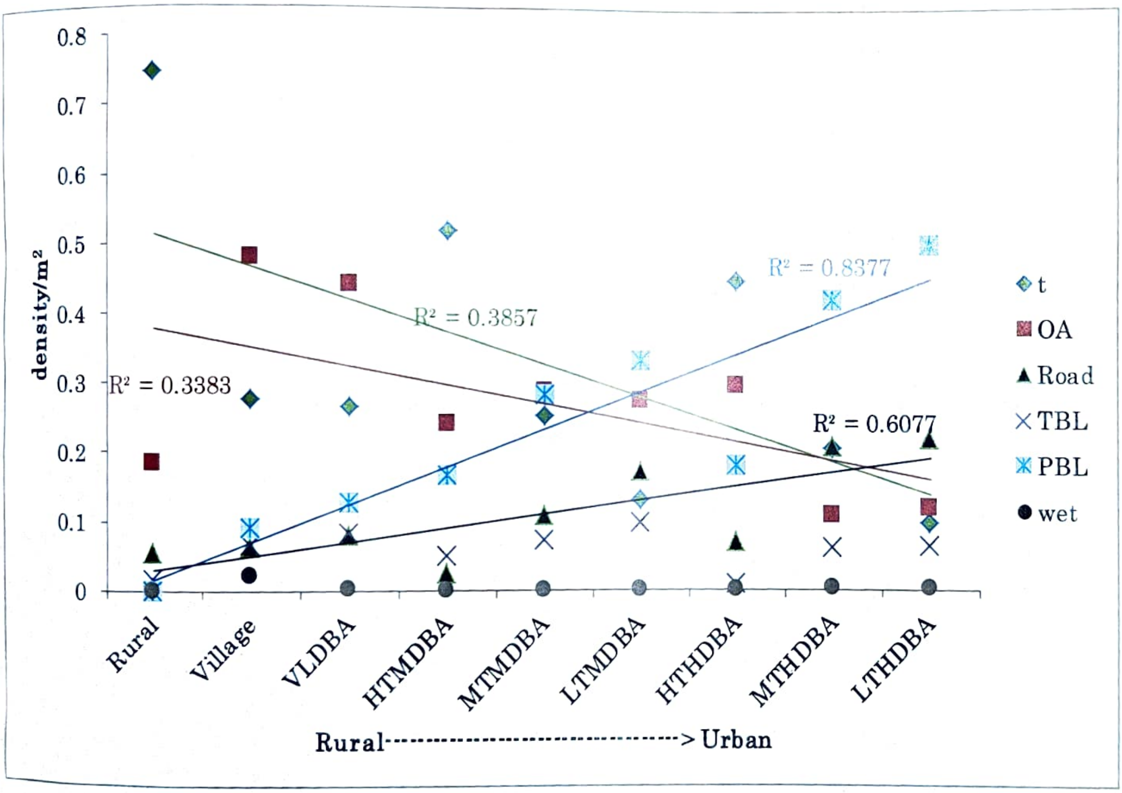


FIGURE 2.8 TREND OF LAND USE LAND COVER VARIABLES A LONG AN URBANIZATION GRADIENT OF THE COIMBATORE CITY

The areas under more natural land use decreased with urbanization. Whereas, the urban land use such as roads and buildings increased with urbanization intensity.

Abbrev. LULC variables: PBL=Plastered building, TBL=Tiled Building, OA=Open areas with scrub/dispersed tree/agriculture, Wet=Wetland, T=Tree canopy cover; LTHDBA=high density building with low tree cover, MTHDBA= high density building with medium tree cover, HTHDBA= high density building with high tree cover; HTMDBA= Medium density building with high tree cover, MTMDBA= Medium density building with medium tree cover, L TMDBA= Medium density building with low tree cover; VLDBA= area with very less density of buildings.

TABLE 2.4 THE CORRELATION OF LAND USE LAND COVER (LULC) VARIABLES IN URBAN RURAL LANDSCAPE OF THE COIMBATORE CITY

The density of LULC variables were used for the analysis.

df=8	t	OA	Wet	Road	TBL	PBL
T	1	-0.02, p=0.96	-0.16, p=0.69	-0.75*, p=0.02	-0.77*, p=0.02	-0.78*, p=0.01
OA	-0.02, p=0.96	1	0.65, p=0.06	-0.57, p=0.11	0.26, p=0.502	-0.60, p=0.091
Wet	-0.16, p=0.69	0.65, p=0.06	1	-0.21, p=0.56	0.20, p=0.61	-0.31, p=0.42
Road	-0.75*, p=0.02	-0.57, p=0.11	-0.21, p=0.59	1	0.41, p=0.28	0.91**, p=0.00
TBL	-0.77*, p=0.02	0.26, p=0.50	0.20, p=0.61	0.41, p=0.28	1	0.399
PBL	-0.78*, p=0.01	-0.60, p=0.09	-0.31, p=0.42	0.91**, p=0.00	0.40, p=0.29	1

Significance level (p) is given next to the correlation value, separated by comma.

* Correlation is significant at the 0.01 level (2-tailed)

** Correlation is significant at the 0.05 level (2-tailed)

Abbrev. LULC variables: PBL=Plastered building, TBL=Tiled Building, OA=Open areas with scrub/dispersed tree/agriculture, Wet=Wetland, T=Tree canopy cover

TABLE 2.5 STEPWISE REGRESSION OF LAND USE LAND COVER (LULC) VARIABLES IN THE URBANIZATION GRADIENT SELECTED IN THE COIMBATORE CITY

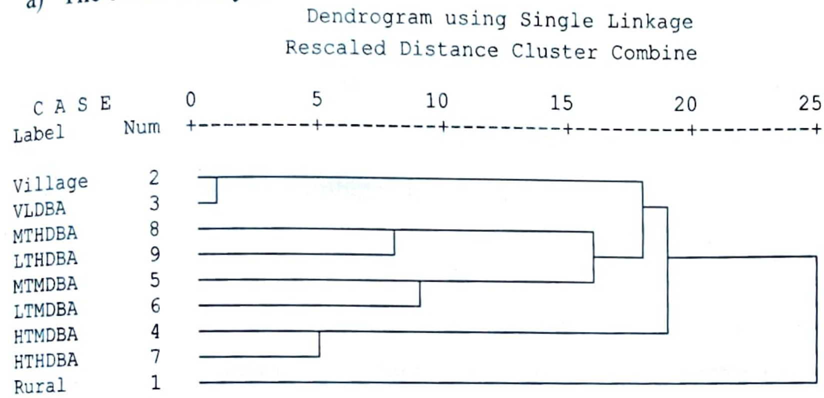
Model	Variable	df	Std.Error of estimate	R^2	F	Sig.
1	PBL	8	0.47	0.97	264.38	0.000

Abbrev. PBL=Plastered building, OA=Open areas with scrub/dispersed tree/agriculture

2.4.3 Similarity of land use types

The land use types did vary in the urbanization levels with respect to land cover land use (LULC) details, than distance from the urban centre. In the MDS plot, each habitat is assigned a value based on LULC variables. Hence, the sites, which had high tree canopy cover such as HTMDBA and HTHDBA were clubbed together, irrespective to the proximity to urban centre. Rural area was placed far apart considering the amount of trees and low level of urbanization. The land use type with high tree cover such as HTMDBA and HTHDBA were clustered very close. Land use types such as MTMDBA and LTMDBA, and MTHDBA and LTHDBA were clustered based on the building density. The land use types with high density of buildings had more tree canopy cover than that of other land uses of medium density (MTHDBA, LTMDBA) and low density buildings (Village, VLDBA). Village and VLDBA were similar based on the low level of buildings and trees; these land use types had relatively more open space (Figure 2.9).

a) The cluster analysis



b) The MDS PROXAL plot

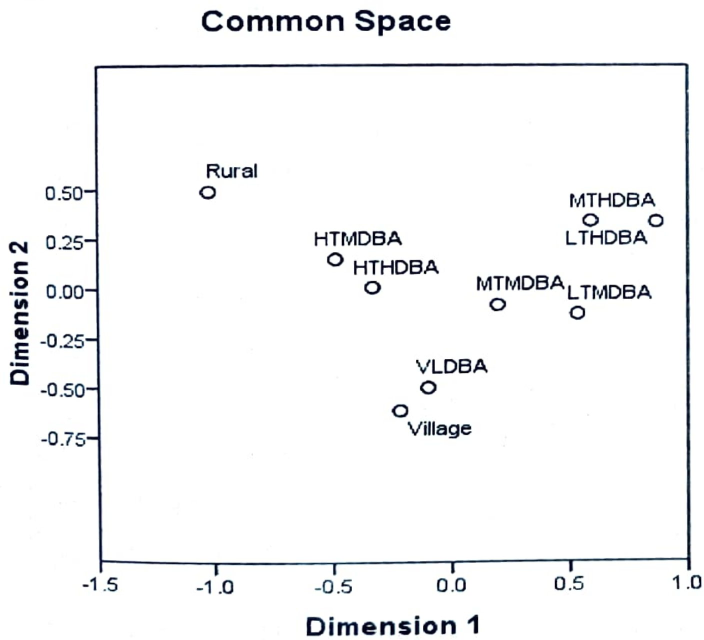


FIGURE 2.9 SIMILARITY OF LAND USE TYPE SEEN ALONG THE URBAN RURAL GRADIENT

Similarity of land use types based on the density of land use land cover variables was found by a) cluster analysis and b) MDS PROXAL plot, for more visual clarity. The first dimension of the MDS plot represents variables related to urbanization activities such as building. The second dimension mainly represents tree canopy cover. The land use type with high tree cover such as HTMDBA and HTHDBA were clustered very close. Land use types such as MTMDBA & LTMDBA and MTHDBA & LTHDBA were clustered based on the building density. Village and VLDBA were similar based on the low level of buildings and trees; these land use types had more open space. Rural area was placed far apart considering the amount of trees and low level of urbanization.

Abbrev. LTHDBA=high-density building with low-density tree cover, MTHDBA= high-density building with medium-density tree cover, HTHDBA= high-density building with high-density tree cover; HTMDBA= Medium-density building with high-density tree cover, MTMDBA= Medium-density building with medium-density tree cover, LTMDBA= Low-density building with low-density tree cover; VLDBA= area with very less density of buildings

2.5 DISCUSSION

The study found that in the Coimbatore city, distance from urban centre to rural area was not applicable to identify an urbanization gradient, whereas land use type approach was more suitable. The land use type was not distributed evenly across the distance gradient. Buildings and roads were the predictive factor across the urbanization gradient based on land use types.

I tested both linear and land use type based approach to get an urbanization gradient. The linear approach looks at the urbanization along distance from the city centre. However, upon analysing the results I found that it was not applicable in the case of Coimbatore city. The result was not surprising and agreed with the findings of (e.g., Medley et al. 1995; McDonnell et al. 1997). In the land use type approach I considered land use types (habitats) classified along the urban rural landscape, with physical / LULC variables present in each land use types. This method was after du Toit and Cilliers (2011), and Hahs and McDonnell (2006) found that including physical variable along with landscape matrices were effective in finding urbanization gradient.

The classification of the land use types were based on two aspects – (1) density and type of building such as city (HD), suburb (MD) and rural (LD) and (2) the qualitative proportion of tree/green area present in each land use such as HT, MT and LT, where H=high, M= medium, L= Low and BA= Building and T= Tree canopy cover. Thus the classification under city need not have high density of buildings; rather the basis of the classification into HD is based on the type of buildings such as multi-storeyed and type of green area such as lawns, parks and planted greeneries.

The urbanization gradient was arranged based on the density of artificial area in each land use type. The combination of land use types that showed maximum R^2 value (0.97) in a linear regression was chosen with a minor change. Interestingly, in this combination the land uses followed the linear pattern such as city, suburb and rural classification, except for HTMDBA and HTHDBA, which was placed near to 'Rural'. However, the former fell in the suburb (MD) category, whereas the latter belong to city (HD). This land use type consisted of mostly multi-storey buildings and independent bungalows and the greeneries were mostly planted, which is seen along the pavements, house garden, lawns and park. Considering the type of buildings and type of greeneries, these areas were placed near to the respective land uses in the HD and MD classification and a regression slope was plotted again. Even though, the linear regression fit has now reduced to $R^2 = 0.81$, this gradient reflects real progression of urbanization by the inclusion of two highly urbanized land use types with more greeneries along with the other similar land use types.

The step-wise regression ascertain that rather than the decrease of natural areas (tree canopy cover and OA – scrub and grasses cover), the increase of built-up areas (roads and buildings) was much relevant. This shows that the land use type featured a gradient of buildings rather than a gradient of natural area. This would also mean that the natural cover, though decreased with urbanization intensity, is not that significantly predictable as that of built-up areas across the urbanization gradient.

2.5.1 Trend of Urban growth

The study found that Coimbatore city was not spread even within the linear study plot, which points to the fact that urbanization in Coimbatore city did not follow a linear pattern. A few land use types (i.e., LTHDBA, HTHDBA) were restricted to the city (core urban area), whereas, certain land use types were randomly spread across the urban rural landscape (E.g. MTMDBA), which was relatively older featured with tiled building that stands in association with new built-up areas. In addition, high-class residential areas were also seen in the core areas of city with lawns and open grounds. The MDS done to find the similarity of land use types show that most of the built-up areas in the city had higher area under tree canopy; agricultural areas were also found in the city. This concurs to the presence of educational campus such as Forest College, Institute of Forest Genetics and Tree Breeding (IFGTB), Govt. Model Engineering College and Tamil Nadu Agricultural University (TNAU). The Forest college campus is largely planted with Acacia trees and harbours some rare avifauna that one would not expect in an urban area such as Paradise flycatcher and Grey Partridge – ground nester (*pers. obs*). Towards the east, experimental agriculture plots of TNAU were spread in acres of land.

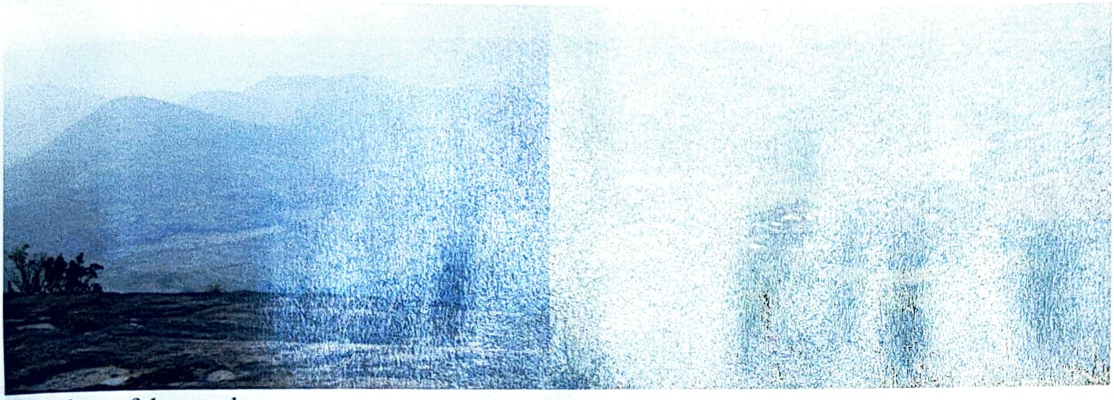
The above trend in the land use is justified by the study by Joy, (1975). She studied the spatial organization of Coimbatore city and concluded that original spatial layout of the city has not been totally replaced by a new one. Instead, it underwent a gradual blend of old and new principles in the built-up structure as the city grew in small accretion owing to the slow historical process. She has also shown that city growth in Coimbatore was according to the muti-nuclei theory or poly centric, which has different growth centres.

2.5.2 FACTORS UNDERLYING THE URBANIZATION TREND

The growth of the Coimbatore city is mainly skewed towards east direction along National Highway (NH-47), where majority of the industries were located. Another important factor that could halt the urban growth towards centre and west is due to the occupation of land by educational institute such as Agricultural and Forest College. In addition However, with the establishment of technical and educational institutes and mills, urban sprawl have majorly happened towards North, Northeast and East of the city; the influence is also impacted on the western side of the city (City development plan for Coimbatore, 2006). Towards the South, i.e. Anaikatty-Thadakam road, majority of land is occupied by Brick Industries. The lack of other industries in this area also could be due to the restriction by law pertaining to the presence of Anaikatty Reserve Forest, which lies in the foothills of the Western Ghats.

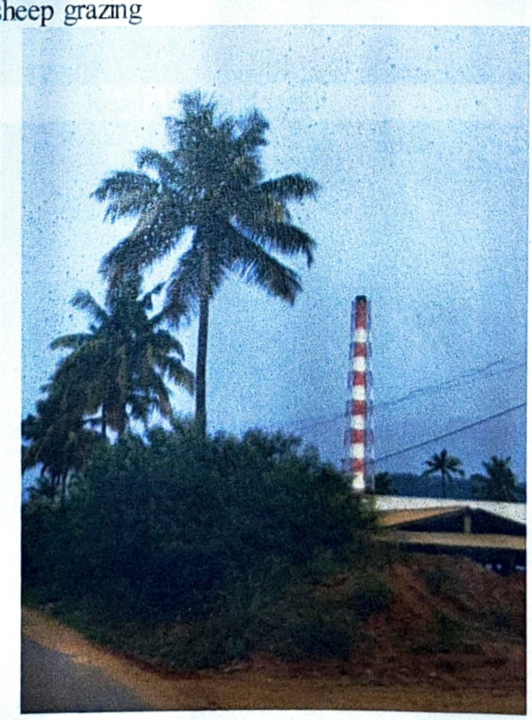
The polycentric growth of the Coimbatore city is evident from the land use type distribution in the landscape. This uneven distribution is indicative of an unplanned urbanization. According to the city development plan (Coimbatore corporation, 2006), in the past, urban development was mainly focussed on the east along the NH-47, however now urban sprawl in Coimbatore city is fast spreading to other directions along all the major roads of the city. Coimbatore city, bordered by Western Ghats in the south and south west, the only river - River Noyyal that traverse through the centre of the city, increasing number of Industries, urge for an immediate and comprehensive sustainable urban growth plan and its implementation.

PLATE 2. 1 VIEW OF THE RURAL AREAS OF THE COIMBATORE CITY



Over view of the rural areas

Picturesque scene in a rural area – a herd of sheep grazing

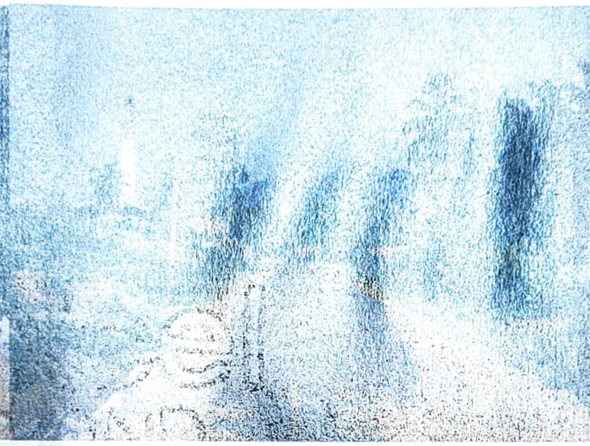


Sdhalavriksha – the deity

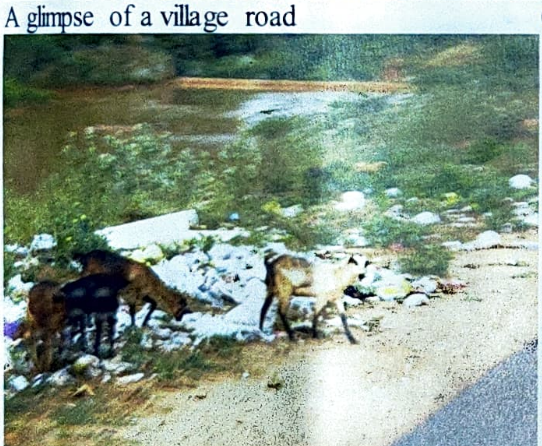
Brick kiln in a village setup

PLATE 2. 2 FEW SCENES ALONG THE URBAN TO RURAL GRADIENT OF THE COIMBATORE CITY

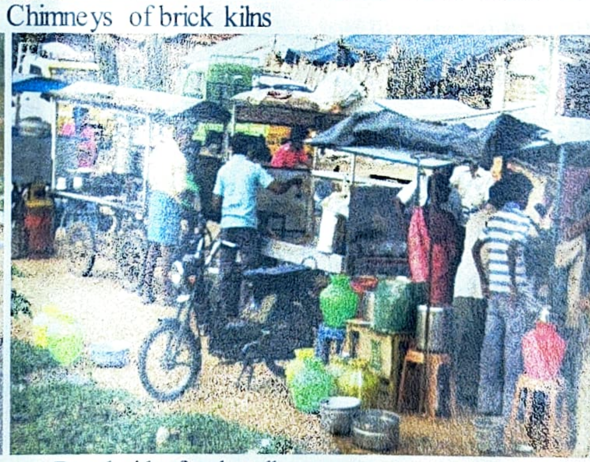
A glimpse of a village road



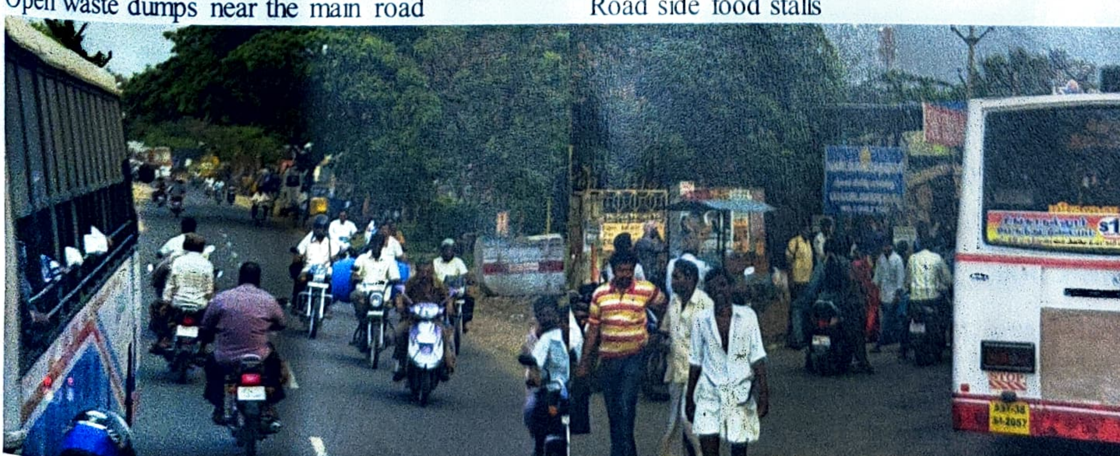
Chimneys of brick kilns



Open waste dumps near the main road



Road side food stalls



Busy road

CHAPTER 3

PATTERNS AND PROCESS –

SPECIES AT DIFFERENT SCALES OF URBANIZATION

3.1 ABSTRACT

Urbanization extensively alters the habitat. The changes becomes a serious concern when considering the fast pace of the growth of urban areas across the world. This leads to the depletion of natural habitats for species and leads to their disappearance. This study was undertaken to study the response of bird species to urbanization intensity. The population trend of bird species was examined along an urban-rural gradient of the Coimbatore city, Tamil Nadu in India. The population density of species in each urban grade was regressed with respective area under land use category and other selected urban parameters. It was seen that species richness declined with urbanization intensity whereas, the abundances of few species increased. The areas under natural cover significantly correlated with the declining population of majority species. The species that frequented urban areas showed species specificity in their relation with the urban parameters. Thus, the study agreed with the studies elsewhere that urbanization homogenized avian community.

3.2 INTRODUCTION

Several studies conducted in the urbanization gradients have noticed that bird diversity reduces with the progression of urbanization with a few species showing higher abundance, indicating biotic homogenization. A few relevant works in this aspect are (Devictor et al., 2008; Blair, 2004; Melles et al., 2003; Lockwood and McKinney, 2001; Marzluff, 2001).

Blair (2001a) examined the distribution and abundance of birds along an urban gradient in southwestern Ohio. Reale and Blair (2005) studied the nesting of birds across an urban gradient and concluded that nesting success is determined by nest site availability and the ability to produce multiple broods and that may drive the bird distribution along the gradients. There are some long-term studies (Luniak and Mulsow, 1988; Bezzel, 1985; Walcott, 1974; Batten, 1972), which documented avifaunal change at a site that became increasingly urbanized over a century. Luniak and Mulsow (1988) studied Blackbirds for over a period of 150 years and documented their increasing density in response to urbanization and identified increased fecundity and survival as the mechanisms for the density increase. Mills et al. (1989) has found that urban bird density and richness strongly correlated with native vegetation. The urban environment favours species that can utilize small, discontinuous patches of vegetation (Beissinger and Osborne, 1982), and densities of urban exploiters are strongly correlated with lawn area and the volume of exotic vegetation (Mills et al., 1989).

Some species seemingly tolerant to urban constraints are able to maintain populations in urban areas, whereas, others appear intolerant (Blair, 1996) and they decline in numbers. Ecologists have shown that these two kinds of species differ in biological traits such as feeding habitat, diet, nesting, migratory behaviour, and behavioural flexibility (Kark et al., 2007; Clergeau et al., 2006; Lim and Sodhi, 2004). Studies have found that species with similar and befitting requirements colonise urban areas, displacing a variety of other species and in effect simplify the overall composition leading to functional homogenization of bird communities (Clergeau et al., 2006; McKinney, 2006; Crooks et al., 2004; Olden et al., 2004; Blair, 2001b).

However, the patterns that are responsible for the distribution are not yet explored fully. A gradient approach is used in many studies to understand the process of selection of species with the progression of urbanization. In order, to understand the distribution patterns in urban areas I collected data of bird species richness and abundances from the built-up matrix along the urban-rural gradient in the Coimbatore city. In this study, the density of bird species was correlated to the habitat parameters at different levels of urbanization. The analysis was continued classifying the species as urban exploiter, urban adapters and urban sensitive according to the level of sensitivity to urbanization. Further analysis emphasised on the urban exploiter species, looking at the factors responsible for their distribution at a species level.

3.3 Method

Study area: An urban rural gradient of the Coimbatore city was taken as the study area (refer chapter 2 for details, Figure 3.1).

Bird survey: The study of birds in the Coimbatore city was carried out during 2007 – 2010 in the study area located on a rural to urban gradient. Bird survey was carried out in the morning hours following point count method (Bibby et al., 1992) for 8-10 minutes in the survey points. After several trials with transects and point counts, I found point counts more effective as it clearly represented a location and covered more area, thus increased the randomness of sampling. The point counts were laid along the study area (mentioned in Chapter 2., Method 2.) placed along a rural to urban gradient with the help of satellite imageries. At a single point I spent an average of 25minutes, the first 5-10 minutes were spent to acquaint with the area, and birds were counted for 5-8 minutes. The following details were collected -

- Bird survey - species richness (number of species) and abundance (number of individuals)
- Nests, and nest site details
- Land-use quantification (explained in chapter 2), and types of buildings
- The presence of anthropogenic food availability was quantified based on the presence-absence data of grocery shops, bakeries, hotels, open waste-dumps and fruiting trees. Other landscape details such as presence of coconut trees, mobile towers, open wells etc. were also recorded.

The sampling efforts in different habitat: Rural=30, Village= 116, VLDBA=24, HTMDBA=14, MTMDBA=77, LTMDBA=29, HTBA=40, MTBA=64, LTBA=39 points respectively.

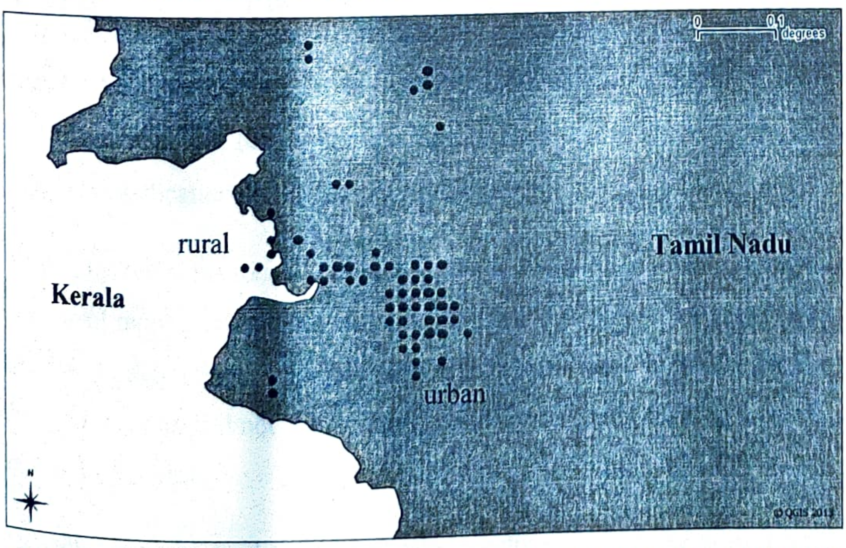


FIGURE 3.1 PART OF THE COIMBATORE SHOWING SAMPLING POINTS ALONG AN URBAN TO RURAL GRADIENT OF THE CITY.

A few points surveyed outside the sampling location, which were not considered for analysis is also shown in the figure.

3.3.1 DATA ANALYSIS

Migratory and wetland species were removed from the analysis, as we focussed only on terrestrial breeding birds. All analysis was done based on the species richness of (UE, UA and US) and species density (density/ha). The species richness and density are calculated by the following equation.

$$Species\ richness = \mathrm{n} - \mathrm{N}$$

Where, n = number of species per sample, N= Total number of species sampled

$$Density = \frac{n \times 10000}{\pi r^2 C}$$

Where, n= total number of species, πr^2= Area, C= total number of point count samples

The species across urban to rural gradient was classified based on their presence in the most urbanised areas (here habitats LTHDBA, MTHDBA and HTHDBA). Urban exploiter (UE), species present in most urban sites, Urban adapter (UA), species present in moderate number of urban sites, Urban sensitive (US), species very rare or absent in urban areas. These terms were adopted from the classifications followed after (Blair, 1996).

We first looked at the trend of species richness along the gradient. The species richness for a habitat is the total number of species encountered from different point counts conducted within a habitat. The species richness per counts for different habitats were subjected for Kruskal-Wallis analysis (as the species counts did not show normal distribution), in order to get significant levels of difference among the habitats.

Secondly, to understand the community structure, the species constituent within a habitat and its similarity across an urbanization gradient was found using species dissimilarity matrix and turnover rate across the urbanization gradient. The species dissimilarity matrix was found using Jaccard's formula and this was used to draw the turnover rate for habitats along an urbanization gradient. The species dissimilarity matrix between habitats was found using Jaccard's Index.

$$B = \frac{a + b}{a + b + c}$$

B=beta diversity, a=species richness of habitat 1, b=species richness of habitat 2, c= species common for habitat 1 and 2.

$$Turnover\ rate = B - 1$$

Turnover rate was calculated as the inverse of the dissimilarity and plotted according to the urbanization gradient.

As a third step, the frequency and density of species across the gradient was checked. The species abundance is the total number of individuals encountered from different counts conducted within a habitat; species density was calculated from the species abundance accounting for the total area in hectare surveyed for a habitat. A cluster analysis and MDS-Alscal (for better visualization) was performed to understand the distribution based on the frequency per habitat. The presence-absence data of sites sampled within a habitat was used for this analysis (this data can accord for the group size differences in species as some species are seen in groups and some in pairs).

To obtain an overview and the extremely large counts in the dependent variable, histogram of the observed count frequencies was employed. The histogram illustrates that the marginal distribution exhibits both substantial variation and a rather large number of zeros. Furthermore, for a clear picture the dependent variable was log-transformed.

As the data was based on point counts (along a rural to urban gradient of the Coimbatore city) General Linear Models (GLM, Poisson, Negative Binomial) would best explain the fit. Exploratory analysis (histograms, scatter plots, box plots) was done as a first step to look at the trend of the data and to check if there is any over dispersion. Further, as a first attempt to capture the relationship between the dependent variable and the regressors in a parametric regression model, basic Poisson regression model was fitted and coefficient estimates was obtained along with associated partial Wald tests. As the exploratory analysis suggested over-dispersion in all the data set, the Wald tests was re-computed using sandwich standard errors (Coef test). This result was then compared with other models that deal with over-dispersion (and excess zeros) in a more formal way such as quasi Poisson, Negative Binomial. The best fit model was chosen based on the improvement of the likelihood ratio (Akaike Information Criterion, AIC) of the model. The analysis was done with open source statistical package R version 2.11.1.

3.4 RESULTS

Of the total 76 identified species (five unidentified species was excluded from the total count) observed during the counts, 41 were breeding terrestrial resident birds (which were considered for further analysis) and 17 were migrant terrestrial species, three nocturnal and 10 wetland birds. Migrant species which were seen in urban areas were Grey wagtail, Blyth's reed warbler, Greenish leaf warbler, Great reed warbler, Barn swallow, Brahminy myna, Chestnut-tailed myna, Malabar parakeet, Marsh harrier. In short, a total of 41 terrestrial diurnal resident species were located from 433 points sampled along an urbanization gradient of $7x21km^2$ from rural areas to the Coimbatore city.

Agreeing with the trend across the globe, in this study also species composition was seen homogenising as the urbanization levels increased. The density pattern showed that the homogenized community greatly increased in numbers in all the grades except the rural areas, which is the most natural site studied in this context.

The species richness, turnover rate, frequency and density of the avian community along urbanization helped us conclude that urbanization induced homogeneity in urban habitat. The species richness declined across habitats (Figure 3.2). The highest richness was observed in rural areas, which declined after a slight peak at the medium level of urbanization and thereafter declined again. Therefore, only a few species frequented sites under higher urbanization levels, as indicated by the decline of species richness (Figure 3.2); increase in species similarity and decrease in the turnover rate was also seen with the urbanization ascend (Figure 3.3). Thus, the species constituent attained similarity, in other words a different community 'emerged' with urbanization ascend as indicated by the turnover rates and dissimilarity values (Figure 3.4).

The rate of turnover decreased steeply with the urbanization ascent. When the habitats which has greenery was removed, as these habitats were similar to rural areas in the MDS analysis, based on habitat variables (refer Chapter 2)., turnover rate acquired a parabolic shape, which was less at the lower levels of urbanization (village-rural), and then peaked in the middle and decreased towards highly urbanized areas. The turnover rate indicates the change of species composition. At the lower levels of urbanization, the species composition was different, dominated by UA type species, in the medium levels the richness of the three species groups such as US, UA and UE were more or less similar and then again it changed drastically to give way for UE species richness as the urbanization intensity increased (Figure 3.4).

An MDS analysis (Figure 3.5) revealed a cluster of species that were sensitive to urbanization (Urban sensitive, US); few species were seen in a loose cluster that were mostly present in moderate levels of urbanization (Urban adapters, UA); and a few species were seen in isolation, accounting for Urban exploiter (UE) types, which were seen in most of the sites.

The density of individuals of 433 sampling units was 35.71 per hectare (Table 3.1, Figure 3.6). The minimum count was one and maximum was 13 species; majority sites (86%) had species richness ranging from 1 to 4. The density of UE species group was (32.54), the highest compared to UA and US, the abundances per habitat (counts of individuals pooled for respective species per habitat) ranged from 0 to 146. They were absent only in 12.5% (53 point count stations) sites. The species richness in the category UA was in the range from 0 to 15 species per site; with a density of 2.57; 70% (305 point count stations) of the sites were deprived of UA species. The species richness in the US category ranged from 0 to 13 species per site, the density was the least when compared to the former (0.59). These were the most sensitive species to urbanization and were absent from majority sites (93.5%, 405 point count stations).

The densities of individuals were more or less similar in all grades of urbanization (Figure 3.6). UA showed gradual decline while, US showed steep decline as the urbanization levels increased. The number of UE species remained more or less the same across the gradient, which might have inflicted in the total density. The above results show that a homogenous community existed in the urban areas.

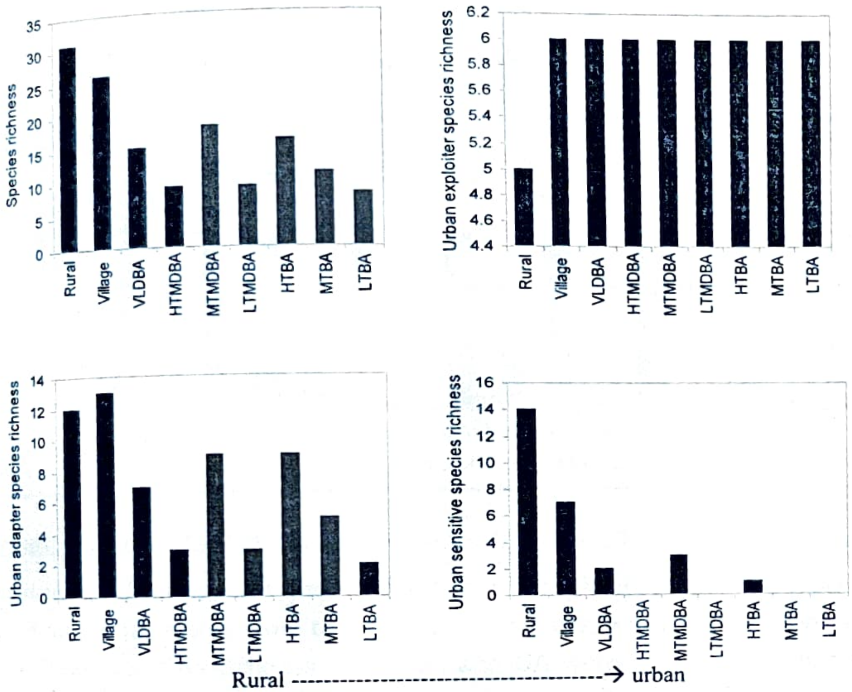


FIGURE 3. 2 SPECIES RICHNESS IN DIFFERENT URBAN GRADES

The species richness of the birds surveyed along an urban to rural gradient of the Coimbatore city is presented here. In addition to the total species richness, the richness of the classification of species based on their frequency in urban areas such as Urban exploiter, Urban adapter and Urban sensitive are also given. The total species richness declined as the urbanization intensity increased. However, the richness of the urban exploiter species did not change considerably.

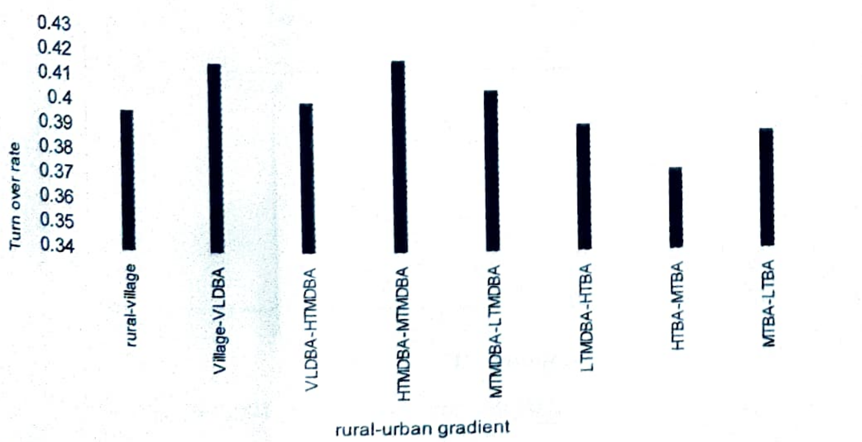
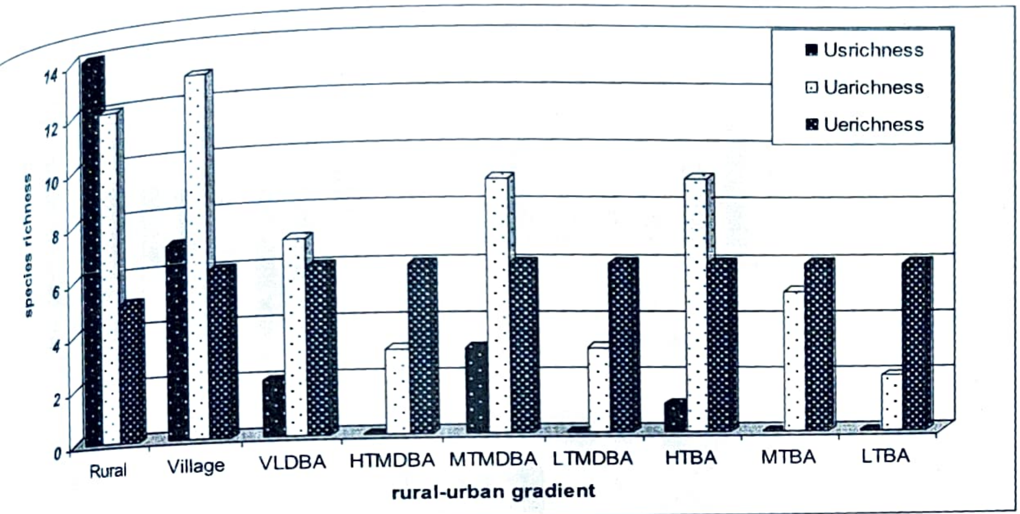


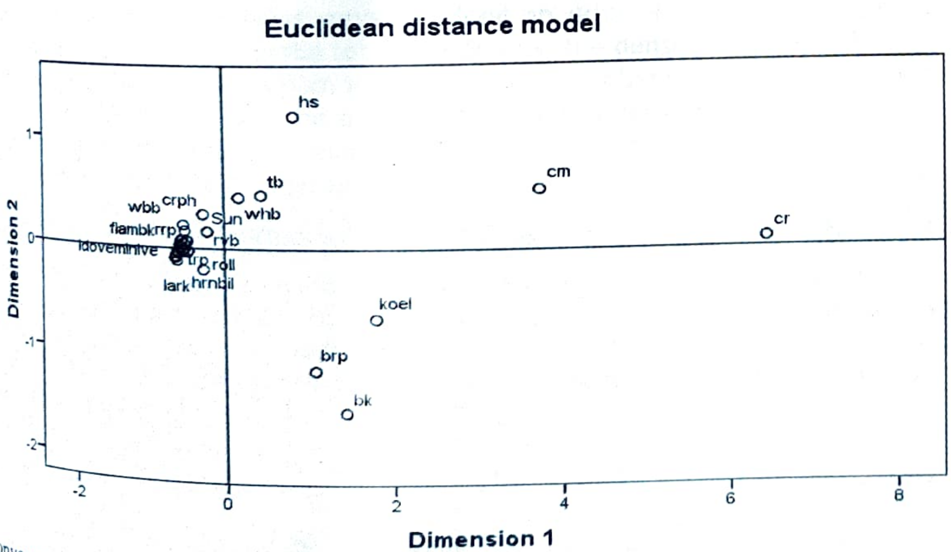
FIGURE 3.3. TURNOVER RATE OF SPECIES SHOWED AN OVERALL DECREASE FROM THE MOST NATURAL TO MOST URBAN SITES

Turnover rates of species in different habitat along an urbanization gradient of the Coimbatore city. The turnover rate was calculated by finding the inverse of the Jaccard's similarity index of species richness across the habitats.



IGURE 3. 4 SPECIES COMPOSITION CHANGED WITH THE ASCEND OF URBANIZATION

he richness of the species classified as Urban sensitive (US), Urban adapter (UA) and Urban exploiter (UE) ased on the frequency (low to high) in urban areas, were plotted along a rural to urban gradient of the oimbatore city. The richness of the US and UA were high in rural extreme, whereas UA and UE were resent towards habitats with higher level of urbanization, however, the number of species represented by ach category was low. The habitats with medium to high tree cover showed more species richness. owever, the richness of the UE category was not affected by the tree cover.



Convergence Criterion-0.001, Minimum S-stress -0.005.

FIGURE 3. 5 FEW SPECIES FREQUENTED URBAN AREAS

MDS (ALSCAL) plot of the frequency of species (presence-absence) for the sites surveyed per habitat. The first dimension explains the frequency of presence and second dimension explains the sensitivity of species to urbanization. In dimension 2, the value '0' indicates presence of species in all habitats, and -ve value indicates affinity of species to more urbanized habitats and +ve value indicates less urbanized habitats.

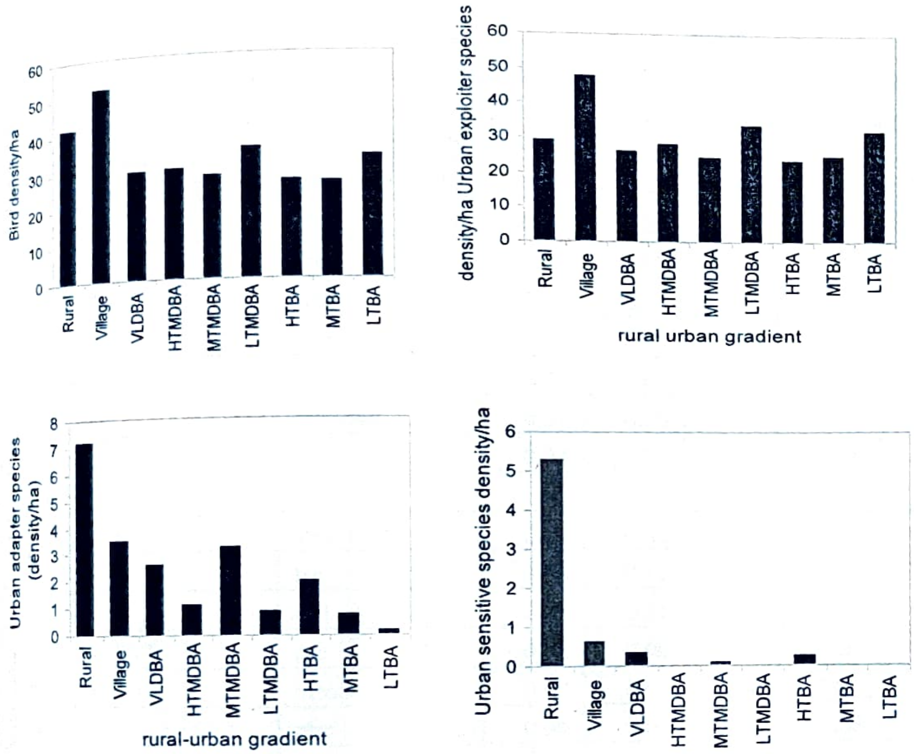


FIGURE 3. 6 SPECIES DENSITY ALONG THE RURAL-URBAN GRADIENT OF THE COIMBATORE CITY

The density of the bird species surveyed along an urban to rural gradient of the Coimbatore city is presented here. In addition to the total bird density, the density of the classification of species based on their frequency in urban areas such as Urban exploiter, Urban adapter and Urban sensitive are also given. The total species density declined as the urbanization intensity increased. However, the density of the urban exploiter species did not change considerably. Urban adapter species showed an increase in the habitat with medium urbanization intensity.

TABLE 3. 1 DENSITY OF SPECIES ALONG THE URBAN TO RURAL GRADIENT OF COIMBATORE CITY

The density is found from 433 point count laid along the urban to rural gradient of the Coimbatore city. The urban exploiter, urban adapter and urban sensitive species were specified and given as separate category. The cells are highlighted by a colour gradient that ranges from black to white. The darker the colour, higher the density and vice versa; black indicates the highest density and white indicate absence of a species from a particular urban grade.

Species	Abbr.	Rural	Village	VLDBA	HTM DBA	MTM DBA	LTM DBA	HTBA	MTBA	LTBA
Urban exploiter										
Crow	cr	1.39	0.76	1.95	2.41	1.96	2.06	1.88	2.15	1.80
House sparrow	hs	0.26	0.13	0.11	0.37	0.17	1.08	0.06	0.16	0.47
Common myna	cm	0.95	0.69	1.52	1.30	1.55	1.08	1.23	1.06	0.53
Rock pigeon	brp	0.09	0.07	0.32	0.37	0.30	0.36	0.91	0.97	0.87
Black kite	bk	0.00	0.09	0.65	0.56	0.17	0.27	0.84	1.14	1.33
Asian koel	koel	0.52	0.34	0.65	1.30	0.61	0.27	1.10	0.41	0.27

Urban adapter										
Yellow-billed babbler	whb	0.52	0.11	0.43	0.00	0.37	0.27	0.19	0.08	0.00
Tailor bird	tb	0.61	0.20	0.54	0.19	0.47	0.09	0.19	0.12	0.13
Ashy prinia	ap	0.09	0.07	0.00	0.00	0.17	0.00	0.00	0.00	0.00
Purple-rumped sunbird	Sun	0.35	0.09	0.22	0.00	0.14	0.00	0.19	0.00	0.00
Shikra	shi	0.00	0.02	0.22	0.19	0.17	0.00	0.13	0.08	0.00
Black drongo	dro	0.00	0.07	0.00	0.00	0.14	0.09	0.06	0.04	0.00
Greater coucal	crph	0.61	0.07	0.11	0.00	0.07	0.00	0.13	0.08	0.00
Lesser flameback	flambk	0.26	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.07
Copper-smith barbet	csb	0.35	0.04	0.00	0.00	0.00	0.00	0.13	0.00	0.00
Indian peafowl	Peafowl	0.17	0.07	0.00	0.19	0.00	0.00	0.06	0.00	0.00
Rose-ringed parakeet	rrp	0.09	0.04	0.00	0.00	0.10	0.00	0.06	0.00	0.00
Urban sensitive										
Bay-back shrike	shrike	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.06	0.00
Treepie	trp	0.09	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Indian roller	roll	0.09	0.07	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Red-vented bulbul	rvb	0.43	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Magpie robin	mrob	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pied bush chat	pbc	0.09	0.09	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Red-whiskered bulbul	rwb	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White-browed bulbul	wbb	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
White-cheeked barbet	sgbar	0.09	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Brown headed barbet	bhbar	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laughing dove	ldove	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grey jungle fowl	gjf	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Spotted dove	sdove	0.35	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
Common iora	iora	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Green bee-eater	sgbe	0.26	0.04	0.11	0.00	0.00	0.00	0.00	0.00	0.00
Grey hornbill	hrnbil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Small minivet	minive	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashy-crowned sparrow lark	lark	0.09	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Jungle myna	jmy	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hoopoe	Hoopoe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sirkeer malkoha	Sirmal	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Black-shouldered kite	bskite	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Large-grey babbler	lgbab	1.13	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Abbrev. VLDBA= area very low density buildings, LTMDBA = Medium-density buildings with low-density tree cover, MTMDBA = Medium-density buildings with medium-density tree cover, HTMDBA= Medium-density buildings with high-density tree cover, LTHDBA= High-density buildings with low-density tree cover, MTHDBA= High-density buildings with medium-density tree cover, HTHDBA= High-density buildings with high-density tree cover.

Although, UE type species showed higher densities in all gradients, a species level perspective would give a better view. Hence, we looked at the densities and frequencies of selected UE species. Six species were regarded as urban exploiter species such as Crow, House sparrow, Rock pigeon, Common myna, Asian Koel and Black kite that were seen frequently in areas with relatively higher urbanization levels. Jungle crow and House crow was regarded as one species considering the chances of misidentification in field while counting. Except House sparrow and Asian koel all other species showed a distinct trend along the rural-urban gradient. The rock pigeon and Black kite increased with urbanization intensity, whereas as Crow and Common myna decreased with urbanization ascent (Figure 3.7).

When looked on the basis of frequency, among UE types (Figure 3.5), three species were present in all the gradients more or less equally (Crow, Koel and Common myna); two species were restricted mostly to the well urbanized areas (Rock pigeon and Black kite); and House sparrow was restricted mostly to the less urbanized areas. The most frequent species was crow (inclusive of both Jungle and House crow *Corvus macrorynchus* and *C. Splendens*), Common myna, Asian koel, Black kite, Rock pigeon and House sparrow. However, the abundances of crows were the highest, followed by Rock pigeon, House sparrow and Common myna *(Acridotherus tristis)*.

BOX 3. 1 THE POPULATION OF URBAN EXPLOITER SPECIES ALONG THE URBANIZATION GRADIENT OF THE COIMBATORE CITY

Crow (House crow and Jungle crow): The total individuals counted from all the sites were 2748. It was absent only from 22% of the total sites sampled. They were observed mostly (50% of the total sites, range - 0-86) in groups of 1-6 individuals (6.35 $\pm$ 9.9 individuals); in 18% of the sites they were observed in 7-15 individuals. A large group of crows were observed occasionally (>15 individuals).

House sparrow (HS) showed mean presence of 1.55 $\pm$ 5.22, ranging from 0-66 individuals. Total individuals counted from all sites were 671. Sparrow was absent from majority sites sampled (81%). They were mostly sighted in a range of 1-8 individuals (14%). The counts of >8 individuals were present in few sites.

Common myna (CM) was present on an average of 2.03 $\pm$ 4.87 individuals, with counts varying from 0-65. Total individuals counted were 880. Myna was absent in 51.5% sites. In majority sites (42%) they were seen within a range of 1-6 individuals.

Rock pigeon (BRP) was counted at an average of 1.28 $\pm$ 5.811 individuals, varying from 0-60; total individuals counted were 552. Pigeon was absent in majority sites (82.4%). They were mostly encountered in 1-3 individuals. Seen in places with large amount of food availability like go-downs where cereals are stored, or in buildings during resting/roosting in the evening. Occasionally seen flying together in the sky in high numbers.

Black kite (BK), were recorded on an average of 0.95 $\pm$ 4.78 individuals, minimum was 0, maximum count was 70; total individuals recorded were 412. They were absent from majority sites surveyed, as majority citation were from the most urbanized localities. They were mostly found in frequencies of 1-3 (15%) individuals soaring high.

Asian koel was seen on an average of 0.36 $\pm$ 0.96, range 0-13; total individuals counted were 157. They were not sighted in 77.4% sites, and were mostly present in frequencies of 1-3 individuals (21.4%).

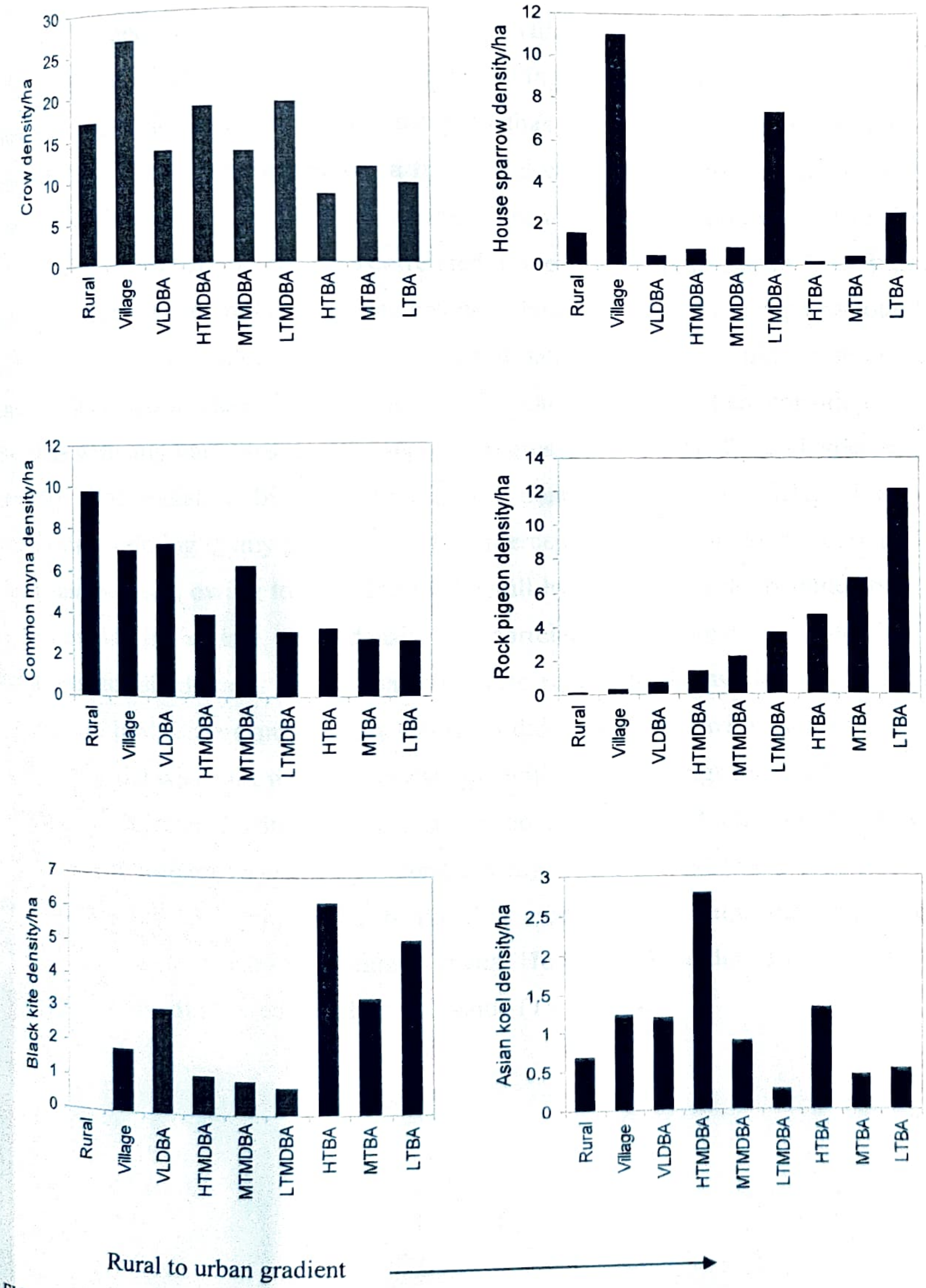


FIGURE 3. 7 DENSITY OF THE URBAN EXPLOITER SPECIES ALONG AN URBANIZATION GRADIENT

The density of the species under urban exploiter category surveyed along an urban to rural gradient of the Coimbatore city is presented here. Each species showed different population trend across the gradient.

3.4.1 PROCESS – FACTORS UNDERLYING SPECIES DISTRIBUTION IN URBAN AREAS

In order, to understand the factors associated with the avian distribution in urban areas General Linear Model (GLM) regression was done taking data of few selected study points. Negative binomial regression showed a much better fit than Poisson model in all analysis. In the negative binomial model for each regression, a full model was made at first and then a reduced model and the model with high AIC values was selected. The independent parameters were also chosen species specifically if two parameters were correlated. For example in the case of Rock pigeon multi-storied buildings were chosen rather than tree cover, as buildings and tree cover was found correlated. The US and UA was correlated with the presence of natural areas. They did not show any correlation to any artificial parameters. The species in the category UE, when considered together did not correlate with any variables. Hence, separate regression was done for each species belonging to UE category. The negative binomial regressions done for Crow and Black kite were not found significantly relating to any parameters. The intercept of regression done for Black kite resulted in a significant p-value, owing to rejection of the null hypothesis that the parameters did not contribute to the variation in the data. Crow density was correlated to the presence of tiled buildings and hotel, but it was not significant. House sparrows were related to the availability of anthropogenic food (presence of bird feeders and grocery shops). It did not correlate with the area under tiled buildings. A second model was built with grocery shops (with tiled buildings removed), where House sparrow density was correlated with the presence of grocery shops. Rock pigeon was correlated to the presence of multi-storied buildings. Common myna was related to the presence of house garden, natural areas and trees with fruits. In the first model, only natural areas and house garden were correlated with the density of Common myna. However, the reduced model with trees (tree with fruits was removed) showed a higher AIC value (Table 3.2).

TABLE 3.2 NEGATIVE BINOMIAL REGRESSION DONE ON SPECIES ABUNDANCE WITH URBAN VARIABLES

The negative binomial regression done with the species abundance of selected point counts conducted along an urbanization gradient against the land use land cover as well as selected urban parameters of the study area in the Coimbatore city is presented here. The model with highest AIC values is presented here. In the case of Common myna and House sparrow, two models are given that had very similar AIC values. The standard error of these two models did not vary considerably. The regression was done after removing the correlated variables. The result show that species that did not belong to urban exploiter category was correlated with the presence of natural land cover such as open grounds with bushes and trees; whereas, there were considerable differences within species belonging to urban exploiter category.

		Estimate	Std. Error	t value	Pr(>|t|)		AIC
Urban sensitive, df=164	(Intercept)	-0.3067	1.3309	-0.230	0.8180		1101.1
	oab	3.2239	1.2990	2.482	0.0141	*	
	blt	1.7354	1.0537	1.647	0.1016		
	gar	-0.3431	1.8296	-0.188	0.8515		
	tem	-0.8235	1.4791	-0.557	0.5785		
	fedr	-2.6106	3.9070	-0.668	0.5050		
	fdtre	-2.4704	1.5961	-1.548	0.1237		
Urban adapters df=164	(Intercept)	0.3398	1.3136	0.259	0.7962		1096.8
	oab	3.1867	1.2821	2.486	0.0140	*	
	blt	1.7184	1.0400	1.652	0.1005		
	gar	0.5534	1.8059	0.306	0.7597		
	tem	-1.4290	1.4599	-0.979	0.3292		
	fedr	-3.3180	3.8563	-0.860	0.3909		
	fdtre	-2.5674	1.5754	-1.630	0.1052		
Urban exploiters, df=165							
Crow	(Intercept)	2.2602	0.8475	2.667	0.00844	**	1098.3
	hot	2.3810	1.2225	1.948	0.05321	.	
	blt	1.9638	1.0192	1.927	0.05578	.	
	fedr	-2.5178	3.8463	-0.655	0.51366		
	tem	1.7166	1.4386	1.193	0.23452		
	gar	1.3665	1.7753	0.770	0.44259		
House sparrow Model 1	(Intercept)	0.05465	0.51667	0.106	0.916		798.86
	oab	0.37138	0.49965	0.743	0.458		
	blt	0.56236	0.41350	1.360	0.176		
	gar	-0.93853	0.71845	-1.306	0.193		
	tem	-0.12942	0.58374	-0.222	0.825		
	fedr	9.67884	1.54347	6.271	3.21e-09	***	
House sparrow Model 2	(Intercept)	-0.02488	0.47179	-0.053	0.95801		792.37
	oab	0.33587	0.48984	0.686	0.49391		
	groc	1.23920	0.42995	2.882	0.00449	**	
	gar	-0.68042	0.70643	-0.963	0.33691		
	tem	-0.05152	0.57053	-0.090	0.92816		
	fedr	9.21881	1.52276	6.054	9.7e-09	***	
Common myna Model 1	(Intercept)	-0.06699	0.56247	-0.119	0.905346		850.73
	oab	1.97326	0.58400	3.379	0.000914	***	
	groc	-0.28564	0.51260	-0.557	0.578137		
	gar	2.53488	0.84222	3.010	0.003039	**	
	tem	0.55362	0.68019	0.814	0.416903		
	fedr	-1.42092	1.81545	-0.783	0.434969		
Common myna Model 2	(Intercept)	-0.1244	0.5545	-0.224	0.82271		846.65
	oab	1.7540	0.5822	3.013	0.00301	**	
	groc	-0.2579	0.5050	-0.511	0.61033		
	gar	2.3791	0.8320	2.860	0.00481	**	
	tem	0.6274	0.6706	0.936	0.35089		

	fedr	-1.2085	1.7902	-0.675	0.50062		
	fdtre	1.7471	0.7171	2.436	0.01594	*	
Rock pigeon	(Intercept)	0.93133	0.55635	1.674	0.09608	.	1019.7
	blt4	3.66030	1.28655	2.845	0.00502	**	
	groc	-0.85044	0.85433	-0.995	0.32102		
	gar	-1.09501	1.40521	-0.779	0.43699		
	tem	0.03742	1.13492	0.033	0.97374		
	fedr	-0.01184	3.02070	-0.004	0.99688		
Black kite	(Intercept)	0.29903	0.11691	2.558	0.0115	*	443.39
	blt	0.04154	0.14178	0.293	0.7699		
	blt4	0.09913	0.22834	0.434	0.6648		
	gar	-0.15052	0.24736	-0.608	0.5437		
	tem	-0.08917	0.20043	-0.445	0.6570		
	fedr	-0.24683	0.52903	-0.467	0.6415		
	fdtre	-0.20149	0.21307	-0.946	0.3458		
Asian koel	(Intercept)	-0.07892	0.29493	-0.268	0.789362		359.27
	t	0.25482	0.28943	0.880	0.379979		
	blt	0.07352	0.10958	0.671	0.503243		
	blt4	-0.06984	0.17660	-0.395	0.693022		
	hot	-0.04670	0.13134	-0.356	0.722627		
	gar	0.20724	0.19194	1.080	0.281919		
	tem	0.29600	0.15470	1.913	0.057526	.	
	fedr	-0.36152	0.41322	-0.875	0.382970		
	fdtre	0.62873	0.16505	3.809	0.000199	***	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Abbrev. t= tree, blt= tiled building, blt4= multi-storied building, oab=open area with bushes and dispersed trees, gar= garden, fdtre= trees with fruit, fedr= bird feeders, tem= temple, groc= grocery shop

3.4.1.1 Nest habitat nested within the foraging habitat

In the present work, the nest density was significantly related with the population density of the species, except in the case of Rock pigeon and Common myna (Figure 3.9). It could be thus deemed that their distribution is also controlled by the breeding areas. It was seen that the nest substrate use (nest placement) was in par with the availability of the substrates as the nest density was comparable with the progression of the urbanization gradient (Figure 3.8).

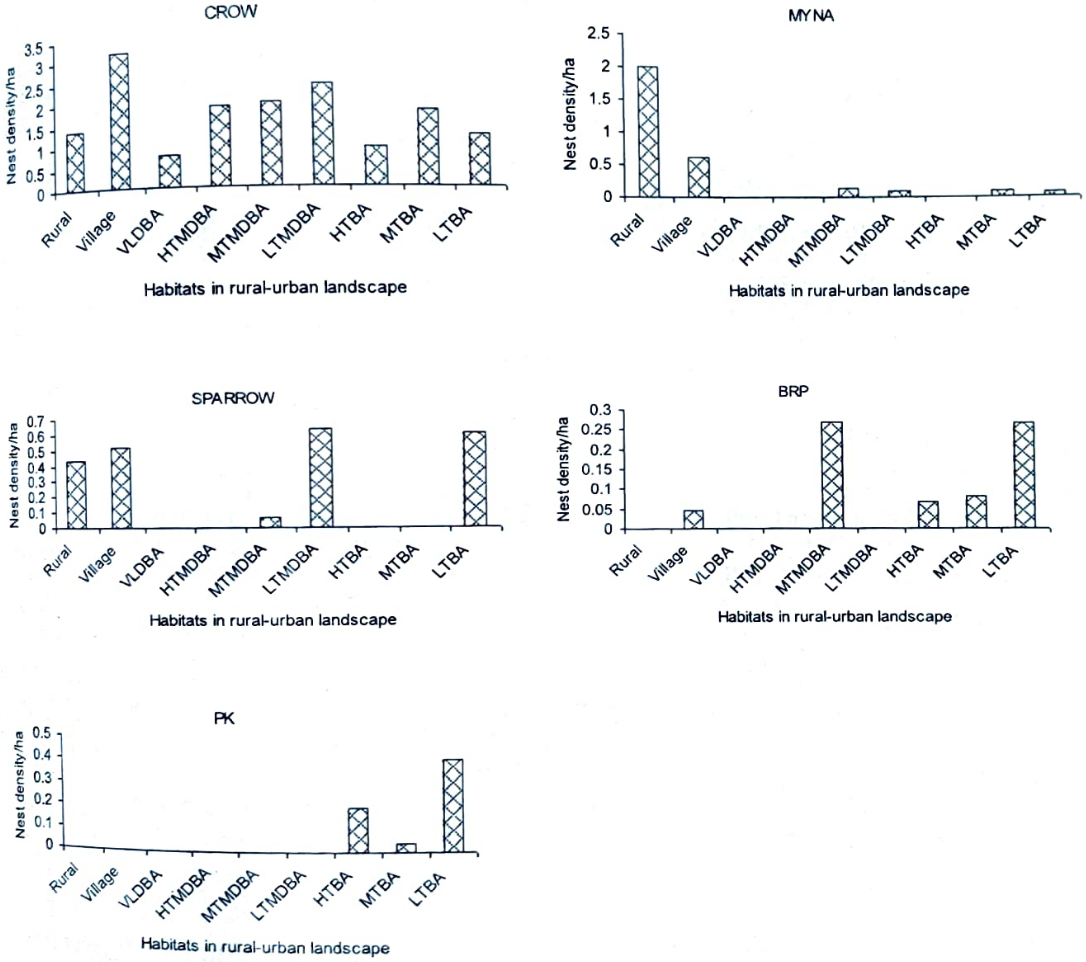


FIGURE 3.8. NEST DENSITY OF URBAN EXPLOITER SPECIES IN DIFFERENT HABITATS

The density of the nest of species belonging to urban exploiter category, recorded in different habitats along an urbanization gradient of the Coimbatore city is presented here. Crow nested in every habitat, whereas other species showed discrete nesting patterns. The density of the Common myna nest in rural areas was high. The density of the House sparrow nests did not vary considerably in different habitats. Rock pigeon and Black kite mainly nested in habitat under higher urbanization levels.

Abbr. Myna = Common myna, Sparrow= House sparrow, BRP= Rock pigeon, PK= Black kite.

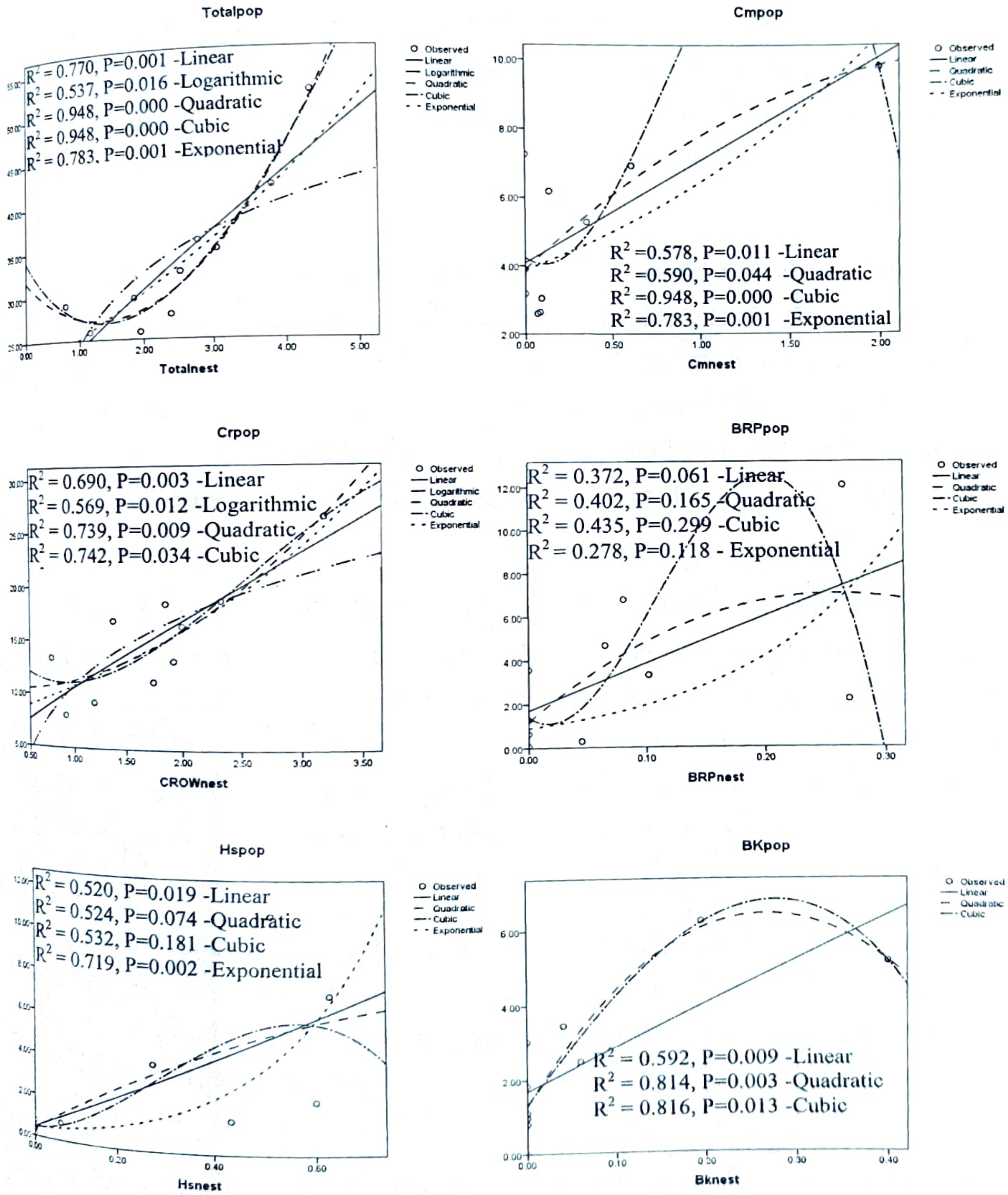


FIGURE 3.9 NEST DENSITIES OF URBAN EXPLOITER SPECIES CORRELATED WITH ITS POPULATION

The linear regression results done with the nest density of species belonging to urban exploiter category versus their population recorded in different habitats along an urbanization gradient of the Coimbatore city is presented here. It was seen that except for Rock pigeon, the nest density of all other species correlated with their population density in each habitat.

Abbr. Cr=crow, Cm = Common myna, Hs= House sparrow, BRP= Rock pigeon, BK= Black kite, pop=population.

3.5 DISCUSSION

The trend in community composition across rural-urban gradient was not different from the earlier research in this subject area. The species richness declined along the gradient. However, there were species level differences in the case of urban exploiter species and hence, they did not show a clear and general trend with the urbanization levels. Community composition was different along urban-rural gradient.

Similar to the results of research across the world that compared natural areas with urban areas (McKinney, 2006; Chace and Walsh, 2006; Clergeau et al., 2006, 1998; Marzluff, 2001; McIntyre et al., 2001; Blair, 1996; Beissinger and Osborne, 1982), this study has also seen a decline of diversity and increase in the abundances as urbanization increased. The results of this study are contradictory to the findings of Minor and Urban (Minor and Urban, 2010) who reported that the number of bird species in the same study area in North Carolina did not differ across the urban gradient.

Similar to the findings of (Chace and Walsh, 2006; Sandström et al., 2006; Mills et al., 1989; Emlen, 1974), we found that as vegetation cover increases toward the rural parts of the city, species diversity increases. We found a slight increase in the species richness in areas of intermediate disturbances (village and suburban areas) agreeing with the general trend (Blair, 1999). The turn-over rate of species was also low as the urbanization level peaked, indicating similar species composition which joined with the findings of (Croci et al., 2008), signifying biotic homogenization.

The high densities of birds in the cities, irrespective of its magnitude and direction of development were reported in many studies (Rodewald and Shustack, 2008; Chace and Walsh, 2006; Marzluff, 2001; Emlen, 1974). Compared with adjacent, more natural ecosystems, urban settings normally have higher bird abundances (Chace and Walsh, 2006; Marzluff, 2001; Beissinger and Osborne, 1982).

The regression analysis of the point count data across urbanization gradient show that anthropogenic food was one of the main sources that controlled diurnal distribution of birds in the urban area of Coimbatore, except for Common myna that chose to graze even though, it also did ate human manipulated food. The species that depended only on landscape variables perished away with urbanization. Increase in food abundance is the most common mechanism described in the literature for the increase in bird densities (Bolger et al., 2001; Marzluff, 2001; Mennechez and Clergeau, 2001; Emlen, 1974). This increase may reflect the combined effect of an increase in exotic vegetation, refuse, and, in many cases, the presence of bird feeders. Seeds, either raw or cooked, processed into different forms are abundantly available mainly in the open dumps or from bird feeders in Coimbatore. Open waste dumps are common in cities of developing countries. This monopoly of seeds in food could be correlated with the highest incidence of seed eaters in cities; the abundance of seed eaters in cities was recognized by Shochat et al. (2010a) in their review.

The density of nests was correlated with the population density of species in the case of all urban exploiter species. However, in the present study I was not able to check how species population is affected by food availability and nest site availability. This needs to be addressed in future studies.

The trend of individual urban exploiter species was different; certain species were more abundant in rural areas whereas, certain others were restricted to more urbanized areas. The factors underlying their distribution were species specific. The regression analysis at two scales of urbanization, one at habitat level and another at microhabitat level revealed interesting patterns.

It was found that densities of UE species were related to the presence of anthropogenic factors. Emlen, (1974) associated this increase with both high supply of seeds in feeders and higher productivity in the urban environment due to urban lawns and weeds. An analysis at species level showed that all species were distinct and different factors controlled their distribution.

House sparrow did not correlate with any landscape variables, other than grocery shops. However, the abundance of the species was not only related to the anthropogenic food sources, as its population skewed towards the rural end. This study agrees with the finding from a study conducted in Delhi (Khera et al., 2010). On the other hand, agricultural area and open areas with bushes in rural areas provides food in the form of grains and insects (Balmori and Hallberg, 2007). Studies have also suggested that a decline in insect population may be a major cause of the House Sparrow population decline (Van der Poel, 2000; Peach et al., 2008) . As the diet of the young sparrow constitutes weevils, grasshoppers, and caterpillars, of which aphids constitute an important constituent (Crick, 2002). The nest of House sparrow also correlated with the sparrow abundances. This indicates that food availability was one of important factors that were connected with the House sparrow abundance.

Crow, Common myna and Koel were denser at lower urbanization levels. In the present study, crow population did not significantly change across the gradient, even though there was a slight increase in the village areas. This was contrary to the findings of (Marzluff et al., 2001), that crow population reached their peak at the suburban and rural areas. This difference could be due to the fact that cities in developing countries has lot of road side waste dumps and spilling from shops and hotels, whereas, cities in developed countries in general have better waste management system. This sole reason could influence the abundances of birds in urban areas that depend mainly on anthropogenic food.

Common myna generally nests in the cavities in the trees or buildings and feed mainly on insects from lawns, open grounds with bushes or agriculture. The regression results also indicate that the density of Common myna was correlated with the abundance of natural areas and house garden/lawns. This could be the reason for the less density of Common myna in the city limits. Their preference for the agricultural lands is one of the reasons for them being reported as pests in many studies done on myna and starlings. However, being a communal rooster, the roosting populations of myna in the parks were quite high (data not presented here) in cities. Rock pigeon and Black kite was present mainly in cities. However, Black kite was not correlated with any parameters. This could be due to the bias while surveying as they soar high. Rock pigeon on the other hand was correlated with the presence of high-rise buildings in the Coimbatore city. High-rise buildings were negatively correlated with tree cover in the Coimbatore city. The Rock pigeon was mainly recorded from the older parts of city and few locations in the new city. The buildings in the older parts of the city are comparatively old, offer many cavities and thus serve as a roosting and nesting location for the species. However, their density was less in urban areas when compared to the density of crow population or even few other cities surveyed in India (data not presented here). Against the expectation, apparently, many studies have reported that cavity nesters are at a disadvantage in urban areas (Croci et al., 2008; Lim and Sodhi, 2004).

The species that frequent urban areas responded species specifically to different parameters in urban areas. The parameters in the urban areas such as availability of food, presence of house garden/lawns, multi-storied buildings and the presence of natural areas served important for different species. The species specificity might have an influence contributed by their specific life-history traits. The recent studies suggest that life-history traits do influence the selection of species in urban areas (Croci et al., 2008). This aspect will be dealt in the following chapter.

CHAPTER 4

LIFE-HISTORY TRAITS AND STRATEGIES OF BIRDS IN URBAN AREAS

4.1 ABSTRACT

There are certain species that live in heavily human manipulated habitats. This study looked into the life-history traits and strategies of bird species that survive in urban areas. The details of the life-history traits were taken from published literatures. It was found that species frequenting urban areas could be clearly distinguished based on the life-history traits. The linear stepwise regression with life-history traits show that habitat of the species was correlated with the species categories such as US, UA and UE that indicate their tolerance to urbanization. Species that survive in urban areas formulated certain strategies such as finding analogues in artificial structures for nesting, expanding breeding timings and adjusting activity patterns during hot hours. The functional telencephalon ratio was high in urban group than in the non-urban group. However, there was high variation within the urban group itself. The study concludes by asking a question whether high cognitive capacities seen in certain species of the urban group help them to survive in urban areas.

4.2 INTRODUCTION

Urbanization – the process of constructing built-up structures for human use alters a natural area by significantly changing the natural features in a habitat. It creates novel habitat for wild animals where selection pressures may differ drastically from those in natural habitats. Animals are exposed to a variety of novel opportunities and risks such as novel food sources (Beckmann and Berger, 2003; Fleischer Jr et al., 2003), alternative breeding sites (Moller, 2010; Yeh et al., 2007), and an altered fauna of predators compared to natural habitats (Sorace and Gustin, 2009). Animal species vary in their ability to tolerate, invade or persist in urban environments, which attributes to ecology, life history, physiology and behaviour of the species (Bonier et al., 2007; Carrete and Tella, 2011; Evans et al., 2011; Møller, 2009; Kark et al., 2007). The ability to exploit urban resources (Chace and Walsh, 2006) and behavioural flexibility may play a significant role in order to survive in urban areas (Kark et al., 2007). Gilbert (1991) observes that the ability of a bird to learn and identify its 'habitat analogues' determine its survival in a changing landscape. Ecological theory states that niche-breadth differences among species are the result of an evolutionary trade-off between the ability of species to exploit a range of resources and their capability to use each one (Kawecki, 1994). This difference in species tolerances has been associated with several life-history traits (Brouat et al., 2004; Tripet et al., 2002). The species seen abundantly in urban areas differ in several life-history traits such as feeding habitat, diet, nesting, migratory behaviour, and behavioural flexibility (Kark et al., 2007; Clergeau et al., 2006; Lim and Sodhi, 2004). Hence, the way community function is very likely to be influenced by the relative amount of specialist and generalist species. However, the urban habitat appears to favour generalists to such an extent that the habitat is monopolised by them inducing biotic homogeneity. The functional homogenization of bird communities in urban areas has been reported by many studies (McKinney, 2006; Clergeau et al., 2006; Crooks et al., 2004; Olden et al., 2004; Blair, 2001).

Taking birds as the model organism, the goal of the present study is to identify the traits that characterize species that show differential tolerance to urbanization. Further, investigate in which way the life-history traits favour species in urban areas to adopt survival strategies. The study looks at the phylogenetic classification of species that are distributed in urban, suburban and rural areas, and then proceeds to find the life-history traits that distinguish species that seem to be tolerant to urbanization, and finally on the basis of few hypothesis, I try to find out few strategies adopted by the urbanization tolerant bird species to survive in urban areas.

4.3 METHODS

The study was conducted during 2008-2011 in the urban to rural gradient of the Coimbatore city in Tamil Nadu State of India. (see chapter 2 for details).

To understand if the composition of urban community is different from the distribution of natural population, the species count at Order, Family and Genus level of urban and suburban areas of the Coimbatore city were correlated with natural population. Here, the community in the rural areas of Coimbatore were considered as natural population.

The life-history traits of the resident breeding terrestrial species along rural-urban landscape were subjected for Multiple Correspondence Analysis (MCA, as this analysis was appropriate for string data). The traits were selected based on few hypotheses (Box 4.1) on habitat preference, diet, sociality, territoriality, nest substrate choice, nest type and height, body weight and nomadic nature of the species. The details of the life-history traits were procured from the published literatures (Del Hoyo et al., 1992), (del Hoyo *et al.* (1992-2002, 2003-2008, Appendix 2).

The species across urban to rural gradient was classified based on their presence in the most urbanised areas (here habitats such as LTHDBA, MTHDBA and HTHDBA – see chapter two for details of habitat). Urban Exploiter (UE) were the species present in most urban sites, Urban Adapters (UA) were present in moderate number of urban sites and Urban Sensitive (US) were very rare or absent in urban areas. These terms were adopted from the classifications followed in Blair (1996).

The role of life-history traits in the selection of species to urban areas were studied based on the tolerance category of species to urbanization such as US, UA and UE. The life-history traits were converted into dichotomous data (into presence absence) based on the hypotheses (Appendix 2). This data was then subjected for step-wise linear regression using SPSS version 16.0 (after checking for multi-collinearity) taking urban sensitiveness or tolerance as the dependent variable. Pearson correlation was found between life-history traits to remove auto-correlated traits.

BOX 4.1 HYPOTHESIS BASED LIFE-HISTORY TRAITS, ON SELECTION OF BIRDS SPECIES IN URBAN AREAS, CONSIDERED FOR THE PRESENT STUDY

1) Habitat: Species belonging to closed habitat may find difficulty in finding suitable habitat in urban areas, as it contains very few naturally vegetated areas.
2) Diet: The species that has very specific diet requirement – specialists such as insectivores might not survive in urban areas
3) Breeding:
   a. Nest Substrate: The availability of nest substrate is important for birds. The substrate could be classified in general into fork (trees, bushes), platform (ground, rock) and cavity/hole (ground/trees/rock). In urban areas, cavities and platforms are available in buildings or walls. Hence, species that make nest in the substrate 'fork' might not find sufficient substrates in urban areas
   b. Type of nest: Few birds neatly weave their nest, on the other hand some birds just deposit nest materials. Considering the limitations in the urban areas, the species that weave nests might not survive, whereas species that make nest by depositing nest materials might be favoured.
   c. Nest height: Urban areas might not support species that place nests at a lower height, as there are too many disturbances in the form of people, traffic and lack of vegetation.
4) Sociality: Species that opportunistically flock might find advantage in urban areas as it helps in utilising resources efficiently.
5) Territoriality: Highly territorial birds may not be favoured in urban areas due to limitations in space and food.
6) Body mass: Species with lower body mass might not survive in urban areas due to their high-energy demand, small home ranges coupled with predation pressures.
7) Migration: Species with nomadic nature might be favoured in urban areas as they have larger home ranges and can move locally in search of feeding, nesting or roosting.

4.3.1 SURVIVAL STRATEGIES

Urban areas are habitats under human manipulation, characterised by an array of fabricated structures, where avian species are expected to have limitations in resource availability. Therefore, species might adopt strategies to cope with the changes in urban habitat.

I hypothesise that finding 'analogues' as Gilbert (1991) observed in birds in urban areas, could be one of the strategy to cope with urbanization. To test the hypothesis, nest substrate use of birds in urban areas were studied. As urban areas are dominated by manmade structures, species might find limitations to find substrates for nesting. The analogues of the nest substrate were identified during nest search conducted in the study area. A place was considered as analogue, if the basic structure in the artificial substrate to an extent to match with that of the natural substrate. E.g. Tree branch vs. forks of the mobile tower, cavity in the tree or ground vs. ventilations, electric posts, or holes in the buildings (Plate 4.1).

Cost for breeding is high. However, flexibility in nesting timings is essential to survive in a challenging habitat. Species with multiple broods at different time are known to survive in urban areas (Blair 1996). For the present study, the duration of breeding activities in urban species was taken as the indicator of the flexibility of breeding. In order, to document the timings of breeding, the active nests sighted or activities such as collecting nest materials, nest construction; adult birds flying with food, were taken as breeding observations, which were then tabulated in the presence-absence checklist for the respective months.

Thermal stress could be a major problem in urban areas in tropical countries, where the effect of the phenomenon of heat islands is more prevalent owing to the lack of covering in urban areas and closely placed building. The diversity of covering regulates avian communities that settle in an area (Lo Valvo et al., 1985). The condition might be more obvious in the case of tropical cities. In tropical forests, bird species rest during 'hot' hours as evident from their activity patterns. The question I ask is does heat stress affect bird species in urban areas of tropical city? In order to check if it could affect bird species in urban areas, this study compared substrates and activity levels at different times of the day, such as morning (700-1100hrs), afternoon (1100-1500hrs) and evening (1500-1900hrs). This classification enabled a clear comparison of hot hours with other timings.

The activities of the species were collected using spot samples and were categorised and recorded as agonistic, fly, forage and sit. The activity 'forage' covered direct observation of feeding and 'fly' included short flights as well as hovering high in the sky. The substrate use was categorised into ground (while bird is seen at height '0' such as open ground and road), building (small shops to high rise buildings), electric wire/post (inclusive of light posts), mobile tower, and air (all occasions when they are on flight). Among the substrates a category 'others' were included to cover the observation of bird species sitting on cattle and 'rocky' outcrops.

The data on the activity and substrate use by birds was collected by spot sampling (observations) of 10-20 seconds. While recording the spot samples, at each spot the activity of only one species was recorded. Such observations from morning to evening were grouped into three time classes of four hour duration (morning (0700-1100hrs), afternoon (1100-1500hrs) and evening (1500-1900), Table 4. 1). The data were then converted into percentages to normalise for unequal number of sampling.

TABLE 4. 1 SAMPLING EFFORT TO RECORD ACTIVITY AND SUBSTRATE USE

The details of spot samples collected to record activity and substrate use.

	Total	BRP	CM	Cr	HS	BK	Koel
Morning	864	65	145	420	122	47	65
afternoon	273	33	47	130	15	25	23
Evening	317	27	48	182	15	32	13
Total	1454	125	240	732	152	104	101

Abrev. BRP = Rock pigeon, CM= Common myna, Cr = Crow, HS = House sparrow, BK = Black kite, Koel = Asian koel

To test if intelligent species occupy urban areas, brain variables were compared between urban and non-urban group. Brain variables were collected from King and Mc Lelland (1985), Iwaniuk et al. (2006) and Burish et al. (2003). The values given in the urban exploiter category except for Rock pigeon and House sparrow were representative. The species in the urban areas were selected based on the published records of species from other cities. Families represented by urban species are regarded as urban families. The analysis comparing brain variables was conducted at a family level. During the analysis, all urban families were deleted from the non-urban list, to avoid any phylogenetic influence. T-test compared different brain variables between urban and non-urban group. To test the differences in the ratio of functional telencephalon present in brain, first Man-Whitney test was conducted to understand the variation between urban and non-urban group. Kolmogorov-Smirnov analysis was conducted to see similarity between the species within urban exploiter groups Non-parametric analysis was used, as the data was not normally distributed.

4.4 RESULTS

Species belonging to seven orders, 19 families and 27 genera represented urban areas (Table 4.2). The distribution of species within Order and Family did not significantly vary between rural and urban areas; the variation was only at a genus level (Table 4.3). On the other hand, urban and suburban community were much similar.

TABLE 4.2 ORDER, FAMILY & GENERA OF BIRDS IN URBAN-RURAL AREA OF COIMBATORE CITY

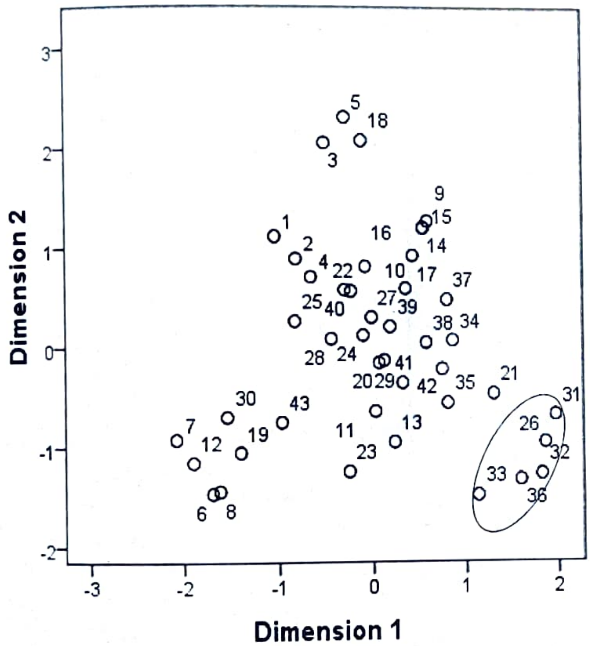
	Rural	Suburb	Urban
Order	12	9	7
Family	33	19	13
Genus	46	27	16

TABLE 4.3 CORRELATION OF ORDER, FAMILY AND GENUS OF BIRDS IN URBAN-RURAL AREA OF COIMBATORE CITY

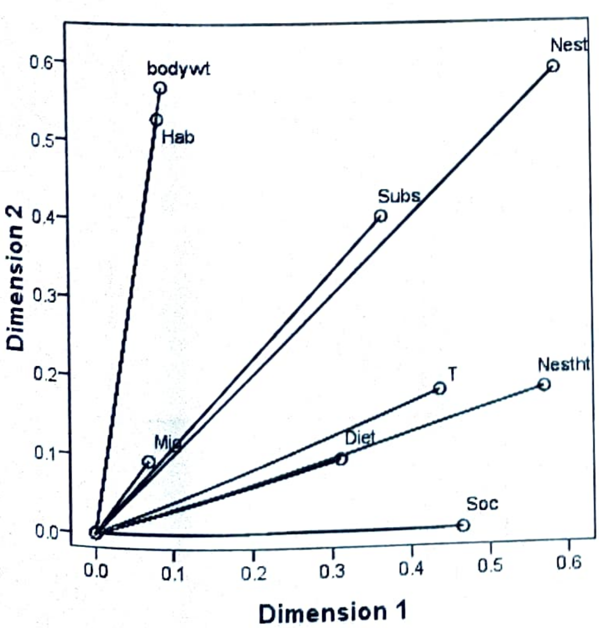
Order, df=12	Order, df=12	Family, df=33	Genus, df=46
Rural*Urban	0.962, p=.000**	0.591, p=.000**	0.140, p=.353
Rural*Suburb	0.985, p=.000**	0.795, p=.000**	0.292, p=.049*
Urban*Suburb	0.974, p=.000**	0.768, p=.000**	0.674, p=.000**

**. Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

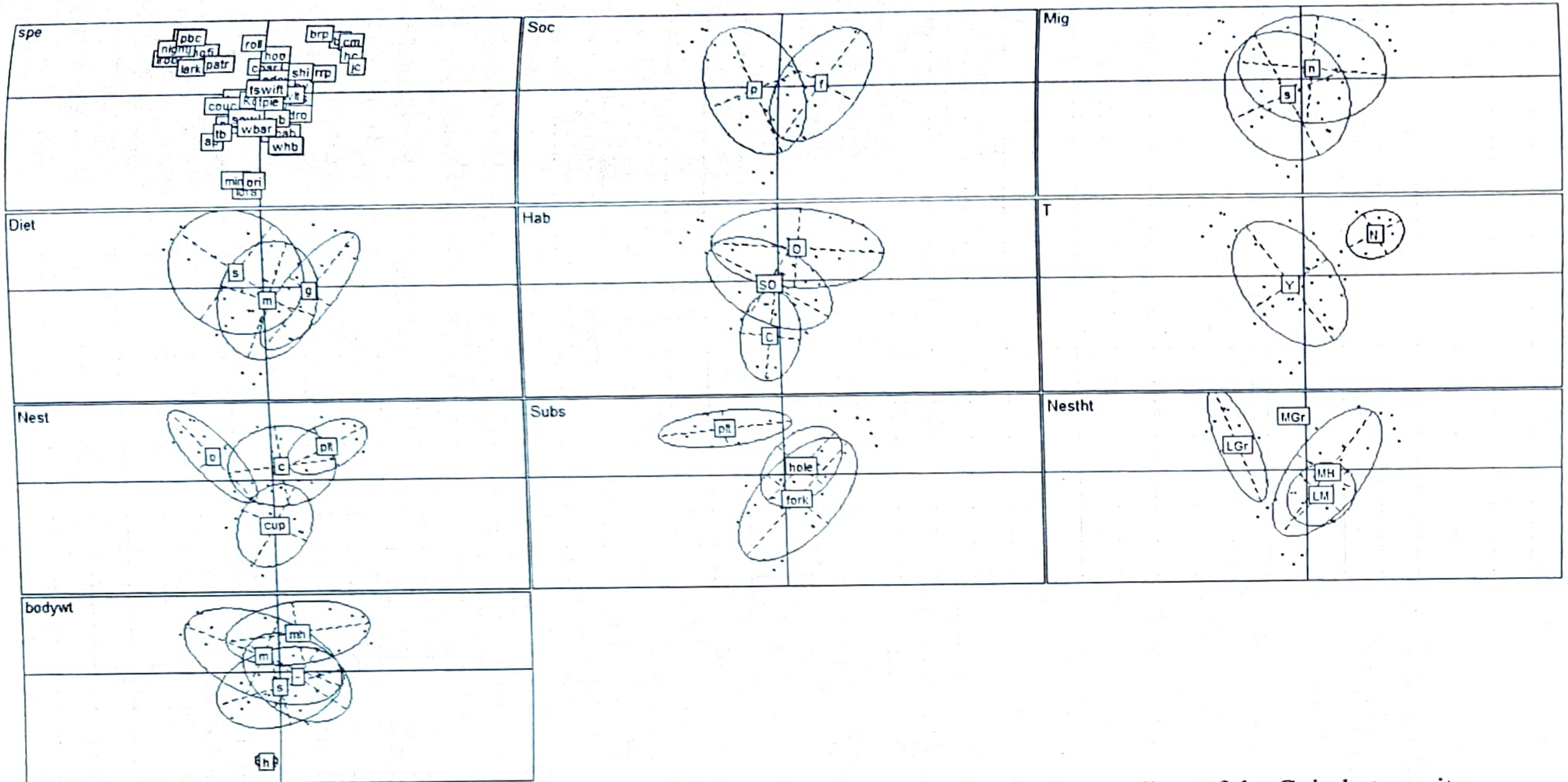
The Multiple Correspondence Analysis (MCA) done on the life-history traits of species revealed four clusters (Figure 4.1a, b). A distinct segregation of species based on life-history traits was seen for UE community from the rest (Figure 4.1a). The exception in this category was Koel. The urban adapter and urban sensitive species could not be distinguished clearly based on life-history traits. The first axis of the bi-plot incorporated 33% variation in the data set and second axis incorporated 29%. Thus, 62% variation in the data was explained by MCA. The first axis of the bi-plot represented species behaviour and nest traits such as sociality, territoriality, diet, nest type, nest height; the second axis constituted habitat, nest type, nest substrate and body weight. The UE species differed from the rest based on nest substrate & type, habitat and body weight (Figure 4.1b). The life-history traits exhibited by UE species were flocking nature, general diet, not territorial, nests at a height of medium to high and made nest of platform or cavity in the substrate fork or cavity were seen more frequent in urban areas. The body weight also fell in a range of medium to high (Figure 4.1c).



a. Multiple correspondence plot indicating species numbers, the highlighted area is the cluster with urban exploiter species. House sparrow and Asian koel did not fall in the cluster along with other species that belong to urban exploiter category. Case numbers of urban exploiter species - Jungle crow (31), Common myna (32), Rock pigeon (33), House sparrow (34), Black kite (36), Koel (24).



b. Multiple correspondence plot showing the life-history variables that contributed for classifying the species. Nest type, nest substrate, body weight and habitat showed maximum values.



c. Scatter plot of MCA done on the life-history traits of bird species across an urbanization gradient of the Coimbatore city
The MCA (Multiple-correspondence analysis) show that they were related based on diet, social structure, nest type and territoriality from the selected variables tested. Each box represents category heads. The black dot represents the species and the circles represent the cluster defined by individual category heads.

FIGURE 4.1 (a, b, c). MULTIPLE CORRESPONDENCE ANALYSIS CARRIED OUT WITH LIFE-HISTORY TRAITS OF THE SPECIES ACROSS URBAN TO RURAL GRADIENT OF THE COIMBATORE CITY.

The correlation of life-history traits converted into dichotomous data based on the hypotheses given earlier (Box 4.1) revealed following (Table 4.4). The species that were seen solitary or in pairs correlated with life-history traits such as specialised diet, territorial nature and small body weight; resident nature of the bird species was correlated with closed habitat; well-constructed nest was correlated with territorial nature, fork nesting and small body weight; small body weight correlated with low nest height (Table 4. 4).

Linear regression and step-wise regression was done with life-history traits. The combinations of life-history traits chosen for analysis were a) sociality, habitat, nest type and nest height / body weight, b) Diet, territoriality, habitat, nest substrate and nest height / body weight. The combinations were chosen after accounting for autocorrelation. Habitat was chosen instead of migration as both were correlated, considering the fact that latter is a resultant of the former. In all analyses 'habitat' (R^2=0.43, p=0.009) turned out to be the only significant factor among the life-history traits selected in the stepwise regression (Table 4.5).

TABLE 4. 4 CORRELATION OF LIFE-HISTORY TRAITS OF BIRDS ALONG URBAN TO RURAL GRADIENT OF THE COIMBATORE CITY

	S	M	D	H	T	N	N. Sub	N. ht	B. wt
S	1	0.248	.427*	0.059	.433**	0.017	0.083	0.144	.420*
		0.15	0.011	0.737	0.009	0.921	0.637	0.408	0.012
M	0.248	1	-0.007	.363*	0.258	0.18	0.141	0.315	0.326
	0.15		0.969	0.032	0.134	0.302	0.419	0.065	0.056
D	.427*	-0.007	1	0.145	0.089	-0.057	0.037	0.207	0.168
	0.011	0.969		0.406	0.612	0.745	0.832	0.233	0.334
H	0.059	.363*	0.145	1	0.272	0.324	0.257	0.068	0.108
	0.737	0.032	0.406		0.114	0.058	0.137	0.698	0.538
T	.433**	0.258	0.089	0.272	1	.361*	0.086	0.25	0.316
	0.009	0.134	0.612	0.114		0.033	0.624	0.147	0.064
N	0.017	0.18	-0.057	0.324	.361*	1	.461**	0.09	.476**
	0.921	0.302	0.745	0.058	0.033		0.005	0.606	0.004
N. Sub	0.083	0.141	0.037	0.257	0.086	.461**	1	-0.229	-0.018
	0.637	0.419	0.832	0.137	0.624	0.005		0.186	0.918
N.ht	0.144	0.315	0.207	0.068	0.25	0.09	-0.229	1	.474**
	0.408	0.065	0.233	0.698	0.147	0.606	0.186		0.004
B. wt	.420*	0.326	0.168	0.108	0.316	.476**	-0.018	.474**	1
	0.012	0.056	0.334	0.538	0.064	0.004	0.918	0.004	

* Correlation is significant at the 0.05 level (2-tailed), ** Correlation is significant at the 0.01 level (2-tailed)

Tabulation of data into presence absence (1,0) is given in the brackets.

Abrev.: S= Sociality (solitary/pair or not), M= Migration status (resident or migratory), Diet (specialist or others), H= habitat (closed habitat or others), T= territorial (territorial or not), N= nest type (nest made by weaving/ constructing or others), N. Sub = nest substrate (fork or not), N.ht = nest height (nest at low height or not), B. wt = body weight (small body weight or not).

TABLE 4.5 STEPWISE REGRESSION OF LIFE-HISTORY TRAIT OF SPECIES AGAINST THEIR TOLERANCE TO URBANIZATION

Model	Variable	df	Std. Error of estimate	R^2	F	Sig.
1	Habitat	34	0.69	0.43	7.65	0.009

4.4.1 STRATEGIES ADOPTED BY SPECIES IN URBAN AREAS

4.4.1.1 HABITAT ANALOGUES USED BY SPECIES IN URBAN AREAS

Habitat/resource analogue can be considered as an alternate that can satisfy the needs of a species. Rock pigeon identifying buildings in urban areas as analogues to 'rock' in the wild that fulfil their nesting and roosting needs, a granivore living on cooked grains, or crows using metal wires for nests instead of stick are common examples of using analogues (Table 4.6).

The use of habitat analogue in the case of substrate used for placement of nest was explored in the urban areas of Coimbatore (Figure 4.2). The nest substrate use of urban exploiter species was mainly in trees (71%), followed by buildings (12%) and Mobile towers (8%). Small percentage (4%) of nests was seen in well and rock. Further classification of the nest substrate use of UE species based on the type of nest they make revealed more details. The UE species that made platform-cup type nest made nests mainly in trees (94%); a small percentage nested in mobile towers (6%). Whereas, the UE species that made platform nests, used mainly buildings (53%) and well (47%). The species that nests in cavities used different nest substrates, mainly buildings (53%), followed by rock (22%), tree (19%) and well (6%).

4.4.1.2 BREEDING ACTIVITIES OF URBAN EXPLOITER SPECIES

All urban exploiter species showed multiple brooding. However, the timings showed species specificity. Non-passerine species such as Rock pigeon and Black kite showed less number of broods when compared to passerines such as crow, myna and sparrow. Rock pigeon had mainly 2-3 broods spread over six months, whereas Black kite had only one brood. Crow had around three broods spread over seven months. Common myna had around three-four broods spread over nine months. House sparrow also like myna had around three-four broods spread over eight months. Thus, in general urban exploiter species showed on an average two-three broods per year (Table 4.7).

4.4.1.3 SUBSTRATE USE OF URBAN EXPLOITER SPECIES DURING THE DAY

Of the six species studied, Rock pigeon, Black kite and Asian koel used only a few substrates when compared to others (Figure 4.4). Majority of the time Rock pigeon used ‘air’, followed by ‘building’; other categories comprised only very small percentages. Afternoon showed a slight increase in the amount spent in the ‘air’.

Asian koel spent most of the time in trees and relatively lesser time in air; they were rarely seen on building. In the case of koel also afternoon witnessed slightly higher time in flight. Black kite also used a major portion of their time in the air, and very small proportion in trees. There was no notable difference in time spent on each substrate between morning, afternoon and evening. Very small amount of time was spent by the species in mobile towers.

Common myna, House sparrow and Crow used diverse substrates during the day. Common myna used majority proportion of time on trees that gradually increased from 32% in the morning to 64% in the evening. In the ‘air’ they spent 28 – 35 % of time, lesser in the morning than in the afternoon. In the morning these species spent their time on the substrates in the sequence - tree (31%), air (28%), followed by ground (15%), building (14%); electric wire/post (8%), mobile tower (3%) and others (1%). In the afternoon the proportion of time spent on tree and air increased, whereas time spent on building and ground decreased considerably. Building and ground use was absent in these birds during evening. Whereas, the proportionate usage of mobile tower, electric post/wire and others remained same in the afternoon as in the morning time, while usage of those substrates was not seen in the evening.

The usage of substrates differed considerably with timings of the day in the case of House sparrow also. In the morning sparrows spent 44% time in the buildings, it rose to 60% in the afternoon and reduced to 27% in the evening. In the morning time sparrows spent less time in the air (17%), than both afternoon and evening (27%). The time spent in the ground was high in the morning (19%), lower in the afternoon (7%) and absent in the evening. The time spent in the electric post/wire in the morning (12%), which decreased in the afternoon (7%) and rose to the highest in the evening (27%). In the case of Crow, tree usage was highest in the afternoon (56%) and evening (40%), than morning time (35%). Building usage was highest in the morning (21%), least in the afternoon (5%) and medium level in the evening (15%). During the day crow spent 30 - 39% time in the ‘air’. They spent a small fraction of time in the ground during morning (7%), afternoon (2%) and evening (1%).

4.4.1.4 ACTIVITY OF URBAN EXPLOITER SPECIES DURING THE DAY

Rock pigeon (49%, 64%, 56%) and Black kite (87%, 96%, 91%) spent majority time in flight during morning, afternoon and evening respectively (Figure 4. 5). Other activities were negligible in the case of Black kite. Rock pigeon spent 43%, 36% and 41% time in 'sit' during morning, afternoon and evening respectively. Asian koel spent most of the time in 'sit' and flight was restricted to morning and afternoon. In the afternoon, time under 'fly' showed a slight increase than under the 'sit'. The time spent in flight increased from 18% in the morning to 21% in the afternoon, and was least in the evening (8%). The activity 'sit' was higher in the evening (92%) and was lesser during both afternoon (74%) and morning (75%). Flight in House sparrow abruptly increased from morning (15%) to 27% in the afternoon and evening. In the morning 50% time was spent in 'sit', 53% in the afternoon and 60% in the evening. In the morning sparrows spent more time for foraging (28%) and only 6% in the afternoon. Agonistic activities were minimal. Crow was seen in flight 31% time during both morning and afternoon time, and it rose to 45% in the evening. They spent almost half of their time in sitting/resting during morning (52%), afternoon (56%) evening (53. Crow also spent majority time for foraging in the morning. The time expenditure for foraging was morning (10%), afternoon (5%) and evening (2%). Agonistic activities were present in negligible amounts during all the time.

4.4.1.5 EXPLORING BRAIN VARIABLES OF BIRD SPECIES IN URBAN AREAS

The Man-Whitney test show that functional telencephalon ratio of the brain was significantly higher in urban group than the non-urban group (z= -3.037, df=63, p=0.002, Figure 4. 6). However, the Kolmogrov-Smirnov test carried out to see if the functional telencephalon ratio was similar within the urban species, show that species significantly differed (Z=0.404, p=0.997, df=11, Figure 4. 7). The crow had the highest functional telencephalon ratio, followed by myna and sparrow. Koel and Pigeon had the least proportion of functional telencephalon value. None of the other brain variables were significantly different from the non-urban species (Table 4.8).

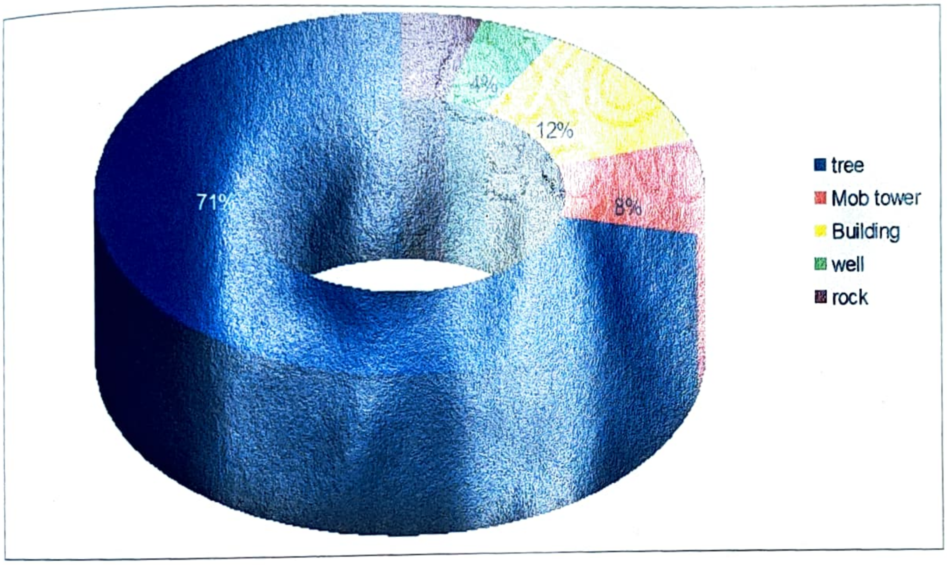


FIGURE 4. 2 NEST SUBSTRATES USED BY URBAN EXPLOITER SPECIES IN COIMBATORE

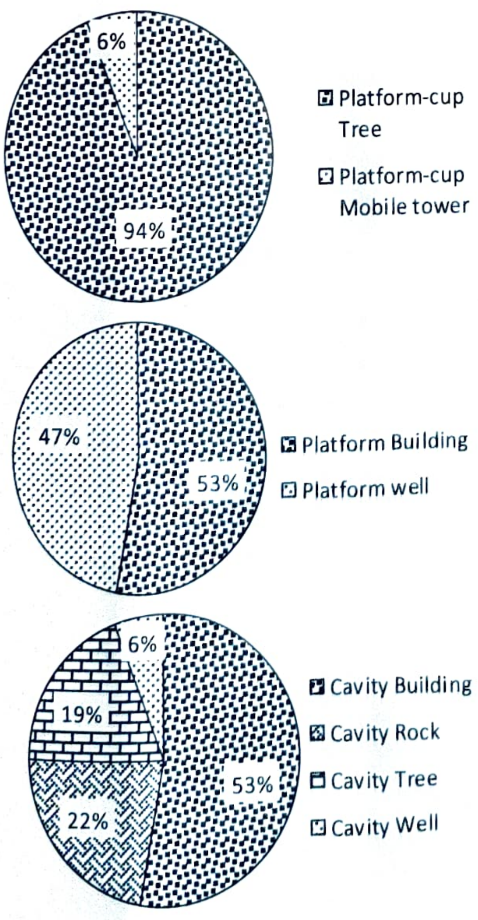


FIGURE 4. 3 NEST SUBSTRATE USE IN URBAN EXPLOITER SPECIES BASED ON TYPE OF NEST SEEN IN THE URBAN AREAS OF THE COIMBATORE CITY

TABLE 4.6 HABITAT ANALOGUE USED BY BIRD SPECIES SEEN IN URBAN AREAS

Trait	Type	Substrate use in primary habitat	Analogue used in urban area
Diet	Omnivorous	All	Cooked fruit /vegetable/ seed/meat
	Frugivorous	Fruit, honey and insect	Cooked fruits /vegetables/ rice
	Granivorous	Grain and insect	Cooked seed and its products
	Carnivorous	Invertebrates and vertebrates	Cooked meat
Nest	Platform	Rock	building ventilation / sunshade
	Platform-cup	Tree branch	building sunshade, mobile tower
	Cavity	Tree hole, rock crevice	building ventilation / sunshade/ shutter / hole, light post
	Cup	Tree / bush / grass	NIL
Nest material	Platform	Stick, feather	Metal wire/ cable
	Platform-cup	Stick, fibre, feather	Metal wire/ cable, plastic cover
	Cavity	Fibre, feather, leaves	Plastic wire, fabric, plastic cover
	Cup	Fibre, feather, leaves	Plastic wire, fabric, plastic cover

TABLE 4.7 SEASONALITY OF ACTIVE NESTS OF URBAN EXPLOITER SPECIES OBSERVED IN URBAN AREAS OF COIMBATORE DURING 2008-2010

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BRP			■	■				■	■		■	
Crow			■	■	■		■		■	■	■	
Myna	■		■	■	■	■	■		■		■	■
BK			■									
Sparrow	■		■	■	■	■		■	■		■	

Note: Coloured cells indicate months with records of breeding activity

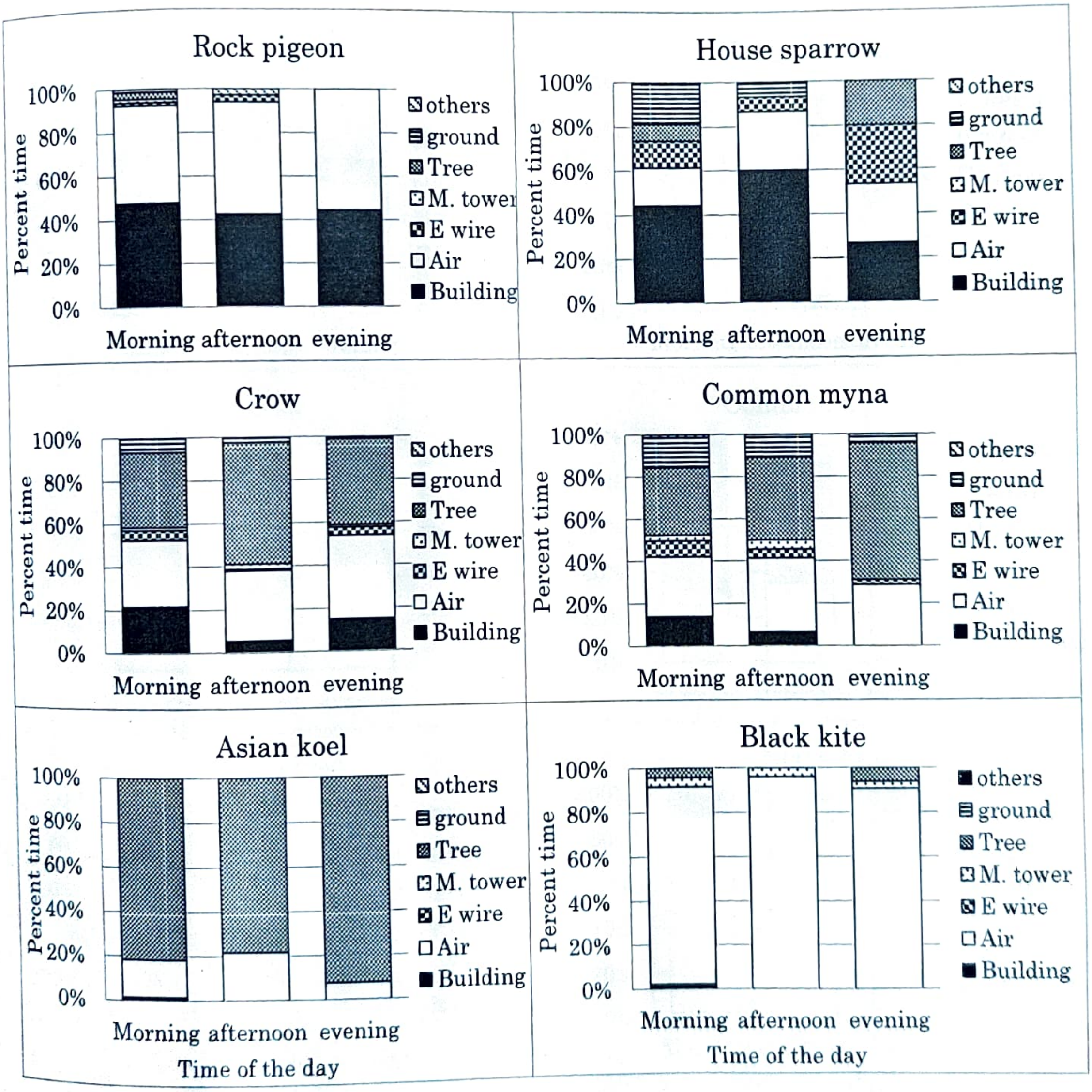


FIGURE 4. 4 SUBSTRATE USE BY URBAN EXPLOITER SPECIES AT DIFFERENT TIMINGS OF THE DAY

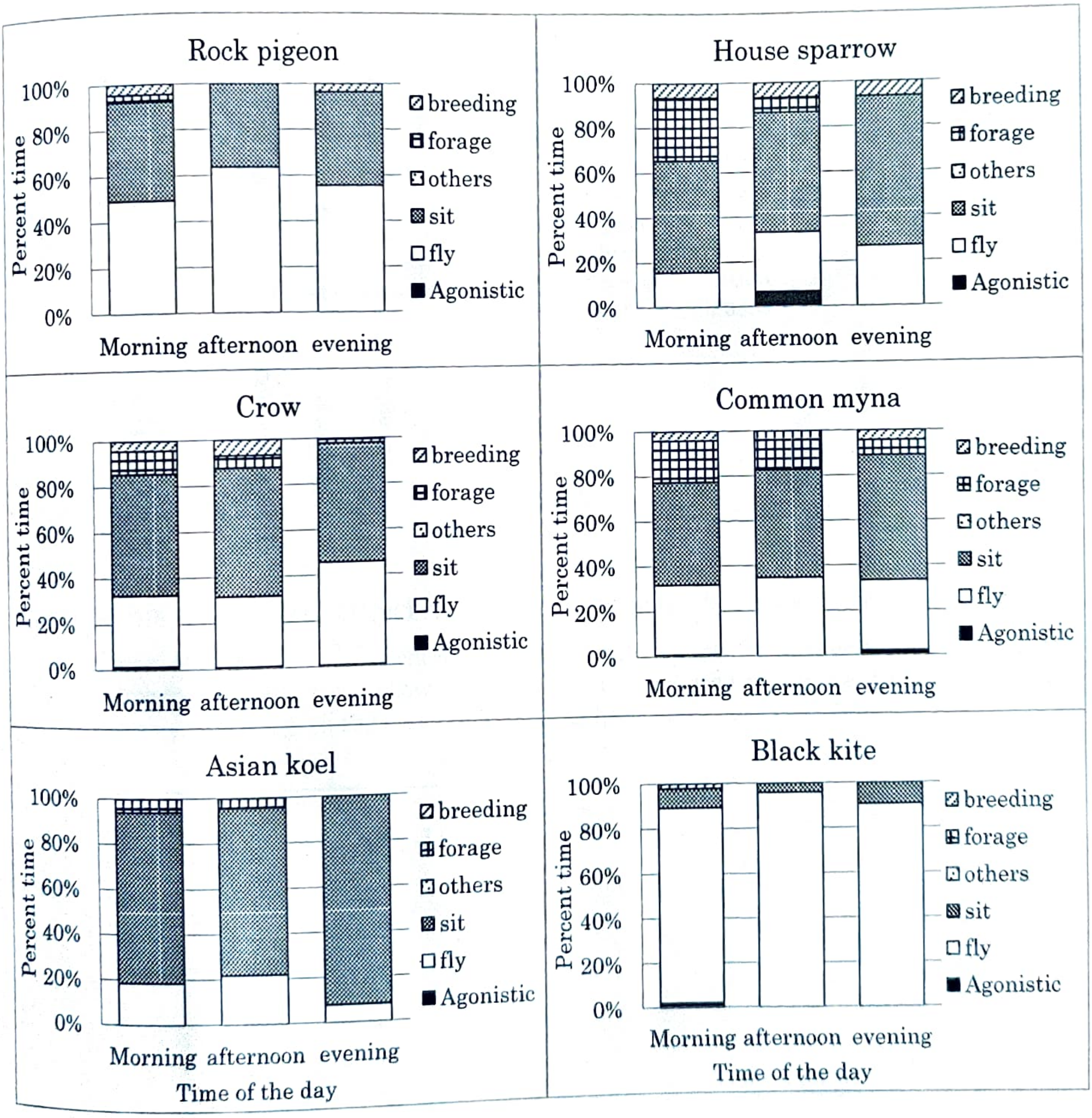
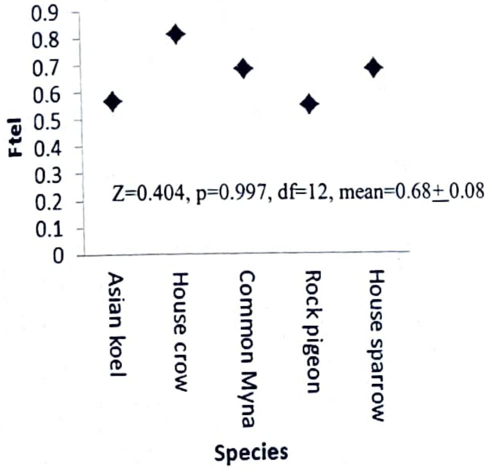


FIGURE 4. 5 ACTIVITY OF URBAN EXPLOITER SPECIES AT DIFFERENT TIMES OF THE DAY



	Ftel
Crow	0.806
Pigeon	0.552
Myna	0.683
Sparrow	0.686
Koel	0.564

FIGURE 4. 6 THE FUNCTIONAL TELENCEPHALON RATIO OF BRAIN IN URBAN EXPLOITER SPECIES

The proportion of the functional telencephalon of the urban exploiter species were subjected for Kolmogrov-Smirnov test. The result show significant variation between the species belonging to urban exploiter category. Except pigeon and koel all other species had comparatively high values.

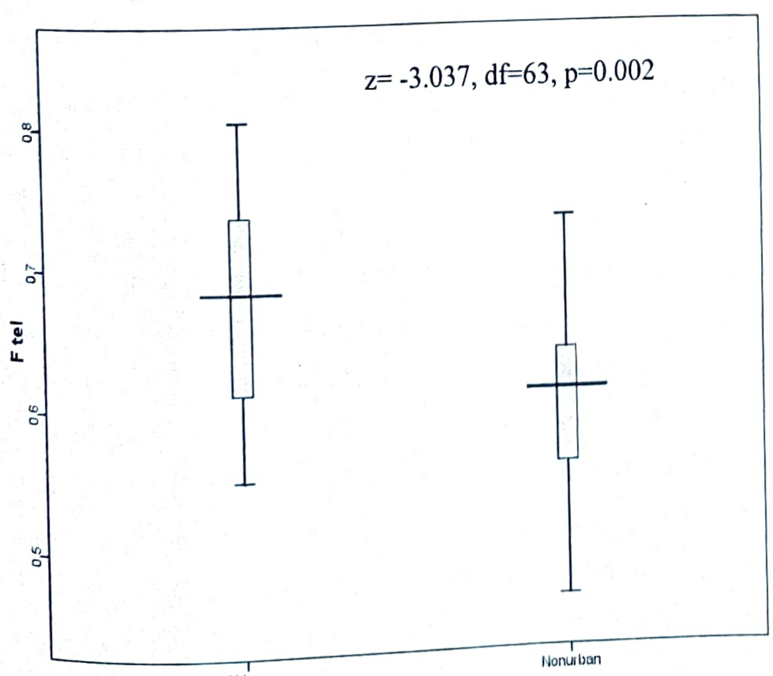


FIGURE 4. 7 SPECIES THAT SURVIVE IN URBAN AREAS HAD COMPARATIVELY HIGHER FUNCTIONAL TELENCEPHALON RATIO

TABLE 4. 8 COMPARISON OF BRAIN VARIABLES BETWEEN URBAN AND NON-URBAN BIRD SPECIES

The brain variables of urban and non-urban species were compared using a t-test. The variables chosen were brain volume, the ratio of brain volume to body mass, volume of Cerebellum and the ratio of Cerebellum volume to body mass and brain volume. The result shows that there was no significant difference between the two groups.

t-test for Equality of Means			
	t	df	Sig. (2-tailed)
Brain volume	1.371	41	0.178
BVBM	-0.485	41	0.63
Cb	-1.959	37	0.058
Cb/BM	0.713	37	0.48
Cb/BV	2.777	37	0.009

Abb. BV=Brain volume, BM=Body mass, Cb= Cerebellum

4.5 DISCUSSIONS

This study found that life-history traits of a species played major role in species survival, than the phylogenetic affinities. The distribution of species was not significantly different at the order or family level in urban areas, even though the number of species seen in the Coimbatore city was lower. The correlation between the urban and rural communities at the level of genera also did not correlate. This means that the species selection to urban areas was not influenced by their phylogeny.

The life-history traits such as type of nest, substrate where the nest is placed, natural habitat of the species and body weight differentiated species that survive in urban areas from the rest. However, when species were grouped as US, UA, UE in response to the effect of urbanization on the species, and then life-history traits were examined, habitat was found to be the only significant trait that played a significant role in species selection to urban areas. In order to survive limitations in urban areas, these life-history traits also helped them adopt certain strategies such as finding habitat analogues, flexible breeding periods, changing substrate usage to endure heat stress and maintain reasonable activity levels all through the day, even during peak heat period.

The multiple correspondence analyses also revealed that the species in the urban exploiter category were different from the rest based on life-history traits such as nest substrate, nest type, habitat and body weight. However, House sparrow and Asian koel was not included in the cluster. This was mainly because of their territorial nature that stands out from other species. Moreover, Asian koel was mostly seen in pairs, unlike all other UE group that were seen in flocks and did not make aby nest as it was a brood parasite. The urban exploiters made mainly platform, platform-cup or cavity nests.

However, 'habitat' was found to be the significant factor when it comes to the effect of urbanization on the species. The results were revealed by the step-wise regression on life-history traits of the species against their tolerance categories to urbanization as the dependant factor. The results agree with the findings of other studies that the habitat of species is important in the selection of species to urban areas (Clergeau et al., 2006; Blair, 2004). The studies of (Reale and Blair, 2005) report the importance of nesting habitat for the survival of birds. The species belonging to 'closed' habitat did not thrive in urban areas. It means that urban areas favour open habitat species. All species in urban exploiter category recorded from the Coimbatore city belonged to 'open' habitat. This finding agreed with the opinion of (Lundholm and Marlin, 2006) that urban environments most closely approximate cliff or talus slope environments.

The results of the step-wise regression analysis partly support and partly contradict previous studies that life-history strategies differ between urban sensitive (US), urban adapter (UA) and urban exploiter (UE) group, especially based on habitat, diet, sociability, and migratory status (Kark et al., 2007; Devictor et al., 2007; Clergeau et al., 2006; Lim and Sodhi, 2004). In the present study diet, sociability and migratory status was not the characters distinguishing UE from UA and US. The present results differ, partly due to the data considerations, as I have made the data based on presence absence based on specific questions asked. This was to make data more sharp and simple to interpret. On the other hand, the categorical regression done (results not presented here), with the original data on life-history traits of species (not dichotomously arranged) against the three urban sensitive categories such as US, UA and UE as dependant variable revealed strong correlation between territoriality, habitat and diet. Moreover, migratory status of the species was strongly correlated with the habitat. Habitat was considered for further analysis, considering the fact that migration is a resultant of habitat factors. Thus the stepwise regression with the dichotomously arranged life-history traits could successfully indicate the most significant result.

The composition of species in the study area could be another reason for the contradictory results with the previous researches. The type of forest in Anaikatty Reserve Forest is semi-arid in nature characterised mostly by dry areas with scrub and small thorny trees. This kind of forest hold fairly large diversity of birds, than other type of forest as it provides different habitats. 194 species of birds belonging to 45 families and 17 orders were recorded from this region (Nirmala, 2013). Moreover, the present study was conducted in a tropical area where diversity is expected to be more than temperate areas, where the above studies were conducted.

Habitat or resource analogues appear as a decisive factor that determines the survival in urban areas. Gilbert (1991), Lim and Sodhi (2004) also found that certain man-made structures, such as ventilations in the buildings, which are analogues to their original micro habitat needs, are used by bird species in urban areas to meet specific requirements for breeding/roosting. The species that were tree nesters used mobile towers, and species that were cavity or platform nesters used windowsills or ledges on the buildings, open wells or rocks (Figure 4.8).

The species, except Black kite was seen nesting in more than one season. Non-passerines rarely and many passerines exhibit multiple brooding. The result of the present study is supported by the finding that feral Rock pigeon, a non-passerine exhibit multiple brooding in urban areas. Reale and Blair (2005) studied nesting of birds across an urban gradient and concluded that nesting success is determined by nest site availability and the ability to produce multiple broods that may determine bird distribution along the urbanization gradients. It is found that the food availability determines the number of brood (Perrins and Arlott, 1987). More number of broods observed in the urban exploiter species might be connected to the increased supply of food in urban areas. Even though, urban areas are characterised by increased supply of food, the main source is low quality anthropogenic refuse (Sauter et al., 2006). This could be one reason for the declining species abundances of certain species.

The factors such as flexibility in the nest placement, material choice and investment in nest making influenced by the life-history traits might help species in maintaining the costs of breeding in urban areas. The nest types such as platform, platform-cup or cavity are seen in urban exploiter species. Rock pigeon and Black kite make platform nests, Crow make platform-cup, Common myna and House sparrow make cavity nest. These types of nests can be made with less investment as the materials are placed loosely and less organised and require fewer materials and less time, unlike the well-structured nests. The birds have also explored different analogues for both placement of the nest substrate and constructing the nest (see Table 4.6 and Figure 4.2 in results).

The activity pattern and substrate use shows that the basic habitat requirements of the urban exploiter species are retained even in urban areas. The canopy dweller species such as Crow, Common myna and Koel spent majority time in trees. Rock pigeon spent most of the time in buildings and air, whereas House sparrows spent most of the time in building, ground and air. House sparrow exhibits the characteristics of a grassland species, at least in the morphology. Rock pigeon as the name indicates belongs to rocky areas as its natural habitat. The pigeon occupied high-rise buildings, whereas sparrow was mostly seen at lower heights (*pers.obs*). The inclusion of height in the analysis would have imparted more clarity into this matter.

During the hot hours, the usage of building by Crow and Common myna reduced, where as it increased in the case of House sparrows. Crow spent more time on tree, and myna used more time on the ground and tree during afternoon. For the House sparrow during afternoon time, while usage of the building increased, the use of electric posts / wires and ground reduced; these substrates were used predominantly during morning and evening. Time spent in sitting and flight was comparatively more during afternoon. These results indicate that higher heat in the afternoon hours affected the activity and substrate use of species such as Crow, common myna and House sparrow. These species retreated to the substrates under shade, such as building, or natural substrate such as tree and ground during the 'hot' hours.

The maintenance of the flight level and foraging shows that species foraged even during hot hours. The substrate use indicates that Crow was using tree and Sparrow was using buildings during afternoon time, probably for shade to escape from scorching heat. At the same time, foraging was also seen in these species in the afternoon. The level of activity 'fly' in the afternoon show that they probably were making use of the shade in the tree or building in the afternoon, and occasionally made small flights to the nearby shop/houses on the availability of food. In the case of Common myna also the trend was similar. However, this trend was not obvious in the case of Rock pigeon, Black kite and Asian koel. Asian Koel was mostly seen in the trees, which could have masked the actual activity from being recorded. Whereas, the difference in the taxonomic classification such as passerines and non-passerines explains the differences in the activity and substrate use of Black kite and Rock pigeon with the rest.

The activity pattern and substrate use of urban exploiter species in the present study show that non-passerines (Rock-pigeon and Black kite) were more tolerant to 'openness' as they spent most of the time in buildings or in air. The differences in their activity pattern could be related to the differences in the basal metabolic rate (BMR) of the species. Non-passerines are reported to have less BMR (basal metabolic rate) than passerines, i.e. they spent less energy per unit time (Gavrilov, 1999).

They seem to be apt for urban areas with resource limitation. However, urban areas are represented by comparatively higher proportion of passerines in terms of number of species. The BMR is highest for small sized birds. House sparrow is a passerine of low body weight. The observation of the use of more building in the afternoon time clearly states that this species is affected by heat. However, foraging and flight activity levels, though at a reduced levels, was maintained in the hot hours also. The fact that concrete buildings radiate heat coupled by the lack of natural substrates such as small trees in urban areas to sit points to a valid reason for the disappearance of House sparrow from tropical cities. The lack of small tree is found to be one of the major factors for House sparrow disappearance from urban areas of Coimbatore (Dhanya 2011).

This result of the substrate use and activity of urban exploiter species, support the hypothesis of the present study that thermal stress could be a major problem faced by bird species in the urban setups in tropical countries. The effect of the phenomenon of heat islands is more prevalent in tropical situations. Studies have found that the presence of bird species is affected by the cover in an area (Lo Valvo et al., 1985), perhaps as a means of shade from exposure to high temperature. The stepwise regression analysis of life-history traits in the present study also found that species were selected to urban areas for the 'openness' of the habitat; closed habitat species was rare at the progressive level of urbanization in Coimbatore city. The Purple-rumped sunbird and Tailor bird, an example of closed habitat species, were rarely seen in the city and was restricted to areas with house gardens and / or pavements with bushes or small trees. In one occasion, a pair of Tailor bird could not be located later after the last flowering bush was removed from the courtyard of a building in a commercial area of Coimbatore city. However, present data is not enough for a conclusive statement as of now. However, the question asked in the present study, "weather heat stress affect bird species in urban areas of tropical city?" require further in depth studies in this direction.

Opportunistic observations show that urban exploiter species extended foraging time to night hours utilizing the light source near food sources. Few species (House sparrow, Black drongo, House crow) were seen feeding on the insects that were attracted by the light during night (*pers. Obser.*). This finding was comparable with the results of some earlier studies. Using artificial food patches, Shochat, (2004) found that urban birds were more efficient foragers than desert birds. (Valcarcel and Fernández-Juricic, 2009) found that house finches in more urbanized areas formed larger flocks, had less tolerance to human approaches, and increased their pecking rates to compensate for the lower amount of foraging time than those in less urbanized areas in Southern California.

Most species that survive in urban areas utilize food available from anthropogenic sources such as hotel, butcher shop, go-downs and houses. Certain species such as Crow, track food sources by forming a network by scattering around, through which the information on food or danger of any kind is communicated across the flock that is spread out in a network. When a food source is located they aggregate. This maximises their return on effort to find food. In the present study, Crows were mostly seen in individuals of 1-6 and were seen in most of the sites surveyed. In fact it seems that they spread around and form a network so as to cover a larger area, and alert the members of food availability/danger of any kind. This phenomenon was evident from their occasional population rise to 60-70 individuals or more during this study. Black kites were also seen in groups hovering up the sky, scanning a larger area, which essentially serves similar purpose, but need more information to confirm whether it is a form of social networking. Pigeon and Myna were also seen scattered but does not seem to be similar to Crow, as the individuals do not seems to communicate with each other as effectively as Crows as these birds were scattered far apart. House sparrows were seen always in groups, confining mostly to their respective territories. Exhibition of social networking was based on the basic needs of species. Crow and Black kite showed certain degrees of scavenging behaviour, as they depended on anthropogenic food sources such as cooked grains and meat. However, Rock pigeon, House sparrow and Common myna were different in their choice of food (Table 4.6).

The survival strategies of crow (food preference, social networking, nest placement, brood selection, timing and nest substrate selection), perhaps aided by their larger functional telencephalon ratio (probably, enabling higher cognition), might be sustaining their population in cities. . It would be worthy to investigate whether the bird species that face pressure on survival in urban areas use intelligence / cognitive abilities to find solution strategy?

The range of flexibility and opportunistic behaviour exhibited by these species gave way for a question; are urban birds smarter? Do species that survive in urban areas have better cognition than the rest? The brain size of individual UE species compared to that of other species shows that UE types were not special as such, as there were other species that had similar levels of brain capacities; even among the UE types there were significant differences in brain capacities. The result match with the conclusion of the study of Maklakov et al. (2011) that passerines in urban areas have higher cognition. We propose that when there is a stress period then species might require higher cognition to formulate strategies. The studies suggest that the ability to learn, behave flexibly and innovate would be favoured under unpredictable variations in the availability of resources, as it would enable organisms to adjust to novel conditions (Schuck-Paim et al., 2008). Sol et al. (2005) reaffirmed the hypothesis that larger-brained organisms would be better prepared to cope with environmental challenges by introducing birds to novel situations. Schuck-Paim et al. (2008) measured the head size of neo-tropical parrots in different climatic regions and showed that brain size is associated with adaptation to climatic variability. In a study conducted to find out the specific traits in passerines species that made them adjust breeding cycles to the changes in biological timings, it was seen that species with the broadest ecological and thermal niches, the shortest mean migration distances and the largest brains were most able to adjust their breeding phenology to temperature variations (Moussus et al., 2011).

However, the present data is not enough to substantiate the relevance of cognition, as we are yet to understand that if behavioural strategies require higher cognition or weather the process of identifying analogues requires a certain or higher level of cognition. Rock pigeons adapted for a higher flight has a compact central nervous system (CNS) that can carry out exceptional ability of visual perception of landscape features. Visual perception is a process of understanding features as symbol codes that re-creates a virtual analogous structure in mind to identify features in reality. According Gibson's ecological approach to visual perception, mental processing is unnecessary to account for perceptual relationship with the world. Rather visual perception is direct and requires only a selection from information present in the ambient light (Gibson, 1992). The present study is supported by the observations of Gilbert (1991) and (Kark et al., 2007), that all birds that frequented urban area found analogous structures or materials for food, nesting or resting. However, it is not properly understood if the use of analogues by these species is just a passive act or it require a certain level of cognition. The survival ability of crow in urban area is exceptional with diverse strategies. This definitely justify higher ratio of functional telencephalon. Thus cognition might be relevant at least in the case of crow species that survive in urban areas. However, the data supported by the functional telencephalon ratio might not be sufficient to answer this question. The interpretation could be better augmented by an experimental study in future.

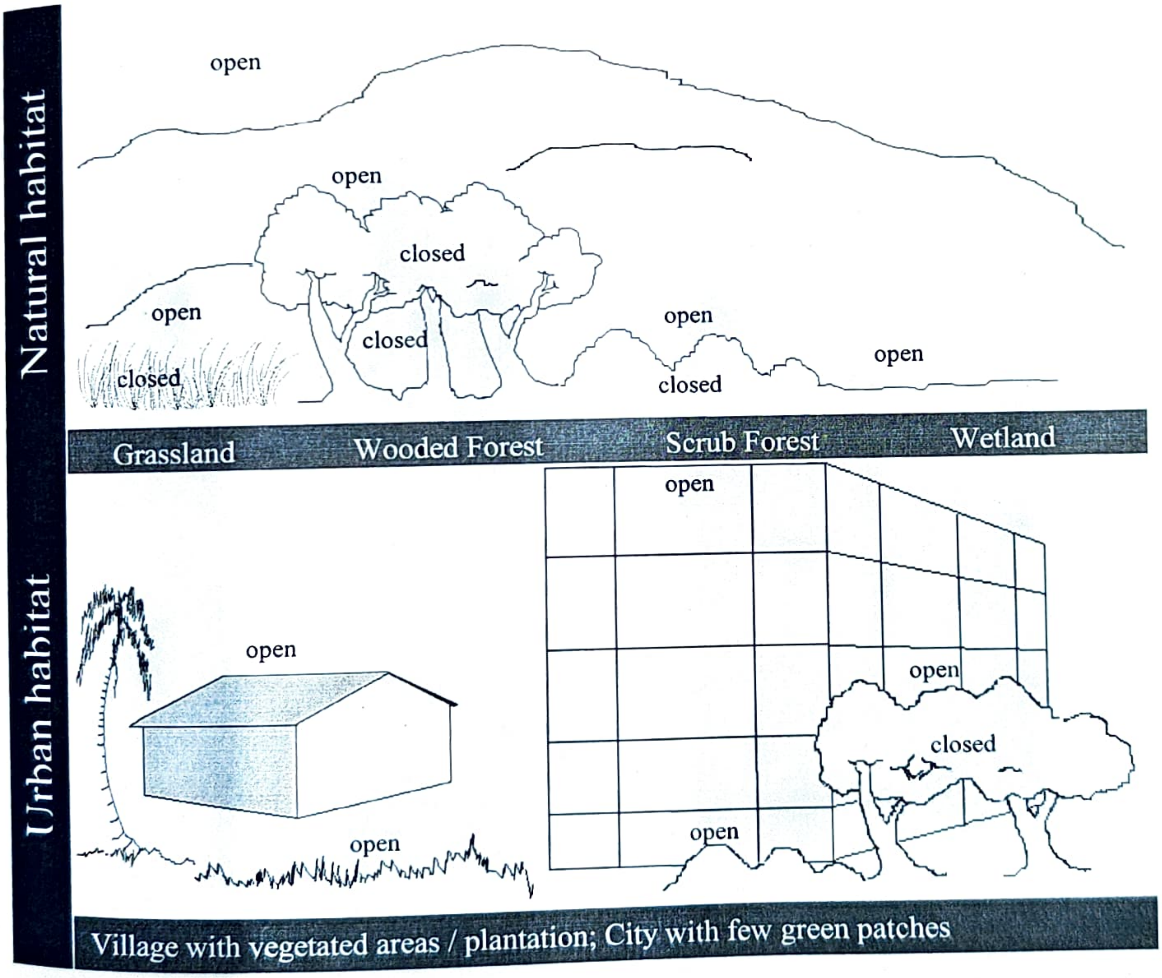


FIGURE 4.8 THE PICTORIAL DEPICTION ON THE CONCEPT OF ANALOGUES IN URBAN AREAS

The first half of the picture shows the natural habitat classified into open and closed habitat types. The open habitats are those occupied by species that are opened up, with free exposure to sunlight falls such as exposed rocks, open areas in grasslands, scrublands and wetland, and top of tree canopy. Closed habitats consists of cavities / caves in the rock, under the grass/scrub or wetland vegetation, inside the canopy or under the trees. The lower half of the picture depicts the urban habitat where the analogous structures and microhabitats could be found. Given a case, the buildings could be an analogue of rock; lawns could be an analogue of grasslands. The remnant patches of the trees and scrub also could be used by species.

PLATE 4. 1 HABITAT ANALOGUE USE IN BIRDS – NEST SUBSTRATE

The comparative picture of the nest placement of Crow in its natural substrate - the tree branch and its analogue that crow found in a mobile tower. The inset shows a closer picture of the nest placed in a mobile tower, that focus on the supporting bars of the tower that are analogous to the 'forks' of a tree branch.

Plate 4.2 The habitat analogues of House sparrow

House sparrow, a cavity nester found its analogue in a lamp shade in the veradah of a house, and in a street light in in Thadakam at Coimbatore city. The plate below is the analogue that crows found to sit. These two pictures that depict analogues of 'nest' and 'sit/rest' were given to clarify the concept of Analogues.

PLATE 4.3. CROWS IN THEIR NATURAL HABITAT IN COIMBATORE

CONCLUSION

As urbanization progresses natural landscapes changes and give way to novel habitats. The intensity and dimensions of urbanization is not linearly progressive and is difficult to predict. Various factors determine the pattern and progression of urbanisation and consequent changes in ecological features of a city. In that context, questions such as why and how certain species survive in urban areas, while majority disappear? were addressed in the present study by a) describing the community pattern of bird species along an urbanization gradient, b) attempting to explore the mechanism underlying this pattern by interpreting the population trend along the urbanization gradient with a focus on life-history trait of the species and c) explore the survival strategies adopted by species in urban areas. The bird community pattern exhibited a non-linear pattern with urbanization. Natural habitat of the species (where they originally belong to) acted as the key driver for the distribution of species with differential urbanization tolerance such as urban exploiter, urban adapter and urban sensitive. Further, investigations into the life of urban exploiter species shed more light into the importance of certain life-history traits of a species. The results show that species were favoured by the strategies or life-history traits they naturally possess (multiple brooding, type of nest - platform, platform-cup or cavity nest) or they adopted certain strategies (identify habitat analogue, change activity patterns and substrate usage in response to extreme climatic condition, forming social network in order to explore and spread the information on locally clustered resources among the flock members) to deal with limitations in urban areas. The findings of the present study concludes with a hypothesis that species do formulate strategies to survive in urban areas partly aided by their life-history traits that match with the habitat structures in urban areas and partly by their intelligence / cognitive capabilities.

Research in urban-rural gradient could be applicable to four different areas such as recreation (bird watching), conservation (wildlife in urban area), research and Management. The results of the research on community patterns in the present study could be a knowledge addition to the present literature. The checklist of birds in the Coimbatore city could be benefitted by bird watchers. The factors underlying the species distribution helps conservation efforts to restore species that are rare in the urban to rural gradient of the Coimbatore city. This study could also be of interest for those who study dynamics of changing landscapes; a community pattern along urban-rural gradient is best suited for such studies. The ecological research on urban-rural gradient provides details of urbanization process that happens from city to rural areas such as rate of urbanization and land use patterns. Such studies could directly benefit in urban planning with a focus on ecosystem process. Developing countries like India, where urbanization is unplanned, benefit from such study by way of baseline data on city growth pattern and urban sprawl. Corporation, Municipalities and Panchayats within the study area in Coimbatore could benefit from this study in undertaking management measures. Designing sustainable urban ecosystems that support species-rich bird communities also include maintaining key ecosystem services, such as clean air and water, waste decomposition, and pest control.

This study provides a preliminary investigation into the factors underlying species distribution and survival in the urban area of Coimbatore city in India. In future it is encouraged to undertake this study in different cities of India. India represents different climate zones in near proximity which would be the major significance of this study. Moreover, age of the city is reported to affect diversity. If we conduct a study all over India we could answer a wide range of questions that are unanswered in ecological patterns and processes, which is still in the stage of infancy of understanding. This could be expanded as a larger study that synchronise all branches that emanates from the ecological research in urban areas that congregate in management measures. Management measure synchronise people, wildlife, urbanization and research, and make urban areas a better place to live.

Whole point of research is to benefit human beings, either by monitoring existing activities for better management by further (a) refinement or (b) controlling existing standards or (c) by inventing technologies that are cost effective and efficient. We live in a delicate ecosystem, where all these studies/ activities/ initiatives are all a part of managing the ecosystem balance. The ultimate motive of 'conservation' is to manage ecosystem balance by protecting forests and wildlife. Conservation is the 'need of the hour' in urban areas, especially in the arena of unplanned urbanization reaching nooks and corner of the Earth. Hence, research in urban ecosystem is equally important as in any other field.

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APPENDICES

APPENDIX 1 ORDER, FAMILY AND GENERA OF BIRDS IN URBAN-RURAL AREAS OF COIMBATORE

	Rural	Suburban	Urban
Order			
Apodiformes	1	0	0
Caprimulgiformes	1	0	0
Columbiformes	1	1	1
Coraciiformes	1	1	0
Cuculiformes	1	1	1
Falconiformes	1	1	1
Galliformes	1	1	0
Passeriformes	1	1	1
Piciformes	1	1	1
Psittaciformes	1	1	1
Stringiformes	1	1	1
Turniciformes	1	0	0
Total	12	9	7
Family			
Accipitridae	1	1	1
Aegithinidae	1	1	0
Alaudidae	1	0	0
Alcedinidae	1	0	0
Bucerotidae	1	0	0
Campephagidae	1	0	0
Capitonidae	1	1	0
Caprimulgidae	1	0	0
Columbidae	1	1	1
Coraciidae	1	0	0
Corvidae	1	1	1
Cuculidae	1	1	1
Dicaedae	1	0	0
Dicruridae	1	1	0
Estrildidae	1	0	0
Hemiprocnidae	1	0	0
Meropidae	1	1	0
Monarchidae	1	0	0
Motacillidae	1	1	1
Muscicapidae	1	1	1
Nectariniidae	1	1	1
Oriolidae	1	1	1
Passeridae	1	1	1
Phasianidae	1	1	0
Picidae	1	1	1
Picnonotidae	1	1	0
Ploceidae	1	0	0
Psittacidae	1	0	1
Stringidae	1	1	1
Sturnidae	1	1	1
Turnicidae	1	0	0
Tytonidae	1	1	0
Upupidae	1	0	0
Total	33	19	13

	Rural	Suburban	Urban
Genus			
Accipiter	1	1	1
Acridotheres	1	1	1
Aegithina	0	1	0
Athene	1	1	1
Caprimulgus	0	1	0
Centropus	1	1	1
Circus	0	1	0
Columba	1	1	1
Copsychus	1	1	0
Coracias	0	1	0
Corvus	1	1	1
Dendrocitta	1	1	0
Dicaeum	0	1	0
Dicrurus	1	1	0
Dinopium	1	1	1
Eremopterix	0	1	0
Eudynamys	1	1	1
Francolinus	0	1	0
Halcyon	1	1	0
Haliaster	0	1	0
Hemiprocne	0	1	0
Leptocoma	1	1	1
Lonchura	0	1	0
Megalaima	1	1	0
Merops	1	1	0
Milvus	1	1	1
Motacilla	1	1	1
Ocyceros	0	1	0
Oriolus	1	1	1
Orthotomus	1	1	1
Otus	0	1	0
Passer	1	1	1
Pavo	1	1	0
Pericrocotus	0	1	0
Ploceus	0	1	0
Prinia	1	1	0
Psittacula	1	1	1
Pycnonotus	1	1	0
Saxicola	0	1	0
Saxicoloides	0	1	0
Streptopelia	1	1	0
Terpsiphone	0	1	0
Turdoides	1	1	1
Turnix	0	1	0
Tyto	1	1	0
Upupa	0	1	0
Total	27	46	16

APPENDIX 2 LIFE HISTORY TRAITS OF BIRDS SPECIES RECORDED ALONG URBAN TO RURAL GRADIENT (USED FOR LINEAR REGRESSION ANALYSIS)

							Nest			
Species	spe	Social	Nomadic	Diet	Habitat	Territoriality	Type	Substrate	height	Body weight (g)
Ashy prinia	ap	1	1	1	1	1	1	1	1	7
Black kite	BK	0	0	1	0	0	0	1	0	1000
Rock pigeon	BRP	0	1	0	0	0	0	0	0	500
Black-shouldered kite	bskite	1	0	1	0	1	0	1	0	291
Common myna	CM	0	0	0	0	0	0	0	0	110
Crow	Cr	0	0	0	0	0	0	1	0	300
Greater coucal	crph	1	1	1	0	1	0	1	0	268
Copper-smith barbet	csb	1	0	1	0	1	0	0	0	41
Black drongo	dro	0	0	0	0	1	1	1	0	-
Black-rumped flameback	flambk	1	1	0	0	1	0	0	0	110
Grey jungle fowl	gjf	0	1	1	1	1	0	0	1	907
House sparrow	HS	0	1	0	0	1	0	0	0	30
Common iora	iora	1	1	0	1	1	1	1	0	15
Jungle myna	jmy	0	0	0	0	0	0	0	0	-
Asian koel	Koel	1	1	0	0	1	0	1	0	220
Ashy-crowned sparrow lark	lark	1	1	0	0	1	0	0	1	-
Laughing dove	ldove	0	0	0	0	1	0	0	0	93
Small minivet	minive	1	1	1	1	1	1	1	0	9
Magpie robin	mrob	1	0	1	0	1	1	0	0	35
Pied-bush chat	pbc	1	1	1	0	1	1	0	1	20
Indian peafowl	Peafowl	0	1	0	0	1	0	0	1	4000
Indian roller	roll	1	0	1	0	1	0	0	0	170
Rose-ringed parakeet	rrp	0	0	0	0	0	0	0	0	130
Red-vented bulbul	rvb	0	0	0	0	1	1	1	0	34
Red-whiskered bulbul	rwb	0	0	0	1	1	1	1	0	27
Spotted dove	sdove	1	0	0	0	1	0	0	0	159
White-cheecked barbet	sgbar	1	1	0	1	1	0	0	0	80
Green bee-eater	sgbe	1	0	1	0	1	0	0	1	17
Shikra	shi	1	1	1	0	0	0	1	0	-
Sirkeer malkoha	Sirmal	1	1	1	1	1	0	1	0	-

Purple-rumped sunbird	*Sun*	1	1	0	0	1	1	1	0	9
Tailor bird	*tb*	1	1	0	0	1	1	1	1	9
Rufous Treepie	*trp*	1	0	0	0	1	0	1	0	-
White-browed bulbul	*wbb*	0	1	0	1	1	1	1	0	-
Yellow-billed babbler	*whb*	0	1	0	0	1	1	1	0	63

APPENDIX 3 THE BRAIN VARIABLES OF URBAN AND NON-URBAN GROUP OF BIRD SPECIES

Family	Genus	Species	n	Body mass	Brain volume	BV/BM	Cb volume	Cb/BM	Cb/BV
Non-urban									
Apodidae	Common swift	*Apus apus*	1	38	642	16.89	106.33	2.80	0.17
Apodidae	Glossy swiftlet	*Collocalia esculenta*	2	5	121	24.20	28.51	5.70	0.24
Apterygidae	Brown kiwi	*Apteryx australis*	?	2120	11300	5.33	–		
Aegothelidae	Feline owlet-nightjar	*Aegotheles insignis*	1	71	1540	21.69	242.40	3.41	0.16
Caprimulgidae	Spotted nightjar	*Eurostopodus argus*	1	121	1013	8.37	135.52	1.12	0.13
Caprimulgidae	Parauque	*Nyctidromus albicollis*	1	53	910	17.17	200.56	3.78	0.22
Nyctibiidae	Grey potoo	*Nyctibius griseus*	2	257	1980	7.70	300.50	1.17	0.15
Podargidae	Tawny frogmouth	*Podargus strigoides*	2	387	5759	14.88	445.21	1.15	0.08
Steatornithidae	Oilbird	*Steatornis caripensis*	1	414	3900	9.42	586.29	1.42	0.15
Accipitridae	Brown goshawk	*Accipiter fasciatus*	1	403	4631	11.49	634.91	1.58	0.14
Accipitridae	Wedge-tailed eagle	*Aquila audax*	1	3350	15997	4.78	1850.45	0.55	0.12
Accipitridae	Common buzzard	*Buteo buteo*	?	900	8452	9.39	1169.15	1.30	0.14
Accipitridae	Bald eagle	*Haliaeetus leucocephalus*	?	4419	18040	4.08	–		
Accipitridae	White-bellied sea eagle	*Haliaeetus leucogaster*	1	3004	12541	4.17	1376.11	0.46	0.11
Phasianidae	Ruffed *grouse*	*Bonasa umbellus*	2	650	3136	4.82	268.39	0.41	0.09
Phasianidae	Blue grouse	*Dendragapus obscurus*	?	1010	3070	3.04	–		
Phasianidae	Turkey	*Meleagris gallopavo*	?	9839	6781	0.69	1023.43	0.10	0.15
Phasianidae	Grey partridge	*Perdix perdix*	?	401	1849	4.61	223.34	0.56	0.12
Phasianidae	Ring-necked pheasant	*Phasianus colchicus*	?	1133	3865	3.41	480.75	0.42	0.12
Otidiidae	Australian bustard	*Ardeotis australis*	1	4450	10501	2.36	1072.20	0.24	0.10

Bombycillidae	*Bohemian waxwing*	*Bombycilla garrulus*	?	56	1102	19.86	140.15	2.53	0.13
Menuridae	Superb lyrebird	*Menura novaehollandiae*	1	644	10163	15.78	801.58	1.24	0.08
Muscicapidae	European robin	*Erithacus rubecula*	?	16	592	36.54	73.93	4.56	0.12
Pardalotidae	Brown thornbill	*Acanthiza pusilla*	1	6	434	72.33	35.24	5.87	0.08
Passeridae	Tree pipit	*Anthus trivialis*	?	18	600	32.61	–		
Passeridae	Gouldian finch	*Erythrura goulidae*	1	10	428	42.80	44.19	4.42	0.10
Cacatuidae	Sulphur-crested cockatoo	*Cacatua galerita*	1	765	13933	18.21	1064.72	1.39	0.08
Cacatuidae	Galah	*Cacatua roseicapilla*	1	355	7456	21.00	521.91	1.47	0.07
Cacatuidae	Long-billed corella	*Cacatua tenuirostris*	1	580	13103	22.59	891.95	1.54	0.07
Cacatuidae	Cockatiel	*Nymphicus hollandicus*	1	92	2161	23.49	214.16	2.33	0.10
Trochilidae	Green-fronted lancebill	*Doryfera ludoviciae*	1	6	139	23.17	27.42	4.57	0.20
Trochilidae	Buff-tailed sicklebill	*Eutoxeres condamini*	2	9	257	28.56	41.53	4.61	0.16
Trochilidae	Rufous-breasted hermit	*Glaucis hirsuta*	1	7	123	17.57	18.65	2.66	0.15
Trochilidae	Green-backed firecrown	*Sephanoides sephanoides*	2	5	134	26.80	18.58	3.72	0.14
Rheidae	Greater rhea	*Rhea americana*	?	25000	19228	0.77	2973.89	0.12	0.15
Struthionidae	Ostrich	*Struthio camelus*	?	90000	39631	0.44	5844.31	0.06	0.15
Urban									
Corvidae	Common raven	*Corvus corax*	?	1,175	14,648	12	1,112.80	0.95	0.08
Corvidae	Carrion crow	*Corvus corone*	?	537	9,382	17	753.06	1.40	0.08
Corvidae	Little raven	*Corvus mellori*	1	675	9,834	15	797.37	1.18	0.08
Corvidae	Jackdaw	*Corvus monedula*	?	200	4,593	23	382.03	1.91	0.08
Corvidae	Eurasian jay	*Garrulus glandarius*	?	139	3,806	27	337.24	2.43	0.09
Muscicapidae	European blackbird	*Turdus merula*	?	95	1,745	18	187.27	1.97	0.11
Tytonidae	Barn owl	*Tyto alba*	1?	290	5,857	20	444.12	1.53	0.08

Source: (Iwaniuk et al., 2006)

APPENDIX 4 THE FUNCTIONAL TELENCEPHALON RATIO AND RESIDUAL TELENCEPHALON RATIO OF NON-URBAN AND URBAN GROUP OF SPECIES

Family	Common name	*Latin name*	Ftel	rtel
Non-urban				
Bombycillidae	Bohemian Waxwing	*Bombycilla garrulus*	0.622	–0.1640
Aegithalidae	Long-tailed Tit	*Aegithalos caudatus*	0.62	0.1194
Alaudidae	Eurasian Skylark	*Alauda arvensis*	0.735	0.0421
Alaudidae	Calandra Lark	*Melanocorypha calandra*	0.691	–0.0389
Apodidae	Chimney swift	*Chaetura pelagica*	0.478	–0.3250
Apodidae	Alpine Swift	*Tachymarptis melba*	0.56	–0.1354
Apodidae	Common Swift	*Apus apus*	0.557	–0.1230
Burhinidae	Eurasian Thick-knee	*Burhinus oedicnemus*	0.588	–0.0458
Caprimulgidae	Eurasian Nightjar	*Caprimulgus europaeus*	0.464	–0.3245
Casuariidae	Emu	*Dromaius novaehollandiae*	0.658	0.033
Certhiidae	Eurasian Tree-creeper	*Certhia familiaris*	0.618	0.0584
Certhiidae/Troglodytidae	Winter Wren	*Troglodytes troglodytes*	0.605	0.0715
Cinclidae	White-Throated Dipper	*Cinclus cinclus*	0.622	–0.0858
Cracidae	Chaco Chachalaca	*Ortalis canicollis*	0.555	–0.2370
Fringillidae	Red Crossbill	*Loxia curvirostra*	0.695	0.0988
Fringillidae	Hawfinch	*Coccothraustes coccothraustes*	0.686	0.0539
Fringillidae	European Goldfinch	*Carduelis carduelis*	0.68	0.0668
Fringillidae	Eurasian Linnet	*Carduelis cannabina*	0.674	0.001
Fringillidae	Eurasian Siskin	*Carduelis spinus*	0.648	0.0704
Fringillidae	Chaffinch	*Fringilla coelebs*	0.638	–0.0240
Fringillidae	Island Canary	*Serinus canaria*	0.633	0.1014
Gaviidae	Red-throated Loon	*Gavia stellata*	0.501	–0.2533
Hirundinidae	Northern House-martin	*Delichon urbica*	0.639	–0.1180
Laniidae	Red-backed Shrike	*Lanius collurio*	0.683	0.0548
Meropidae	European Bee-eater	*Merops apiaster*	0.473	–0.1991
Muscicapidae	Song Thrush	*Turdus philomelos*	0.614	–0.1274
Muscicapidae	Spotted Flycatcher	*Muscicapa striata*	0.593	–0.1210
Muscicapidae	European Robin	*Erithacus rubecula*	0.564	–0.0567
Numididae	Helmeted Guineafowl	*Numida meleagris*	0.564	–0.3758
Odontophoridae	Northern Bobwhite	*Colinus virginianus*	0.538	–0.4100
Phasianidae	Golden Pheasant	*Chrysolophus pictus*	0.545	–0.1721
Phasianidae	Western Capercaillie	*Tetrao urogallus*	0.544	–0.3749
Phasianidae	Blue-breasted Quail	*Coturnix chinensis*	0.541	–0.2498
Phasianidae	Red Junglefowl	*Gallus gallus*	0.534	–0.2701
Phasianidae	Grey Partridge	*Perdix perdix*	0.527	–0.3524
Phasianidae	Black Grouse	*Tetrao tetrix*	0.527	–0.3387
Phasianidae	Wild Turkey	*Meleagris gallopavo*	0.502	–0.5253
Phasianidae	Common Quail	*Coturnix coturnix*	0.491	–0.3096
Phasianidae	Indian peafowl	*Pavo cristatus*	0.599	–0.2962
Phasianidae	Silver Pheasant	*Lophura nycthemera*	0.587	–0.2127
Phasianidae	Common Pheasant	*Phasianus colchicus*	0.584	–0.2853

Phasianidae	Chukar	*Alectoris chukar*	0.578	–0.2683
Regulidae	Common Goldcrest	*Regulus regulus*	0.63	0.1317
Rheidae	Greater Rhea	*Rhea americana*	0.568	–0.0811
Sittidae	Wood Nuthatch	*Sitta europaea*	0.685	0.146
Struthionidae	Ostrich	*Struthio camelus*	0.659	0.0315
Sylviidae	Garden Warbler	*Sylvia borin*	0.602	–0.1029
Sylviidae	Eurasian Reed-warbler	*Acrocephalus scirpaceus*	0.585	–0.0944
Tinamidae	Red-winged Tinamou	*Rhynchotus rufescens*	0.594	0.0166
Trochilidae	Blue-tailed	*Chlorostilbon mellisugus*	0.481	–0.3852
Upupidae	Eurasian Hoopoe	*Upupa epops*	0.666	0.1219
Urban				
Columbidae	Rock Pigeon	*Columba livia*	0.552	–0.1549
Corvidae	Common Raven	*Corvus corax*	0.806	0.0306
Corvidae	Carrion Crow	*Corvus corone*	0.767	0.0296
Corvidae	Eurasian Jay	*Garrulus glandarius*	0.71	0.0877
Corvidae	Rook	*Corvus frugilegus*	0.771	0.0658
Paridae	Great Tit	*Parus major*	0.707	0.1864
Passeridae	House Sparrow	*Passer domesticus*	0.686	0.0402
Sturnidae	Common Starling	*Sturnus vulgaris*	0.683	–0.0529
Muscicapidae	Eurasian Blackbird	*Turdus merula*	0.642	–0.1338
Cuculidae	Common Cuckoo	*Cuculus canorus*	0.564	–0.0404

Source: (Burish et al., 2004)