

Relationships of structural characteristics and homeowner socioeconomics with urban
vegetation and bird communities

by

Stephanie Freeman, B.S.

A Thesis

In

Wildlife, Aquatic, and Wildlands Science and Management

Submitted to the Graduate Faculty
of Texas Tech University in
Partial Fulfillment of
the Requirements for
the Degree of

MASTER OF SCIENCE

Approved

Gad Perry
Chair of Committee

Mark Wallace

Melanie Sarge

Mark Sheridan
Dean of the Graduate School

May, 2018

Copyright 2017, Stephanie Freeman

ACKNOWLEDGMENTS

I would like to thank my family for their unwavering support during the pursuit of my master's degree. I am so grateful for the many letters and phone calls that my father, Stan, so graciously gave me over the last few years. Your love and guidance has shaped me into the person I am today. My brother, Andrew, shares half of my heart and knows me better than anyone. I would like to thank him for his endless encouragement and advice. I especially want to thank my late mother, Lisa, for instilling a deep love of nature and wildlife in me at such a young age. I will cherish the lessons you taught me for the rest of my life.

I would also like to take the opportunity to express my gratitude for my incredible group of friends. Lewis, Caiti, and Chandler have stood by me for two decades, and I feel incredibly fortunate to have such loyal people in my life. My roommates, Demi and Brian, have given me a home away from home. Thank you for allowing me to be my most authentic self. I must also thank my partner, Byron. The reassurance, stability, and kindness you are so quick to offer has brought an immeasurable amount of joy to my life. I would also like to thank my fellow graduate students in the Department of Natural Resources Management. I have learned so much from all of you, and I will always cherish the time we spent together.

Thank you Dr. Kathy Gillis and the Texas Tech University Graduate Student Writing Center for providing safe, supportive spaces during my writing process. Thank you Dr. Krista Mougey for your assistance with my ArcGIS and ImageJ analyses. Also, thank you Byron Buckley for helping with my Euclidian Distance calculations. Also, I greatly appreciate my field technician, Connor Helms, for his hard work during bird point

count surveys. Your assistance with data collection was crucial for the completion of this project.

Finally, words can hardly express how grateful I am for my committee members. Thank you, Dr. Gad Perry, for believing in me and offering me the opportunity to conduct this research. Your help has been indispensable along this journey. I would like to thank Dr. Mark Wallace and Dr. Melanie Sarge for their assistance with the development and implementation of this research. I truly appreciate the countless hours each of you invested in me. Thank you for shaping me into the scientist I am today.

TABLE OF CONTENTS

ACKNOWLEDGMENTS ii

LIST OF TABLESv

I. LITERATURE REVIEW 1

 Introduction.....1

 Urbanization.....1

 Urban wildlife4

 Urban wildlife habitat6

 Urban-rural gradients8

 Human valuation of environmental attributes.....10

 Socioeconomic attributes of homeowners12

 Research Objectives.....14

 References.....15

II. STRUCTURAL CHARACTERISTICS OF THE URBAN ENVIRONMENT
AS PREDICTORS OF BIRD SPECIES RICHNESS20

 Introduction.....20

 Materials and Methods.....23

 Results.....28

 Discussion30

 Conclusions.....35

 References.....37

III. INCORPORATING SOCIOECONOMIC ATTRIBUTES OF
HOMEOWNERS INTO TRADITIONAL URBAN-RURAL GRADIENT
ANALYSES TO PREDICT CANOPY COVER AND URBAN BIRD
DIVERSITY46

 Introduction.....46

 Materials and Methods.....51

 Results.....54

 Discussion56

 Conclusions.....64

 References.....66

IV. CONCLUSIONS76

References.....81

APPENDIX

A. BIRD SPECIES OBSERVED IN LUBBOCK, TX DURING SUMMER 201782

LIST OF TABLES

2.1 Hypotheses for Relationships Between Structural Characteristics of the Urban Environment and Exploiter, Adapter, and Uncommon Bird Species Richness During Summer 2017 in Lubbock, TX.41

2.2 Neighborhoods Selected for Bird Point Count Surveys During Summer 2017 in Lubbock, TX.42

2.3 Simple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, Neighborhood Age, and Canopy Cover During Summer 2017 in Lubbock, TX.43

2.4 Multiple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, and Neighborhood Age During Summer 2017 in Lubbock, TX.44

2.5 Multiple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, Neighborhood Age, and Canopy Cover During Summer 2017 in Lubbock, TX.45

3.1 Hypotheses for Relationships of Structural Characteristics of the Urban Environment and Homeowner Socioeconomics with Bird Diversity and Canopy Cover During Summer 2017 in Lubbock, TX.71

3.2 Neighborhoods Selected for Bird Point Count Surveys During Summer 2017 in Lubbock, TX.72

3.3 Simple Linear Regression Analyses Predicting Canopy Cover and Bird Diversity from Human Population Density, Distance to City Center, Neighborhood Age, House Price, Income, and Education During Summer 2017 in Lubbock, TX.73

3.4 Hierarchical Multiple Regression Predicting Percent Canopy Cover From Sample Round, Neighborhood Age, Human Population Density, Distance to City Center, Income, and House Price During Summer 2017 in Lubbock, TX.74

3.5 Hierarchical Multiple Regression Predicting Bird Diversity From Sample Round, Neighborhood Age, Human Population Density, Distance to City Center, House Price, Income, and Education.75

CHAPTER I

LITERATURE REVIEW

Introduction

Urbanization

Urbanization is the alteration of landscapes with built-up, industrialized, and human-dominated settlements (Douglas and James 2015). It is a rapid global trend that modifies the Earth in extensive and irreversible ways (Czech et al. 2000; McKinney 2002; Vitousek et al. 1997). Urban ecology explores the relationships between humans, other organisms, and their surroundings in urban habitats (Douglas and James 2015) and uses social, economic, and ecological science to better understand the effects of urbanization. Since these global alterations unfold as a direct result of rapid human population expansion, understanding the distribution and abundance of organisms in and around cities makes urban ecology an increasingly important field (Pickett et al. 2001).

In 2007, the global urban population rose above the global rural population for the first time in history (United Nations, 2014). Researchers expect that urban dwellers will continue to outpace rural inhabitants in the coming decades, with the number of urbanites likely rising to 66 percent by the year 2050 (United Nations, 2014). By that time, the overall global population is projected to increase by 2.5 billion people (United Nations, 2014). More than 80 percent of United States citizens are currently inhabiting urban areas, and by the year 2050, this statistic will likely rise to 90 percent (United Nations, 2014). Urban areas, classified as densely developed commercial, residential, or other non-residential land use types encompassing 50,000 or more people, (US Census Bureau, 2012), attract residents for a multitude of reasons. Cities offer access to educational

opportunities, cultural and political activities, and social and health services (United Nations, 2014). Although cities offer many benefits for human inhabitants, the environmental impacts associated with urban development have implications for biota across the globe. The process of urbanization results in a system that does not rely on local natural resources to persist (McDonnell and Pickett 1990). Subsequently, the persistent expansion of human-dominated ecosystems is influencing the structure and function of natural ecosystems worldwide by altering Earth's nutrient cycles, contributing to climate change, and accelerating biodiversity loss (Vitousek et al. 1997).

The urban ecosystem is one that humans have transformed to better suit their needs. This process usually replaces native vegetation with exotic plants (Adams et al. 2016; Mack and Lonsdale 2001). During urban development, it is typical to clear the topsoil layer while compacting the remaining soil or “waterproofing” it with an impervious barrier such as concrete or asphalt (Adams et al. 2016). This impervious barrier alters hydrology by reducing the amount of water infiltrating to the soil, thereby increasing surface runoff, which often contains polluting sediments and toxic materials (Adams 1994). In response to the clearing of trees and increased use of impervious surfaces, cities produce a heat island effect, resulting in higher temperatures than those in the surrounding rural areas (Adams 1994; Pickett et al. 2001). Urbanization creates variations in disturbance regimes, biota, landscape structures, physiological stresses, and socioeconomic factors that all have implications for ecological systems the world over (McDonnell and Pickett 1990).

Humans alter landscapes in various ways, yet urban development is the longest-lasting contributor to habitat loss (McKinney 2002), which is considered the leading

cause of global species endangerment (Tilman et al. 1994). Landscape alteration rates are not only predicted to cause irreversible, global biodiversity losses through species extinctions, but these extinctions will occur with a generational time lag concealing the gravity of fragmentation occurring today (Tilman et al. 1994). In the United States, urbanization endangers more species than any other human activity; biota affected by urbanization are impacted not only by the direct removal of native habitat, but also by associated threats from agriculture practices, recreation, road development, and more (Czech et al. 2000). Land transformation practices are conducive not only to widespread extinctions, but to species invasions as well, both of which contribute to the homogenization of Earth's biota (Blair 1999).

Some of the most highly homogenized habitats on our planet occur as a result of urban development. This process designs an ecosystem catered to the narrow needs of a single species, sustaining human life by relying on a substantial input of external resources (McKinney 2006). Various forms of human activity and environmental alterations often create ideal non-native species habitats and allow synanthropic species to flourish (Blair 1996; McKinney 2006). Biological uniqueness is lost as native species are often replaced with nonnative species during urban expansion (McKinney 2002). Furthermore, urban habitats persist in a state of disequilibrium from their bordering natural habitats, and it is not uncommon to find the same suite of exotic species in cities across the globe (McKinney 2006). For example, Blair (1999) found that increasing intensities of urbanization in two distinct ecoregions resulted in similar bird species assemblages in both geographic locations. Habitat loss, species endangerment, and biotic homogenization will persist as long as humans continue to dominate the Earth, making

wildlife conservation in fragmented landscapes of the utmost importance for researchers and managers alike (Marzluff and Ewing 2001).

Urban Wildlife

Urban wildlife research in the United States has been increasing since the 1960s, stemming from wildlife ecology and management practices originally established in the 1900s (Adams 2005). The ways in which scientists study and categorize wildlife have shifted throughout history. Initially classified by their usefulness to humans, early management agencies grouped wildlife species as game, nongame, or nuisance animals (Adams et al. 2016). With the dawn of the environmental movement in the 1970s, more interest in wildlife abundance and scarcity led to the creation of the term “threatened or endangered” as people became more concerned about the population status of various flora and fauna (Adams et al. 2016). It wasn’t until the 1990s that researchers first used the term urban wildlife to classify species based on their proximity to human settlements (Adams et al. 2016).

Urban wildlife live in a unique ecological environment. Threats to wildlife vitality in human-modified environments include noise pollution, toxic waste, automobiles, pets, overhead wires, towers, and windows (Adams 1994). In response to these disturbances, urban species may display marked differences from their exurban counterparts by changing their activity patterns, reproductive behaviors, and feeding strategies (Adams et al. 2016). For example, avian ecologists have found that light pollution in cities is negatively related to the onset of daily bird activity. Urban songbirds exposed to higher light intensities in the evening tend to be active earlier in the morning than rural populations (Dominoni et al. 2014). Many behavioral shifts occur as a result of wildlife’s

tolerance or intolerance to human presence. Birds respond to human activity in a well-documented way (Niemi and McDonald 2004) and can be grouped into categories of exploiter, adapter, and avoider birds based off of these reactions.

Bird diversity changes in response to varying intensities of development and anthropogenic factors. Species have often been delineated as urban exploiters, adapters, and avoiders (Blair 1996; McKinney 2002). Urban avoiders are typically native species that inhabit the most undisturbed areas. Their densities tend to be highest on the city periphery, as they are sensitive to human activities and landscape alterations. Urban adapter species are able to use both natural and human-subsidized resources found at moderate levels of development. Vegetation is typically scarce in the most highly urbanized locations of the city, however, and their population sizes drop in these areas as a result. Urban exploiters have the highest densities in heavily developed areas, where they exploit resources made available by urbanization. This category is comprised of exotic and invasive species.

Researchers often use ecological indicators to serve as representatives for other species that may have similar needs and responses to stressors (Blair 1999). Ecological indicators are used to assess current ecosystem conditions and can also act as early warning systems to predict future responses to anthropogenic disturbances (Niemi and McDonald 2004). They are typically charismatic, easy to identify and measure, inexpensive to study, and are affected by disturbance in a well-documented way (Niemi and McDonald 2004). Birds are one of the most frequently used indicators, as they fit most, if not all of these criteria. They can help inform researchers about the various factors affecting urban habitat quality, as they are not only good indicators of

environmental health, but they are also highly associated with vegetation coverage (Macarthur and Macarthur 1961; Mills et al. 1989; Niemi and McDonald 2004; Sandstrom et al. 2006).

Urban Wildlife Habitat

Humans are the primary dispersers of vascular plants on the planet (Mack and Lonsdale 2001). People began introducing nonnative plant species to the United States as early as the 1800s for utilitarian purposes in order to meet needs for food, fuel, medicine, and forage; the desire for aesthetically pleasing plants followed soon after once colonists started selecting novel, exotic, or ornamental species for importation (Mack and Lonsdale 2001). Both humans and wildlife value vegetation (Farmer et al. 2013). Considering vegetation is one of the most important drivers of changes in bird communities (Mills et al. 1989), it is important to understand how the introduction of non-native species affects avian habitat quality.

Vegetation species richness in urban areas tends to increase as a result of exotic plant importation. However, avian diversity typically does not follow suit. That is, total bird diversity usually decreases as the density of only a few exploiter bird species increases (Chace and Walsh 2006). This phenomenon may be attributed to the variable responses of avifauna to vegetation quality. The volume and structure of native vegetation tends to correlate with native bird diversity and species richness, while non-native bird diversity has a positive relationship with exotic vegetation biomass (Mills et al. 1989). Previous research has revealed that urban parks containing a larger proportion of native vegetation have higher bird diversity and are also inhabited by a higher number of native bird species (Gavareski 1976).

The urban environment is one that humans have modified to better suit their preferences and needs. Urban bird diversity patterns, therefore, may be explained by the resulting variation in resource availability (Chace and Walsh 2006). For instance, native vegetation is important, as it provides native insects for birds to feed on, a resource that non-native plantings do not always provide, because they are often chosen for landscaping due to their resistance to insect “pests” (Mills et al. 1989). Yet exotic species can offer an increase in total vegetation cover (Chace and Walsh 2006; Mills et al. 1989; Munyenyembe et al. 1989; Vale and Vale 1976) as well as a refuge for birds whose natural habitats have been degraded or removed (Chace and Walsh 2006; Gavareski 1976; Mills et al. 1989). For example, exotic plants can still provide protective cover for nesting (Chace and Walsh 2006). While the composition of urban vegetation communities is important for explaining shifts in bird diversity across the cityscape, it is also essential to consider the structural characteristics of the environment.

In their seminal work, MacArthur and MacArthur (1961) explored how landscape structure affects avifauna compositions. They found a strong relationship between landscape structure and avian diversity, with the addition of a new layer of foliage resulting in an increase in bird diversity. From low shrubs to higher tree canopies, more complete vertical stratification increased bird species richness, as varying species use these multiple layers of vegetation for foraging, nesting, and finding cover from predators (MacArthur and MacArthur 1961). More complex landscape compositions not only attract more diverse birds, but observing higher avian diversity can also indicate increasing layers of vegetation structure (Sandstrom et al. 2006). Urban green space that

encompasses natural structures such as larger trees, wooded areas, and developed shrub layers is important for the preservation of ecological diversity (Sandstrom et al. 2006).

Urban-Rural Gradients

Urban-rural gradients are a conceptual framework which allow us to examine the components that make up the urbanization process, how urbanization affects plant and animal species, and what the ramifications are for ecosystems (McDonnell and Pickett 1990). Furthermore, urban-rural gradients are used to study the shifts in both flora and fauna along a transect, often extending from the urban core to more natural areas on city fringes (McKinney 2002). The gradient paradigm is a complex approach for understanding the fragmented and patchy nature of urban land use that is often comprised of varying intensities of development (Blair 1996). It attempts to quantify the interactions between urbanization and disturbance regimes in human-dominated ecosystems and understand how these relationships affect physical structures, biotic components, and human culture and institutions (McDonnell and Pickett 1990).

Varying intensities of disturbance along the gradient affect plant and animal species compositions. Signs of anthropogenic disturbance, such as human population and road density, air pollution, the heat island effect, average annual rainfall, and soil pollution, compaction, and alkalinity, increase in the direction of the urban core (McKinney 2002). Extreme urbanization reduces bird species richness as a result of increasing impervious surface area and decreasing habitat quality; although birds are the most well studied taxonomic group, mammal, reptile, amphibian, invertebrate, and plant species richness mirror similar responses to human modification of the landscape (McKinney 2008). Increased avian density at the city center comes at the cost of native

diversity, as only synanthropic species can typically take advantage of human subsidized resources provided in the most developed areas (Blair 1996).

Metrics used to quantify differing levels of disturbance include human population density, urban age, distance from the urban center, land use types, impervious surface percentages, building densities, and so on. Previous research has assessed the effects of time on urban areas by using a development's age (Gagne et al. 2016; Loss et al. 2009; Martin et al. 2004; Melles 2005; Munyenyembe et al. 1989; Palomino and Carrascal 2006; Strohbach et al. 2009; Vale and Vale 1976). Age is a measure of how much time has elapsed between disturbance created during initial development and the present. It can act as a surrogate for the maturity of garden plantings (Martin et al. 2004; Palomino and Carrascal 2006), which birds respond positively to (Gagne et al. 2016; Vale and Vale 1976). Distance to the city center characterizes the habitat loss gradient spreading from the periphery to the core (Chace and Walsh 2006; Leveau and Leveau 2016; MacGregor-Fors et al. 2011; McKinney 2002; 2006; Mills et al. 1989; Sandstrom et al. 2006). Native habitat is removed more prevalently towards the city center where increased fragmentation and patchiness reduce vegetation availability (Blair 1999; Marzluff 2001), thereby decreasing avian diversity (Leveau and Leveau 2016; MacGregor-Fors et al. 2011; McKinney 2006). Human population density signifies the degree of urban development by indicating the intensity of land use associated with human presence (Gagne et al. 2016; Loss et al. 2009; Martin et al. 2004; Melles 2005; Strohbach et al. 2009). The number of people per square kilometer is positively associated with the intensity of anthropogenic disturbance in that urban area, which has negative implications

for vegetation (Blair 1996; McKinney 2002) and bird diversity (Melles 2005; Strohbach et al. 2009).

Human valuation of environmental attributes

Because urban environments have the potential to provide quality wildlife habitat, the attitudes, values, and beliefs of influential urban “ecosystem engineers” will help inform decisions for urban planners, policy makers, and wildlife professionals alike. Homeowner studies can reveal urban residents’ preferences for wildlife and wildlife habitat through social, economic, and ecological research. Hedonic pricing models offer one way of assessing the benefits and values of urban green space associated with human presence (Bark et al. 2009; Farmer et al. 2013; Jim and Chen 2006; Mansfield et al. 2005; Morancho 2003). They infer how people value certain attributes without asking them directly (Luttik 2000). Rather, homeowners’ preferences are revealed using house sales prices as a function of the value of environmental characteristics and resources related to the home or neighborhood (Jim and Chen 2006).

Hedonic pricing methods combine variables such as a home’s number of bathrooms, bedrooms, or square footage in tandem with environmental attributes such as its distance to green space, exposure to traffic noise, and proximity to forested areas in order to infer the monetary value of ecological services provided within a housing market (Farmer et al. 2013; Jim and Chen 2006). Previous research suggests that views of attractive landscapes (Luttik 2000), proximity to urban green space (Morancho 2003), and nearby bodies of water (Jim and Chen 2006) can all positively affect house prices. Although these studies suggest that certain environmental amenities can add value to urban neighborhoods, not all green spaces are created equal.

Urban areas abound with a multitude of different types of green space, each providing unique societal and ecological services. Benefits of urban forests include their ability to reduce radiation, runoff, heat, and urban noise while improving aesthetics, air quality, human health, and physiological distress (Mansfield et al. 2005). Researchers have questioned whether urban residents can distinguish between the simple existence of green space and quality habitat. For example, when considering indicators of ecological health, Bark et al. (2009) discovered that homebuyers were willing to pay premiums for biologically significant riparian vegetation characteristics. Although it is important to note that the ecological value of neighborhood trees may not measure up to larger, unbroken forest parcels in terms of wildlife habitat quality (Mansfield et al. 2005), groups of yards have the potential to improve habitat connectivity and provide greater total habitat for urban wildlife species (Belaire et al. 2014).

Farmer et al. (2013) developed an ecological indicator to explore the relationships between house values, bird diversity, and canopy cover in Lubbock neighborhoods, using bird species richness, tree canopy density, and list prices of recent home sales. They created their indicator by multiplying the number of adapter bird species by the total number of birds recorded at a site. With the addition of one less ubiquitous bird species near a neighborhood site into their hedonic pricing model, mean home prices increased by \$32,028. This suggests that people may be willing to pay a premium for an improvement in aesthetics, walkability, and wildlife diversity in urban neighborhoods (Farmer et al. 2013). The ecological and economic benefits of a more progressed and varied landscape structure indicate that people may enjoy improved home values while

avoider and adapter bird species can be found in higher quality urban environments they might not otherwise utilize (Farmer et al. 2013).

Socioeconomic attributes of homeowners

Urban patterns of biodiversity are driven in large part by human behavior, as people can act as extremely influential agents of change (Melles 2005). Traditional urban-rural gradients do not take into consideration how human socioeconomic and cultural attributes influence interactions between humans and the environment (Kinzig et al. 2005). Human-wildlife interactions can be viewed through a human ecosystem lens, which accounts for the allocation of critical natural, socioeconomic, and cultural resources found throughout the cityscape (Pickett et al. 2001). This approach combines landscape types with sociocultural and biophysical processes in order to better understand, for example, how the aforementioned variations in plant cover provided by urban residents affect bird species compositions (Pickett et al. 2001).

The urban landscape is shaped by human choices at a myriad of scales, ranging from the preferences of an individual homeowner for certain residential yard design and management practices, to the efforts made by municipal officials who can institute change across a greater geographic extent (Belaire et al. 2014). Patterns of urban biodiversity may be better understood by thinking of yards as designer ecosystems with differences in upkeep, watering regimes, pesticide use, and so on (Bergey and Figueroa, 2016). Local variations in management practices have implications for biota within yards and across the urban cityscape (Bergey and Figueroa, 2016), with groups of yards potentially improving habitat connectivity and providing greater total habitat for certain species (Belaire et al. 2014). Because a significant portion of the urban landscape is

comprised of residential yards, homeowners could help alleviate some of the detrimental effects of the urbanization process by managing them collectively for birds and other wildlife (Lerman and Warren 2011).

Demographic, cultural, and socioeconomic factors affect the dynamics of urban ecosystems (Grove et al. 2006). The ways in which humans interact with the environment can vary based on attributes such as age, gender, culture, education, and economic status (Clucas et al. 2015). Moreover, the allocation of critical natural, socioeconomic, or cultural resources is seldom distributed equally across social groups of different types (Grove and Burch 1997). Therefore, incorporating socioeconomic variables into traditional urban-rural gradient analyses can improve our understanding of fluctuating biodiversity patterns across the cityscape (Kinzig et al. 2005).

Previous research has shown positive associations between homeowner income and plant diversity (Hope et al. 2003; Kinzig et al. 2005; Martin et al. 2004) as well as bird diversity (Kinzig et al. 2005; Lerman and Warren 2011; Melles 2005). People with high-paying jobs may actively landscape based off their preferences and desires for vegetation plantings, while residents of lower-income neighborhoods may choose simpler yard designs, instead prioritizing their disposable financial resources on other expenses (Lerman and Warren 2011). These relationships have been mirrored in many studies on the relationships between educational attainment and urban biodiversity. Highly educated people may be more informed about land management practices and environmental issues, and therefore more likely to engage in pro-environmental behavior such as tree planting (Luck et al. 2009; Luck et al. 2013) and bird feeding (Clucas et al. 2015). Uncovering socioeconomic drivers of the urban environment is essential for managing

the natural resources in this unique ecosystem, as well as educating the people who directly affect it.

Research Objectives

My research objectives were twofold. First, I sought to understand which structural characteristics of the urban environment could explain the variability of breeding bird species richness in Lubbock neighborhoods. My predictor variables included neighborhood age, distance to the city center, human population density, and canopy cover. My outcome variables included three categories of urban bird species: exploiter, adapter, and avoider birds. Second, my objective was to determine whether the addition of homeowner socioeconomic indicators could improve the prediction of neighborhood canopy cover and bird diversity beyond the traditional urban-rural indicators used in urban ecology research. My predictor variables included the three urban-rural gradient measures mentioned above, as well as three socioeconomic predictors of neighborhood income, education attainment, and house price. My outcome variables included the Shannon-Weiner diversity index as well as canopy cover. I included 14 neighborhoods spanning a list price range of \$50,000 – 200,000. This research utilized both ecological and social inquiry in order to enhance our understanding of the dynamics of urban ecosystems.

References

- Adams CE. 2016. Urban wildlife management. Third Edition. Boca Raton (FL): CRC Press Taylor & Francis Group.
- Adams LW. 1994. Urban wildlife habitats: A landscape perspective. Volume 3. Minneapolis (MN): The University of Minnesota Press. 186 p.
- Adams LW. 2005. Urban wildlife ecology and conservation: A brief history of the discipline. *Urban Ecosystems*. 8(2):139-156.
- Bark RH, Osgood DE, Colby BG, Katz G, Stromberg J. 2009. Habitat preservation and restoration: Do homebuyers have preferences for quality habitat? *Ecological Economics*. 68(5):1465-1475.
- Belaire JA, Whelan CJ, Minor ES. 2014. Having our yards and sharing them too: The collective effects of yards on native bird species in an urban landscape. *Ecological Applications*. 24(8):2132-2143.
- Bergey EA, Figueroa LL. 2016. Residential yards as designer ecosystems: Effects of management on land snail species composition. *Ecological Applications*. 26(8): 2538-2547.
- Blair RB. 1996. Land use and avian species diversity along an urban gradient. *Ecological Applications*. 6(2):506-519.
- Blair RB. 1999. Birds and butterflies along urban gradients in two ecoregions of the united states: Is urbanization creating a homogeneous fauna? *Biotic Homogenization*. 9(1):33-56.
- Chace JF, Walsh JJ. 2006. Urban effects on native avifauna: A review. *Landscape and Urban Planning*. 74(1):46-69.
- Clucas B, Rabotyagov S, Marzluff JM. 2015. How much is that birdie in my backyard? A cross-continental economic valuation of native urban songbirds. *Urban Ecosystems*. 18(1):251-266.
- Czech B, Krausman PR, Devers PK. 2000. Economic associations among causes of species endangerment in the united states. *Bioscience*. 50(7):593-601.
- Dominoni DM, Carmona-Wagner EO, Hofmann M, Kranstauber B, Partecke J. 2014. Individual-based measurements of light intensity provide new insights into the effects of artificial light at night on daily rhythms of urban-dwelling songbirds. *Journal of Animal Ecology*. 83(3):681-692.

- Douglas I, James P. 2015. *Urban ecology: An introduction*. New York (NY): Routledge.
- Farmer MC, Wallace MC, Shiroya M. 2013. Bird diversity indicates ecological value in urban home prices. *Urban Ecosystems*. 16(1):131-144.
- Gagne SA, Sherman PJ, Singh KK, Meentemeyer RK. 2016. The effect of human population size on the breeding bird diversity of urban regions. *Biodiversity and Conservation*. 25(4):653-671.
- Gavareski CA. 1976. Relation of park size and vegetation to urban bird populations in seattle, washington. *The Condor*. 78(3):375-382.
- Grove JM, Burch WR. 1997. A social ecology approach and applications of urban ecosystem landscape analyses: A case study of Baltimore, Maryland. *Urban Ecosystems*. 1:259-275.
- Grove JM, Troy AR, O'Neil-Dunne JPM, Burch WR, Cadenasso ML, Pickett STA. 2006. Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems*. 9(4):578-597.
- Hope D, Gries C, Zhu WX, Fagan WF, Redman CL, Grimm NB, Nelson AL, Martin C, Kinzig A. 2003. Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Sciences of the United States of America*. 100(15):8788-8792.
- Jim CY, Chen WY. 2006. Impacts of urban environmental elements on residential housing prices in Guangzhou (China). *Landscape and Urban Planning*. 78(4):422-434.
- Kinzig AP, Warren P, Martin C, Hope D, Katti M. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*. 10(1):13.
- Lerman SB, Warren PS. 2011. The conservation value of residential yards: Linking birds and people. *Ecological Applications*. 21(4):1327-1339.
- Leveau LM, Leveau CM. 2016. Does urbanization affect the seasonal dynamics of bird communities in urban parks? *Urban Ecosystems*. 19(2):631-647.
- Loss SR, Ruiz MO, Brawn JD. 2009. Relationships between avian diversity, neighborhood age, income, and environmental characteristics of an urban landscape. *Biological Conservation*. 142(11):2578-2585.
- Luck GW, Smallbone LT, O'Brien R. 2009. Socio-economics and vegetation change in urban ecosystems: Patterns in space and time. *Ecosystems*. 12(4):604-620.

- Luck GW, Smallbone LT, Sheffield KJ. 2013. Environmental and socio-economic factors related to urban bird communities. *Austral Ecology*. 38(1):111-120.
- Luttik J. 2000. The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape and Urban Planning*. 48(3-4):161-167.
- Macarthur R, Macarthur JW. 1961. On bird species-diversity. *Ecology*. 42(3):594-598.
- MacGregor-Fors I, Morales-Perez L, Schondube JE. 2011. Does size really matter? Species-area relationships in human settlements. *Diversity and Distributions*. 17(1):112-121.
- Mack RN, Lonsdale WM. 2001. Humans as global plant dispersers: Getting more than we bargained for. *Bioscience*. 51(2):95-102.
- Mansfield C, Pattanayak SK, McDow W, McDonald R, Halpin P. 2005. Shades of green: Measuring the value of urban forests in the housing market. *Journal of Forest Economics*. 11(3):177-199.
- Martin CA, Warren PS, Kinzig AP. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning*. 69(4):355-368.
- Marzluff JM, Ewing K. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Springer.
- Marzluff JM. 2001. Worldwide urbanization and its effects on birds. In: Marzluff JM, Bowman R, Donnelly R, editors. *Avian Ecology and Conservation in an Urbanizing World*. New York (NY): Kluwer Academic Publishers. p. 19-48.
- McDonnell MJ, Pickett STA. 1990. Ecosystem structure and function along urban rural gradients: An unexploited opportunity for ecology. *Ecology*. 71(4):1232-1237.
- McKinney ML. 2002. Urbanization, biodiversity, and conservation. *Bioscience*. 52(10):883-890.
- McKinney ML. 2006. Urbanization as a major cause of biotic homogenization. *Biological Conservation*. 127(3):247-260.
- McKinney ML. 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*. 11(2):161-176.

- Melles SJ. 2005. Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats*. 3(1):25-48.
- Mills GS, Dunning JB, Bates JM. 1989. Effects of urbanization on breeding bird community structure in southwestern desert habitats. *The Condor*. 91(2):416-428.
- Morancho AB. 2003. A hedonic valuation of urban green areas. *Landscape and Urban Planning*. 66(1):35-41.
- Munyenyembe F, Harris J, Hone J, Nix H. 1989. Determinants of bird populations in an urban area. *Australian Journal of Ecology*. 14(4):549-557.
- Niemi GJ, McDonald ME. 2004. Application of ecological indicators. *Annual Review of Ecology Evolution and Systematics*. 35:89-111.
- Palomino D, Carrascal LM. 2006. Urban influence on birds at a regional scale: A case study with the avifauna of northern Madrid province. *Landscape and Urban Planning*. 77(3):276-290.
- Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R. 2001. Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics*. 32:127-157.
- Sandstrom UG, Angelstam P, Mikusinski G. 2006. Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning*. 77(1-2):39-53.
- Strohbach MW, Haase D, Kabisch N. 2009. Birds and the city: Urban biodiversity, land use, and socioeconomics. *Ecology and Society*. 14(2):15.
- Tilman D, May RM, Lehman CL, Nowak MA. 1994. Habitat destruction and the extinction debt. *Nature*. 371(6492):65-66.
- United Nations Department of Economic and Social Affairs. 2014. World urbanization prospects, The 2014 revision. New York, New York.
- U.S. Census Bureau. 2016. State and county quick facts: Lubbock, Texas. Data derived from Population Estimates, American Community Survey, Census of Population and Housing, County Business Patterns, Economic Census, Survey and Business Owners, Building Permits, Census of Governments.
<https://www.census.gov/quickfacts/fact/table/lubbockcitytexas,US#viewtop>
- Vale TR, Vale GR. 1976. Suburban bird populations in West-Central California. *Journal of Biogeography*. 3(2):157-165.

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997. Human domination of earth's ecosystems. *Science*. 277(5325):494-499.

CHAPTER II

STRUCTURAL CHARACTERISTICS OF THE URBAN ENVIRONMENT AS PREDICTORS OF BIRD SPECIES RICHNESS

Introduction

Urbanization, the alteration of landscapes with built-up, industrialized, and human-dominated settlements (Douglas and James 2015), is a rapid global trend that is modifying the Earth in extensive and irreversible ways (Czech et al. 2000; McKinney 2002; Vitousek et al. 1997). In 2007, the global urban population rose above the worldwide rural population for the first time in history; the United Nations projects that by the year 2050, not only will the total population rise by 2.5 billion humans, but 66 percent of those people will be urbanites (2014). The process of urbanization results in profound anthropogenic modification of the landscape, culminating in systems that rely on large inputs of outside resources in order to support human life (McDonnell and Pickett 1990). Urbanization is influencing the structure and function of natural ecosystems worldwide through the continuous expansion of “human-dominated ecosystems,” which alter nutrient cycles, contribute to climate change, and accelerate biodiversity loss through the addition or removal of species (Vitousek et al. 1997). As long as humans continue to dominate the Earth, habitat loss, species endangerment, and biotic homogenization will persist, making wildlife conservation in fragmented landscapes of the utmost importance for researchers and managers alike (Marzluff and Ewing 2001).

The gradient paradigm is a complex approach used to understand the fragmented and patchy nature of urban land use that is often comprised of varying intensities of

development (Blair 1996). Researchers can use spatial environmental patterns to examine the drivers of the urbanization process, how urbanization affects plant and animal species, and what the ramifications are for ecosystems (McDonnell and Pickett 1990). Likewise, urban-rural gradients are used to study the shifts in both flora and fauna along a transect, often extending from the urban core to more pristine areas on the city periphery. For instance, natural habitats are often fragmented or replaced more prevalently towards the city center as a consequence of anthropogenic disturbances such as increased road density, air pollution, and soil compaction (McKinney 2002). Cities are some of the most extensively modified areas on the planet and, in the past, have been deemed inconsequential for conservation initiatives; nonetheless, research on fluctuating biodiversity patterns across the cityscape has shown that cities can provide valuable habitat for a variety of wildlife species (Kinzig et al. 2005).

Bird diversity changes along the urban-rural gradient in response to varying intensities and types of development. Threats to wildlife in human-modified environments include noise pollution, toxic waste, automobiles, pets, overhead wires, towers, and windows, yet an insufficient availability of food, water, cover, and space are often the most limiting factors (Adams 1994). Avian species may display marked differences in their tolerance to human presence. In order to delineate between the various responses exhibited by birds to anthropogenic disturbance, they are often grouped into three categories based on the work by Blair et al. (1996): exploiters, adapters, and avoiders. Exploiter birds can take advantage of resources made available by urbanization. They flourish in the urban environment, are typically exotic or invasive, and their populations can increase dramatically in highly developed areas. Partially urbanized

birds, or urban adapters, are able to thrive in moderately developed areas. However, their population sizes decrease in highly urbanized locations where little vegetation is available. Urban avoiders are usually native species and typically reside in the most undisturbed areas. They are sensitive to human activity and modification of the landscape, and they tend to occupy the edges of cityscapes where urban and native habitats converge.

Birds are closely associated with vegetation coverage (Macarthur and Macarthur 1961; Niemi and McDonald 2004), and the composition and abundance of available vegetation affects breeding bird populations in urban habitats (Chace and Walsh 2006; Gavareski 1976; Mills et al. 1989). In their seminal work, Macarthur and Macarthur (1961) found a strong relationship between landscape structure and avian diversity, with the addition of new layers of foliage resulting in increased bird diversity. From low shrubs to higher tree canopies, more complete vertical stratification increased bird species richness, as varying species of birds can use more progressed and varied layers of vegetation for foraging, nesting, and finding cover from predators (Macarthur and Macarthur 1961). The inverse of this relationship is also valid. More complex landscape compositions not only attract more diverse birds, but observing higher avian species diversity can also indicate increasing layers of vegetation structure (Sandstrom et al. 2006). Urban green space that encompasses natural structures such as larger trees, wooded areas, and developed shrub layers is important for the preservation of ecological diversity (Sandstrom et al. 2006).

This study took place in Lubbock, Texas. The city has an estimated population size of 252,506 people and spans a geographic area of 317 km² (U.S. Census Bureau

2016). Lubbock has approximately 96,000 housing units (U.S. Census Bureau 2016), and the front- and backyards of these residential dwellings can provide wildlife habitat (Farmer et al. 2013). The objective for this study is to determine which structural characteristics of the urban environment, including neighborhood age, distance from the city center, human population density, and canopy cover, can explain the variability of breeding bird species across neighborhoods of different types.

I created a different set of hypotheses for each of my categories of bird species richness (Table 2.1). First, I hypothesized that neighborhood age would have a positive relationship with exploiter and adapter bird species richness, and a negative relationship with less common bird species richness. Second, I predicted that higher human population densities would be associated with exploiter bird species richness. Conversely, I expected adapter and less common bird species richness to be negatively related to this measure of disturbance. Next, I hypothesized that neighborhoods located in close proximity to the city center would be conducive to exploiter bird species richness, whereas adapter and less common bird species richness would respond positively to newer neighborhoods. Finally, because vegetation is associated with higher bird diversity, I predicted all three categories of urban bird species richness would respond positively to higher percentages of canopy cover.

Materials and Methods

To assess bird responses to structural characteristics across the urban environment, I compiled a data set of human population density, development age, distance to the city center, canopy cover, and bird species richness in 14 neighborhoods recognized by the Lubbock Association of Realtors (LAR). As an extension of the study

by Farmer et al. (2013), I assigned bird species into three categories (Appendix A). Exploiter birds (Species Group A) were ubiquitous exotic or invasive species, with members of this group being observed at almost every single survey site and often in great number. I selected the same five “less ubiquitous” bird species used in Farmer et al. (2013) to represent adapter bird species (Species Group B). Adapter birds were found at many, but not all, neighborhood sites, and individuals were generally observed much less frequently than exploiter birds. In order to further delineate between the native, far less ubiquitous birds found across the cityscape, I categorized the remaining birds as less common species (Species Group C). As an adaptation of the often used “avoider” bird category (Blair 1996; McKinney 2002), individuals belonging to this group were typically native species, and most were observed in very few neighborhoods overall.

Neighborhood age, distance from the city center, human population density, and canopy cover were chosen as predictor variables. Neighborhood age infers temporal effects on an urban area and is a measure of time elapsed since disturbance occurred during initial development (Gagne et al. 2016; Martin et al. 2004). A neighborhood’s distance from the city center represents a measure of habitat loss due to urban development, as this gradient tends to steepen towards the urban core (McKinney 2002). The human population density of each neighborhood signifies the level of disturbance found in that area because land use intensity is positively related to the number of people per square kilometer (Strohbach et al. 2009). Many of the traditional urban-rural gradient measures can act as surrogates for the quality and abundance of vegetation found across the cityscape. Furthermore, vegetation is widely accepted as the most important driver of changes in bird communities (Macarthur and Macarthur 1961; Mills et al. 1989), and so I

examined the importance of each of these predictors both separately, and in conjunction with, canopy cover provided in residential yards.

I chose neighborhoods that had a high number of recent sales (>20) during the years 2015-2016 (Farmer et al. 2013). Using Multiple Listing Service data sheets provided by the LAR, I calculated the average list price for each neighborhood during my time frame of interest and chose neighborhoods falling within a range of \$50,000 – 200,000. The original study examined a price range of ~\$100,000 – 500,000. I wanted to assess the relationships between neighborhood tree cover and bird richness in a lower price bracket. The City of Lubbock's GIS and Data Services Department provided me with each neighborhood's age, which they determined based on the median year of development for all houses located within each neighborhood's recognized boundary. I compiled a preliminary list of 37 potential study neighborhoods by using ages and average list prices as my selection criteria. I condensed this list by first choosing 5 neighborhoods used in the original study that fell within my price and age range. I then used a random cluster design, pairing various categories of house prices and neighborhood ages to choose 9 new neighborhoods. This resulted in a total of 14 neighborhoods being selected for study (Table 2.2).

I conducted bird point count surveys in these 14 neighborhoods during the summer of 2017. Data collection took place from the middle of April until the end of July during breeding bird season in order to avoid recording non-resident birds. I completed 5 total sample periods and visited 70 sites per period for a total of 350 survey points. I visited each of the 14 neighborhoods during each sample period, and I randomly selected the locations visited during each survey by assigning each neighborhood to a code. I used

a random number generator to select the neighborhood, and then surveyed five different points, ensuring that all points were 200 m apart from one another. Surveys took place on either the sidewalk in front of a home or adjacent to the back alley, beginning 30 minutes before and up to 3 hours after sunrise, each lasting for 5 minutes (Bibby et al. 1992). The timer was paused when vehicles passed by in order to limit noise disturbance during the survey. I recorded the house address, UTM coordinates, date, time, and weather conditions (wind, cloud cover, and temperature) at each site. Each bird seen or heard was identified to species, and the distance to the observer was estimated as <or> 50 m (Bibby et al. 1992). Data collection did not take place during inclement weather such as high winds, rain, or other unfavorable conditions (Bibby et al. 1992).

I then calculated the species richness for all three categories of birds by adding up the number of exploiter, adapter, and avoider bird species recorded at each of the 350 survey points (Appendix A). Exploiter birds (Species Group A) included ubiquitous native and invasive species such as the house sparrow (*Passer domesticus*), great-tailed grackle (*Quiscalus mexicanus*), and European starling (*Sturnus vulgaris*) (Appendix A). Such synanthropic birds are typically invasive species that flourish in the urban environment, and their populations increase with higher levels of industrialization towards the urban core. Adapter birds (Species Group B) are able to thrive in moderately developed areas, yet their population sizes decrease in highly urbanized areas where little vegetation occurs. Examples in this category include American robin (*Turdus migratorius*), blue jay (*Cyanocitta cristata*), mourning dove (*Zenaida macroura*), northern mockingbird (*Mimus polyglottos*), and western kingbird (*Tyrannus verticalis*) (Appendix A). The less common urban birds (Species Group C) in this study were made

up of a wide variety of avoider bird species, which are sensitive to human activity and modification of the landscape. They are typically native bird species that rarely utilize urban habitats and are most often found on the city fringes. Species Group C birds during this study included birds like the burrowing owl (*Athene cunicularia*), cedar waxwing (*Bombycilla cedrorum*), and ladder-backed woodpecker (*Picoides scalaris*) (Appendix A).

I used ArcGIS and ImageJ to estimate percent canopy cover at all 350 survey points. I created maps in ArcGIS (ESRI 2016) using Google Earth imagery made available by the Lubbock GIS and Data Services department. I clipped images at a scale of 1:400 above each survey point's street address so that they included the house lot, the two next-door properties, and the three immediately across the street. After setting the data frame background to black, the final map was clipped at a scale of 1:500 and then exported. This file was then uploaded into ImageJ software, an image analysis program created by the National Institutes of Health (Schneider et al. 2012). To maximize the difference between pixels representing canopy cover and roads, buildings, grasses, or other items located in yards, and using the image's black frame created in ArcGIS as a reference for true black, I first adjusted the hue, saturation, and brightness of the image in order to select and record all pixels represented in the survey area. Using similar color adjusting techniques, I then selected only the pixels delineating trees and shrubs. I divided the number of pixels representing canopy cover by the total number of pixels in the image and then recorded the percentage of site canopy cover.

The Lubbock GIS and Data Services department provided me with Community Profile data sheets, which include Esri forecasts based on U.S. Census Bureau 2010

Summary Files and list demographic information for each neighborhood. I calculated population densities by dividing the 2016 total population by the area of each neighborhood. Neighborhood age was also calculated with data from The Lubbock GIS and Data Services Department by using the median year built for each development. I measured Euclidian distance from each survey point to the city center (14 S 231912.18 E 3717471.46; Sheri Rand, Lubbock GIS and Data Services, personal communications) by using the hub distance package in QGIS (Quantum GIS Development Team 2017). Statistical analyses were performed using IBM SPSS Statistics 22 (IBM Corp 2013).

Results

Initially, I explored the individual effects of neighborhood age, distance from the city center, human population density, and canopy cover on the diversity of the three categories of bird species using simple linear regression models (Table 2.3). Most variables were highly significant predictors for exploiter (Species Group A), adapter (Species Group B), and less common (Species Group C) bird species richness. However, human population density and canopy cover were not significant predictors of Species Group C richness. Furthermore, distance to the city center and neighborhood age explained negligible amounts of the variance in Species Group C richness.

It is important to note that these variables do not exist in a vacuum. Furthermore, vegetation is considered the most influential driver of fluctuations in bird diversity (Mills et al. 1989), and many of the traditional urban-rural gradient variables also represent vegetation quality and availability across the cityscape. For these reasons, I chose to run two sets of multiple regressions to predict species groups in relation to structural characteristics of the urban environment. The first regression only included neighborhood

age, distance to the city center, and human population density. The subsequent multiple regression incorporated canopy cover into the analyses in order to determine which of the variables would emerge as the strongest predictors when considered simultaneously.

I used a multiple regression analysis to jointly assess the effects of neighborhood age, distance to the city center, and human population density on exploiter bird (Species Group A) richness (Table 2.4). The model was statistically significant, $R^2 = 0.195$, $F_{(3, 346)} = 27.862$, $p < 0.001$. Neighborhood age significantly predicted Species Group A richness ($\beta = 0.478$, $p < .001$). Distance and human population density were not significant predictors in this model, however. A second multiple regression was run to predict Species Group A richness from neighborhood age, distance to the city center, human population density, and canopy cover (Table 2.5). The model was statistically significant, $R^2 = 0.198$, $F_{(4, 345)} = 21.270$, $p < .001$. Neighborhood age was the only statistically significant predictor of Species Group A richness ($\beta = 0.458$, $p < .001$).

I used the same multiple regression analysis model to predict adapter bird (Species Group B) richness from neighborhood age, human population density, and distance to the city center (Table 2.4). The model was statistically significant, $R^2 = 0.189$, $F_{(3, 346)} = 26.964$, $p < .001$. Although city center distance was not a statistically significant predictor of Species Group B richness, neighborhood age ($\beta = 0.466$, $p < .001$) and human population density ($\beta = -0.206$, $p < .001$) did explain a statistically significant amount of variance in the outcome variable. Another multiple regression analysis was run to predict Species Group B richness from neighborhood age, human population density, and distance to the city center, and canopy cover (Table 2.5). The model was statistically significant, $R^2 = 0.235$, $F_{(4, 345)} = 26.448$, $p < .001$. Neighborhood age ($\beta = 0.392$, $p <$

.001), human population density ($\beta = -0.122$, $p < .05$), city center distance ($\beta = 0.247$, $p < .01$), and percent vegetation ($\beta = 0.286$, $p < .001$) were all statistically significant predictors of Species Group B richness.

I then examined predictors of neighborhood age, human population density, and distance to the city center for less common bird (Species Group C) richness (Table 2.4). The model was statistically significant, $R^2 = 0.048$, $F_{(3, 346)} = 5.805$, $p < .01$. Neighborhood age ($\beta = -0.179$, $p < .05$) and human population density ($\beta = -0.148$, $p < .01$) were the two statistically significant predictors of Species Group C richness. Finally, I examined predictors for less common bird species richness of neighborhood age, human population density, distance to the city center, and canopy cover (Table 2.5). The model was statistically significant, $R^2 = 0.048$, $F_{(4, 345)} = 4.345$, $p < .01$. Neighborhood age ($\beta = -0.181$, $p < .05$) and human population density ($\beta = -0.146$, $p < .05$) were the sole statistically significant predictors of Species Group C richness.

Discussion

These predictors of neighborhood age, distance from the city center, human population density, and canopy cover, although statistically significant when regressed individually against exploiter, adapter, and less common bird species richness, are also interrelated with one another (Table 2.3). For example, newer neighborhoods are typically developed on the outer edges of cities, contributing to urban sprawl. Furthermore, vegetation is considered the most important driver of changes in bird communities (Mills et al. 1989), and many of the traditional urban-rural gradient variables can act as a surrogate for the composition and quantity of vegetation found across the cityscape. Vegetation requires time to mature and develop, and so newer

neighborhoods typically offer less cover and habitat complexity for wildlife, as they contain younger trees and shrubs (Vale and Vale 1976). Therefore, I combined the urban-rural gradient measures into a multiple regression analysis in order to understand which variables could explain the most variation in each category of urban bird species richness. I then ran a multiple regression analysis including canopy cover, and again assessed my outcome variables in light of the interactions occurring between all of my predictors.

Multiple regression analyses revealed a more nuanced picture of the types of indicators that these three categories of urban birds respond to in residential yards. The results of this study revealed neighborhood age as the single significant predictor of exploiter bird species richness (Table 2.4). Neighborhood age infers the effects of time on urban habitat. Its inclusion as a predictor of species richness helps account for the temporal dynamics affecting urban ecosystems (Gagne et al. 2016). Disturbance created during building and road construction during urban development often replaces native vegetation with impervious surfaces, so neighborhood age can act as a measure of the amount of time elapsed since disturbance originally occurred in a subdivision (Martin et al. 2004; Melles 2005).

My prediction that exploiter species richness would be positively related to neighborhood age was supported. This relationship held true regardless of whether the multiple regression analysis included canopy cover or not (Table 2.5). It is important to note that neighborhood age can act as a surrogate for more progressed and varied vegetation structure, as garden plantings tend to mature over time (Gagne et al. 2016; Palomino and Carrascal 2006; Whitney and Adams 1980; Vale and Vale 1976). However, synanthropic species are typically dependent on human subsidized resources,

and therefore do not rely mainly on vegetation quantity or composition in order to persist (McKinney 2002). Previous research suggests that as neighborhoods age, bird communities comprised of mostly native and migrant species can be replaced with exotic and non-migratory species over time; this may be attributed to the assertion that older homes are often more secluded from natural habitats and are associated with higher intensities of development (Loss et al. 2009).

The predictability of urban adapter bird species richness in Lubbock neighborhoods was related to human population density and neighborhood age. But distance to the city was not a significant variable in the multiple regression analysis. However, the author would like to indicate that distance to the city center had a p-value of 0.051, and was therefore only excluded marginally from the model. Higher richness of adapter bird species was associated with lower human population density (Table 2.4), supporting my hypothesis regarding this predictor variable. Human population density is often used as an urban-rural gradient measure for the level or intensity of urban development (Gagne et al. 2016; Loss et al. 2009; Martin et al. 2004; Strohbach et al. 2009), as higher human population densities are associated with habitat fragmentation, air and soil pollution, and other anthropogenic disturbance regimes (Kinzig et al. 2005; McKinney 2002; 2008). Previous research has suggested that the most densely populated neighborhoods often contain below-average species richness (Strohbach et al. 2009) and abundance (Melles 2005). Adapter birds typically respond negatively to the most highly urbanized areas within the cityscape, which typically provide very little vegetation (Blair 1996; McKinney 2002). However, intermediate levels of urbanization are conducive to adapter bird species habitat. Adapter birds respond positively to human subsidized

resources provided at a moderate intensity of development, such as ornamental yard plantings and water sources found in suburban neighborhoods (Blair 1996; McKinney 2002).

Previous research suggests that neighborhood age is an important predictor of breeding bird species richness (Gagne et al. 2016; Munyenyembe et al. 1989; Palomino and Carrascal 2006; Vale and Vale 1976), and my hypothesis that adapter birds would respond positively to older neighborhoods was supported. Neighborhood age is often used as a measure for the amount of time elapsed since disturbance created during construction. It represents how long the process of succession has had to develop layers of foliage, which can be greatly enhanced in urban areas where humans are actively planting vegetation. Past studies suggest that neighborhood age is positively related to vegetation abundance (Martin et al. 2004; Munyenyembe et al. 1989; Palomino and Carrascal 2006). Moreover, older urban developments associated with higher breeding bird species richness (Gagne et al. 2016). Birds are most likely responding to habitat conditions changing over time, because vegetation planted in residential yards at the time of development mature with neighborhood age. This assertion is supported by the incorporation of canopy cover into the second multiple regression analysis used to predict adapter bird species richness.

All four predictors had a statistically significant relationship with Species Group B richness. The second model maintained the same direction of the relationships found in the preliminary multiple regression analysis, and also revealed positive relationships between adapter bird species richness with canopy cover and distance from the city center (Table 2.5). I expected to find a positive relationship between adapter bird species

richness and canopy cover, because more complete vertical stratification of vegetation increases bird species richness, as varying species of birds can use these multiple layers of vegetation for foraging, nesting, and finding cover from predators (MacArthur and MacArthur 1961). I also expected that adapter birds would be found throughout the urban matrix, but would prefer habitat in closer to the periphery of the city. Previous research also suggests that species richness varies with proximity to the city center (Chace and Walsh 2006; Dallimer et al. 2012; MacGregor-Fors et al. 2011; McKinney 2008). The habitat loss gradient escalates towards the urban core, and the resulting increase in fragmentation and patchiness allows nonnative biota to exploit resources found in heavily altered areas (Marzluff 2001; McKinney 2002). Moreover, vegetation complexity tends to decrease from the city outskirts towards the center (Sandstrom et al. 2006).

Less common species were associated with newer neighborhoods and lower human population densities. When all variables were considered in the final multiple regression model, these were the only two variables to emerge as significant predictors of Species Group C richness. Interestingly, less common birds did not respond to canopy cover as I predicted they would. Therefore, instead of assessing these relationships as proxies for residential yard plantings, I postulate that Species Group C will respond more to the level of and time elapsed since disturbance occurred in each neighborhood.

Avoider bird species, which are characteristically sensitive to human presence and habitat alterations, are typically the first to disappear from a landscape affected by anthropogenic disturbance unless native habitat is intentionally preserved during development (McKinney 2002). Therefore, it seems intuitive to discover that Species Group C in Lubbock are less likely to be found in the most densely populated areas of the city

(Melles 2005; Strohbach et al. 2009). Furthermore, as some research suggests, newer subdivisions may be less isolated from natural habitats (Loss et al. 2009). This is an essential structural component for native species that rely on natural resource availability in order to persist (Blair 1996; McKinney 2002)

Conclusions

Not all species respond to urban development in the same way. Birds are frequently used as ecological indicators to assess current ecosystem conditions and to act as early warning systems to predict future responses to anthropogenic disturbances (Niemi and McDonald 2004). Researchers use ecological indicators, which are easy to identify and measure, inexpensive to study, and respond to disturbance in a well-documented way, to serve as representatives for other species that may have similar ecological needs and responses to stressors (Niemi and McDonald 2004). Urban ecosystems are the only growing habitats on Earth. Urbanization decreases total global biodiversity through anthropogenic enterprises resulting in biotic homogenization (McKinney 2006). Yet cities are not biological deserts, and can in fact provide quality wildlife habitat. As made evident in Appendix A, a variety of species, including exploiter, adapter, and avoider birds, can be observed in cities. Yet the structure of the environment may dictate how they are distributed throughout the urban matrix.

The traditional urban-rural gradient paradigm offers valuable insights on urban bird patterns. However, these measurements do not directly account for the variability in landscaped vegetation provided in residential yards (Lerman and Warren 2011). Interestingly, the original study did not find any relationship between the existence of nearby parks to bird richness or abundance (Farmer et al. 2013), indicating that the “top-

down” decisions made by formal institutions and city planners appear to have less influence on spatial heterogeneity than the “bottom-up” choices enacted by homeowners on private lands in Lubbock (Melles 2005). Therefore, augmenting traditional analyses with canopy cover provided in residential yards can shed light on the primary factors driving avian responses to urbanization and anthropogenic disturbance. Local variations in management practices can have implications for biota within yards and across the cityscape (Bergey and Figueroa, 2016), with groups of yards potentially improving habitat connectivity and providing greater total habitat for certain species (Belaire et al. 2014). Furthermore, urban green spaces are important for their capacity to enhance aesthetics, reduce radiation, runoff, heat, and urban noise, and improve air quality, human health, and physiological distress (Mansfield et al. 2005). Importantly, many urban dwellers will experience nature primarily during time spent in their front and back yards, and their positive experiences with the natural world will promote urban biodiversity through increased stakeholder support for conservation initiatives (Kinzig et al. 2005; Lerman and Warren 2011).

References

- Adams LW. 1994. Urban wildlife habitats: A landscape perspective. Volume 3. Minneapolis (MN): The University of Minnesota Press. 186 p.
- Belaire JA, Whelan CJ, Minor ES. 2014. Having our yards and sharing them too: The collective effects of yards on native bird species in an urban landscape. *Ecological Applications*. 24(8):2132-2143.
- Bergey EA, Figueroa LL. 2016. Residential yards as designer ecosystems: Effects of yard management on land snail species composition. *Ecological Applications*. 26(8):2536-2545.
- Bibby CJ, Hill DA, Burgess N. 1992. Bird census techniques. San Diego (CA): Academic Press Inc.
- Blair RB. 1996. Land use and avian species diversity along an urban gradient. *Ecological Applications*. 6(2):506-519.
- Chace JF, Walsh JJ. 2006. Urban effects on native avifauna: A review. *Landscape and Urban Planning*. 74(1):46-69.
- Czech B, Krausman PR, Devers PK. 2000. Economic associations among causes of species endangerment in the united states. *Bioscience*. 50(7):593-601.
- Dallimer M, Rouquette JR, Skinner AMJ, Armsworth PR, Maltby LM, Warren PH, Gaston KJ. 2012. Contrasting patterns in species richness of birds, butterflies and plants along riparian corridors in an urban landscape. *Diversity and Distributions*. 18(8):742-753.
- Douglas I, James P. 2015. Urban ecology: An introduction. New York (NY): Routledge.
- ESRI (Environmental Systems Resource Institute). 2016. ArcMap 10.4.1. ESRI, Redlands, California.
- Farmer MC, Wallace MC, Shiroya M. 2013. Bird diversity indicates ecological value in urban home prices. *Urban Ecosystems*. 16(1):131-144.
- Gagne SA, Sherman PJ, Singh KK, Meentemeyer RK. 2016. The effect of human population size on the breeding bird diversity of urban regions. *Biodiversity and Conservation*. 25(4):653-671.
- Gavareski CA. 1976. Relation of park size and vegetation to urban bird populations in seattle, washington. *The Condor*. 78(3):375-382.

- IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.
- Kinzig AP, Warren P, Martin C, Hope D, Katti M. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*. 10(1):13.
- Lerman SB, Warren PS. 2011. The conservation value of residential yards: Linking birds and people. *Ecological Applications*. 21(4):1327-1339.
- Loss SR, Ruiz MO, Brawn JD. 2009. Relationships between avian diversity, neighborhood age, income, and environmental characteristics of an urban landscape. *Biological Conservation*. 142(11):2578-2585.
- Macarthur R, Macarthur JW. 1961. On bird species-diversity. *Ecology*. 42(3):594-598.
- MacGregor-Fors I, Morales-Perez L, Schondube JE. 2011. Does size really matter? Species-area relationships in human settlements. *Diversity and Distributions*. 17(1):112-121.
- Mansfield C, Pattanayak SK, McDow W, McDonald R, Halpin P. 2005. Shades of green: Measuring the value of urban forests in the housing market. *Journal of Forest Economics*. 11(3):177-199.
- Martin CA, Warren PS, Kinzig AP. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning*. 69(4):355-368.
- Marzluff JM, Ewing K. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. Springer.
- Marzluff JM. 2001. Worldwide urbanization and its effects on birds. In: Marzluff JM, Bowman R, Donnelly R, editors. *Avian Ecology and Conservation in an Urbanizing World*. New York (NY): Kluwer Academic Publishers. p. 19-48.
- McDonnell MJ, Pickett STA. 1990. Ecosystem structure and function along urban rural gradients: An unexploited opportunity for ecology. *Ecology*. 71(4):1232-1237.
- McKinney ML. 2002. Urbanization, biodiversity, and conservation. *Bioscience*. 52(10):883-890.
- McKinney ML. 2006. Urbanization as a major cause of biotic homogenization. *Biological Conservation*. 127(3):247-260.

- McKinney ML. 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*. 11(2):161-176.
- Melles SJ. 2005. Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats*. 3(1):25-48.
- Mills GS, Dunning JB, Bates JM. 1989. Effects of urbanization on breeding bird community structure in southwestern desert habitats. *The Condor*. 91(2):416-428.
- Munyenyembe F, Harris J, Hone J, Nix H. 1989. Determinants of bird populations in an urban area. *Australian Journal of Ecology*. 14(4):549-557.
- Niemi GJ, McDonald ME. 2004. Application of ecological indicators. *Annual Review of Ecology Evolution and Systematics*. 35:89-111.
- Palomino D, Carrascal LM. 2006. Urban influence on birds at a regional scale: A case study with the avifauna of northern Madrid province. *Landscape and Urban Planning*. 77(3):276-290.
- Quantum GIS Development Team 2017. Quantum GIS (Geographic Information System). Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>.
- Sandstrom UG, Angelstam P, Mikusinski G. 2006. Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning*. 77(1-2):39-53.
- Schneider CA, Rasband WS, Eliceiri KW. 2012. Nih image to imagej: 25 years of image analysis. *Nature Methods*. 9(7):671-675.
- Strohbach MW, Haase D, Kabisch N. 2009. Birds and the city: Urban biodiversity, land use, and socioeconomics. *Ecology and Society*. 14(2):15.
- United Nations Department of Economic and Social Affairs. 2014. World urbanization prospects, The 2014 revision. New York, New York.
- U.S. Census Bureau. 2016. State and county quick facts: Lubbock, Texas. Data derived from Population Estimates, American Community Survey, Census of Population and Housing, County Business Patterns, Economic Census, Survey and Business Owners, Building Permits, Census of Governments. <https://www.census.gov/quickfacts/fact/table/lubbockcitytexas,US#viewtop>
- Vale TR, Vale GR. 1976. Suburban bird populations in West-Central California. *Journal of Biogeography*. 3(2):157-165.

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997. Human domination of earth's ecosystems. *Science*. 277(5325):494-499.

Whitney GG, Adams SD. 1980. Man as a maker of new plant-communities. *Journal of Applied Ecology*. 17(2):431-448.

Tables

Table 2.1 Hypotheses for Relationships Between Structural Characteristics of the Urban Environment and Exploiter, Adapter, and Uncommon Bird Species Richness During Summer 2017 in Lubbock, TX.

	<i>Neighborhood Age</i>	<i>Distance to City Center</i>	<i>Human Population Density</i>	<i>Canopy Cover</i>
<i>Exploiter Bird Species Richness</i>	Positive	Negative	Positive	Positive
<i>Adapter Bird Species Richness</i>	Positive	Positive	Negative	Positive
<i>Uncommon Bird Species Richness</i>	Negative	Positive	Negative	Positive

Table 2.2. Neighborhoods Selected for Bird Point Count Surveys During Summer 2017 in Lubbock, TX.

Neighborhood Name	Category	
	Age	Price
Kuykendall Heights	1959 – 1976	\$81,024 – 120,502
Oakwood	1959 – 1976	\$120,503 – 159,980
Monterey Park*	1959 – 1976	\$159,981 – 199,455
Richland Hills	1977 – 1994	\$81,024 – 120,502
Leftwich Monterey	1977 – 1994	\$120,503 – 159,980
Quaker Heights	1977 – 1994	\$159,981 – 199,455
Cedar Meadows	1995 – 2013	\$81,024 – 120,502
Monterey	1995 – 2013	\$120,503 – 159,980
Fox Ridge	1995 – 2013	\$159,981 – 199,455
<i>Replication Sites</i>		
Overton	1968	\$85,658
Whisperwood	1996	\$183,109
Melonie Park South	1990	\$190,111
Pheasant Run	1997	\$190,894
Farrar Estates	1992	\$191,077

* *Monterey Park was randomly selected, as no other neighborhood fit the 1959-1976 and \$159,981-199,455 category*

Table 2.3. Simple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, Neighborhood Age, and Canopy Cover During Summer 2017 in Lubbock, TX.

Variable	Exploiter Bird Species Richness		Adapter Bird Species Richness		Uncommon Bird Species Richness	
	R ²	p-value	R ²	p-value	R ²	p-value
Human Population Density	0.016	0.019	0.073	0.000	0.009	0.070
Distance to City Center	0.115	0.000	0.075	0.000	0.017	0.015
Neighborhood Age	0.193	0.000	0.147	0.000	0.028	0.002
Canopy Cover	0.085	0.000	0.173	0.000	0.002	0.369

Note: N = 350

Table 2.4. Multiple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, and Neighborhood Age During Summer 2017 in Lubbock, TX.

Variable	Exploiter Bird Species Richness	Adapter Bird Species Richness	Uncommon Bird Species Richness
	β	β	β
Human Population Density	-0.027	-0.206***	-0.148**
Distance to City Center	0.055	0.163	0.029
Neighborhood Age	0.478***	0.466***	-0.179*
R ²	0.195	0.189	.048
F	27.862***	26.964***	5.805**

Note: $N = 350$, * $p < .05$, ** $p < .01$, *** $p < .001$

Table 2.5. Multiple Linear Regression Analyses Predicting Exploiter, Adapter, and Uncommon Bird Species Richness from Human Population Density, Distance to City Center, Neighborhood Age, and Canopy Cover During Summer 2017 in Lubbock, TX.

Variable	Exploiter Bird Species Richness	Adapter Bird Species Richness	Uncommon Bird Species Richness
	β	β	β
Density	-0.005	-0.122*	-0.146*
Distance	0.078	0.247**	0.031
Age	0.485***	0.392***	-0.181*
Canopy Cover	0.077	0.286***	0.008
R ²	0.198	0.235	0.048
F	21.270***	26.448***	4.345**

Note: $N = 350$, * $p < .05$, ** $p < .01$, *** $p < .001$

CHAPTER III

INCORPORATING SOCIOECONOMIC ATTRIBUTES OF HOMEOWNERS INTO TRADITIONAL URBAN-RURAL GRADIENT ANALYSES TO PREDICT CANOPY COVER AND URBAN BIRD DIVERSITY

Introduction

The United Nations (2014) estimates that 54 percent of the world's human population is currently living in urbanized areas. It predicts that urbanites will increasingly outpace rural dwellers in the coming decades (United Nations 2014). Urbanization modifies landscapes with built-up, industrialized, and human-dominated settlements (Douglas and James 2015), and this process has extensive and long-lasting effects (Czech et al. 2000; McKinney 2002; Vitousek et al. 1997). Comprised of fluctuating intensities of development, cities are considered to be some of the most modified ecosystems in the world, and therefore often deemed irrelevant for conservation purposes. However, cities are not biological deserts. They have the potential to provide valuable habitat for a variety of wildlife species (Kinzig et al. 2005).

Urban ecology seeks to understand the distribution and abundance of organisms located in and around cities (Pickett et al. 2001). This field of research explores the relationships between humans, other organisms, and their surroundings within an urban habitat (Douglas and James 2015) and uses social, economic, and ecological science in order to study the effects of urbanization. Habitat loss, species endangerment, and biotic homogenization will persist as long as human-dominated ecosystems continue to expand (Marzluff and Ewing 2001). Since these global alterations unfold as a direct result of ongoing human population growth, understanding how organisms are dispersed throughout the urban matrix makes urban ecology an increasingly important field.

The urban ecosystem is a unique ecological environment that humans have transformed to better suit their needs. Pollution, automobile traffic, pets, overhead wires, and windows all pose threats to wildlife in cities, yet the scarcity of sufficient food, water, cover, and space are the most limiting factors (Adams 1994). Humans are the number one dispersers of vascular plants on the planet, and the process of urbanization usually alters wildlands by clearing native vegetation or replacing it with exotic flora (Adams et al. 2016). In response, wildlife located in and around cities may display marked differences from their exurban counterparts by changing their activity patterns, reproductive behaviors, and feeding strategies (Adams et al. 2016). Many of these behavioral shifts occur as a result of wildlife's response to human presence. To understand different avian responses to anthropogenic disturbance, birds are typically grouped into three categories: exploiters, adapters, and avoiders (Blair 1996). Exploiter birds can take advantage of resources made available by urbanization, are typically exotic or invasive, and their populations flourish in highly developed areas. Adapter birds thrive in moderately developed areas where sufficient vegetation is provided. However, their population sizes decline in intensely built-up locations. Avoider birds are typically native species, sensitive to human activity and landscape alterations, and occupy the most undisturbed habitats on city fringes.

Birds are highly associated with vegetation cover (Macarthur and Macarthur 1961; Niemi and McDonald 2004), and breeding bird populations respond to the quality and abundance of vegetation made available in urban habitats (Chace and Walsh 2006; Gavareski 1976; Mills et al. 1989). In their formative work, Macarthur and Macarthur (1961) found that more complete vertical stratification of vegetation increased bird

species richness. From small shrubs to tall tree canopies, the addition of a new layer of foliage led to an increase in bird diversity, as varying species of birds can use more progressed and varied layers of vegetation for foraging, nesting, and finding cover from predators (Macarthur and Macarthur 1961). Increased bird diversity can also indicate increasing layers of vegetation (Sandstrom et al. 2006). In order to ensure the preservation of ecological diversity, urban green spaces that contain larger trees, wooded areas, and developed shrub layers will be paramount for future avian conservation (Sandstrom et al. 2006).

The urban-rural gradient paradigm uses spatial environmental patterns to examine the drivers of urbanization, how urbanization impacts flora and fauna, and what the consequences are for ecosystems (McDonnell and Pickett 1990). It is a complex approach to understanding the fragmented and patchy nature of urban land use, which is often comprised of differing intensities of development across the cityscape (Blair 1996). Urban-rural gradients are used to study changes in both animal and plant species along a transect extending from the urban center to more natural habitats located on the city fringes. The habitat loss gradient tends to steepen towards the urban core as a result of anthropogenic disturbances such as increased human population density, water pollution, and soil compaction (McKinney 2002).

Environmental factors only paint part of the urban ecosystem picture. Traditional gradients do not take into consideration how socioeconomic and cultural characteristics drive the interactions between humans and the environment (Kinzig et al. 2005). The patterns and processes in cities are driven in large part by human behavior, as people can act as extremely influential agents of change (Melles 2005). It is, therefore, important to

understand why and how landowners behave and make the choices they do on their properties (Grove et al. 2006). Fluctuations in urban biodiversity patterns may be better understood by thinking of yards as designer ecosystems with variations in yard upkeep, watering regimes, pesticide use, and so on (Bergey and Figueroa, 2016). These behaviors may reflect social, economic, and cultural characteristics of homeowners above and beyond the traditional urban-rural gradients used in urban ecology research (Hope et al. 2003). Furthermore, because a large portion of the cityscape is made up of front and back yards, it might be possible to offset some of the detrimental consequences of urban development by collectively managing these areas for birds and other wildlife (Lerman and Warren 2011). For instance, groups of yards have the potential to improve habitat connectivity and provide greater total wildlife habitat (Belaire et al. 2014).

My study took place in West Texas. The city of Lubbock, which has an estimated population of 252,506 people, extends across an area of 317 km² (U.S. Census Bureau 2016). Encompassing about 96,000 housing units (U.S. Census Bureau 2016), the front- and backyards of Lubbock residences have the realized potential to provide wildlife habitat (Farmer et al. 2013). The objective for this study was to determine whether homeowner socioeconomic indicators could improve the prediction of neighborhood canopy cover and bird diversity beyond the traditional urban-rural indicators used in urban ecology research. In order to achieve this, I incorporated biotic, abiotic, and human variables into my analyses.

I selected six predictor variables for my study. Income, education, and house price represented homeowner socioeconomic status, assuming that high values for each of these indicators would represent residents belonging to a higher social class.

Neighborhood age, distance from the city center, and human population density served as my traditional urban-rural gradient measures. Neighborhood age, a measure of the number of years elapsed since disturbance caused by development, insinuates the effects of time on an urban area (Gagne et al. 2016; Martin et al. 2004). Distance from the city center gauges isolation from native habitat, and this gradient tends to steepen towards the urban core (McKinney 2002). Human population density indicates the level of disturbance found in a neighborhood, as higher intensities of land use are positively associated with the number of people residing in the area (Strohbach et al. 2009).

Because vegetation is considered the most important driver of changes in bird communities (Macarthur and Macarthur 1961; Mills et al. 1989), I expected that the direction of the relationships would be mirrored between each indicator and both outcome variables (Table 3.1). For my traditional urban-rural gradient measures, I first hypothesized that neighborhood age would have a positive relationship with canopy cover and bird diversity. Second, I predicted that higher human population density would be negatively associated with urban patterns of biodiversity. Third, I expected that neighborhoods located farther from the city center would be conducive to higher levels of canopy cover and bird diversity. Finally, I presumed that the socioeconomic indicators would contribute to our overall understanding of urban biodiversity patterns, and I hypothesized that the predictors of income, education, and house price would all have positive relationships with percent canopy cover and bird diversity.

Materials and Methods

In order to assess how canopy cover and bird diversity respond to a variety of traditional urban-rural gradient measures as well as homeowner socioeconomic

characteristics, I collected data on human population density, neighborhood age, distance to the city center, income, education, house price, percent canopy cover, and bird diversity in 14 neighborhoods recognized by the Lubbock Association of Realtors (LAR). Building on the study by Farmer et al. (2013), I selected neighborhoods that had a high number of recent sales (>20) during the years 2015-2016. I used Multiple Listing Service data sheets provided by the LAR to determine the average list price of each neighborhood during these years. I then chose those locations falling between \$50,000 – 200,000, as the range used by Farmer et al. (2013) included list prices from ~\$100,000 – 500,000, and I aimed to survey homes in a lower price bracket. The City of Lubbock's GIS and Data Services Department supplied me with each neighborhood's age. This information was based on the median year of development for all houses located within each neighborhood's recognized boundary. After assembling a preliminary list of 37 potential study neighborhoods by using ages and average list prices as my selection criteria, I identified 5 neighborhoods that were also used in by Farmer et al. (2013) to serve as replication sites. I then chose 9 new neighborhoods by using a random cluster design, which paired categories of low, medium, and high house prices with categories of new, mid, and old neighborhood ages. This resulted in 14 neighborhoods being selected for study (Table 3.2).

I conducted bird point count surveys in these 14 neighborhoods during the summer of 2017. Because migratory birds are difficult to detect and do not sing as much as breeding birds attempting to attract mates, data collection took place from the middle of April until the end of July during breeding bird season (M. Wallace, Texas Tech University, personal communication). I conducted 5 total sample rounds and visited 70 sites per

round for a total of 350 survey points. I randomly selected the locations visited during each survey by first assigning each neighborhood to a code, and then using a random number generator to select the neighborhood. I chose five different points in each of the 14 neighborhoods during each sample round, ensuring that all points were 200 m apart from one another. Observations took place either on the sidewalk in front of a home or adjacent to the back alley. They began 30 minutes before and up to 3 hours after sunrise, each adhering to a 5 minute time limit (Bibby et al. 1992). I paused the timer when vehicles passed by in order to limit noise disturbance during the survey. The house address, UTM coordinates, date, time, and weather conditions (wind, cloud cover, and temperature) were recorded at each sampling event. All birds seen or heard were identified to species, and the distance to the observer was estimated as $<or> 50$ m (Bibby et al. 1992). Data collection did not occur during inclement weather such as high winds, rain, or other unfavorable conditions (Bibby et al. 1992). I calculated the Shannon-Weiner Index for each neighborhood, which categorizes species diversity and accounts for the abundance and evenness of the species present in an area.

I used ArcGIS and ImageJ to estimate percent canopy cover at all 350 survey points. Using Google Earth imagery provided by the Lubbock GIS and Data Services Department, I created maps in ArcGIS (ESRI 2016). I clipped images at a scale of 1:400 above each survey location's street address. This ensured the inclusion of the lot, the two next-door properties, and the three immediately across the street. I then clipped the final map at a scale of 1:500, which allowed the data frame's black background to be visible in the final exportation. I then uploaded this file into ImageJ, an image analysis program created by the National Institutes of Health (Schneider et al. 2012). To maximize the

difference between pixels representing canopy cover and roads, buildings, grasses, or other items located in yards, and using the image's black frame created in ArcGIS as a reference for true black, I first adjusted the hue, saturation, and brightness of the image. This process allowed me to select and record all pixels represented in the survey area. I then selected only the pixels delineating trees and shrubs. I divided this result by the total number of pixels in the image to calculate the percentage of pixels symbolizing percent canopy cover at a site.

The Lubbock GIS and Data Services department gave me access to Community Profile data sheets, which contain ESRI forecasts based on U.S. Census Bureau 2010 Summary Files. They also list demographic information for each neighborhood. I calculated population densities by dividing the 2016 total population by the area of each neighborhood. Neighborhood ages, also provided by the Lubbock GIS and Data Services Department, were represented by the median year built for each development. I calculated Euclidian distance from each survey point to the city center (14 S 231912.18 E 3717471.46; Sheri Rand, Lubbock GIS and Data Services, personal communications) by using the hub distance package in QGIS (Quantum GIS Development Team 2017).

Lastly, I assessed socioeconomic attributes of each neighborhood. Income was measured as the median household income for each neighborhood (Lubbock GIS and Data Services). I represented educational attainment by the number of people residing within each neighborhood boundary who held a bachelor's or graduate degree (Lubbock GIS and Data Services). I derived home values from Multiple Listing Service Data sheets provided by the LAR by calculating the average list price of homes sold during 2015-

2016. All statistical analyses were performed using IBM SPSS Statistics 22 (IBM Corp 2013).

Results

I initially explored the effects of each predictor variable on both canopy cover and bird diversity using simple linear regression models, holding the sample round as a constant (Table 3.3). For each outcome variable, all traditional urban-rural gradient measures were highly significant. However, none of the socioeconomic status indicators were significant predictors of canopy cover, and income was not a predictor of bird diversity. Given these results, I chose to run two hierarchical multiple regression analyses in order to find out how the combination of all these variables could explain the variance in canopy cover as well as bird diversity. I kept the sample round as a constant in the first block, and then included the traditional variables in the second block. For the third block, I used stepwise selection for the socioeconomic variables, as I was interested in which of these indicators might be retained in the final model and could help explain the remaining variance in both dependent variables above and beyond the traditional urban-rural gradient measures.

A hierarchical multiple regression was conducted to determine if the addition of socioeconomic indicators improved the prediction of percent canopy cover over and above the traditional indicators while including sample round as a control variable in Model 1 (Table 3.4). The full model of sample round, traditional, and socioeconomic indicators to predict percent vegetation (Model 4) was statistically significant ($R^2 = 0.563$, $F_{(6, 343)} = 73.7$, $p < 0.001$). The traditional indicators uniquely explain a statistically significant amount of variance in percent vegetation (Model 2; R^2 changed = 0.446, $F_{(3,$

$_{345}) = 92.9, p < 0.001$). The socioeconomic indicators were then entered together into a new block of the regression using stepwise selection to determine each indicator's unique contribution to the overall variance in the dependent variable. Income was selected as the first predictor to explain a statistically significant amount of additional variance in percent vegetation (Model 3; R^2 changed = 0.106, $F_{(1, 344)} = 81.5, p < 0.001$). The addition of house price to the prediction of percent vegetation (Model 4) also led to a statistically significant, but small increase in R^2 of 0.010, $F_{(1, 343)} = 7.6, p < 0.01$. Education was removed from the analysis because it did not appear as a statistically significant predictor of percent vegetation.

A hierarchical multiple regression was run to determine if the addition of socioeconomic indicators improved the prediction of bird diversity over and above the traditional indicators while including sample round as a control variable in Model 1 (Table 3.5). The full model of sample round, traditional, and socioeconomic indicators to predict bird diversity (Model 5) was statistically significant ($R^2 = 0.883, F_{(7, 342)} = 367.4, p < 0.001$). The traditional indicators uniquely explain a statistically significant amount of variance in bird diversity (Model 2; R^2 changed = 0.689, $F_{(3, 345)} = 255.1, p < 0.001$). The socioeconomic indicators were then entered together into a new block of the regression using stepwise selection to determine each indicator's unique contribution to the variance in the dependent variable. House price was selected as the first predictor to explain a statistically significant amount of additional variance in bird diversity (Model 3; R^2 changed = 0.159, $F_{(1, 344)} = 360.1, p < 0.001$). The addition of income to the prediction of bird diversity (Model 4) also led to a statistically significant increase in R^2 of 0.025, $F_{(1, 343)} = 66.3, p < 0.001$). Finally, while education was not a significant predictor of percent

vegetation, it explained a small but statistically significant amount of variance in bird diversity (Model 5; R^2 changed = 0.010, $F_{(1, 342)} = 28.7$, $p < 0.001$).

Discussion

Traditional gradient analyses have enhanced our knowledge about the ways in which biota are dispersed across the urban matrix. They can act as indirect measures of disturbance, pollution, predation, and other factors affecting urban biodiversity patterns. Without the inclusion of socioeconomic data, they implicitly assume that the attributes of the people living in particular urban areas are not necessary for understanding how they behave, and that the different ways people interact with the environment can be inferred simply from their inclinations to live in highly populated neighborhoods, at the urban core, and so on (Kinzig et al. 2005). However, humans may prefer different types of landscapes depending on their upbringing, ethnicity, nationality, or financial wherewithal (Kinzig et al. 2005), and they often choose certain environmental amenities, such as residential tree and shrub plantings, based on these socioeconomic and cultural characteristics (Hope et al. 2003). Considering birds are highly associated with vegetation cover (Macarthur and Macarthur 1961; Niemi and McDonald 2004), and the composition and abundance of available vegetation affects breeding bird populations in urban habitats (Chace and Walsh 2006; Gavareski 1976; Mills et al. 1989), we would expect that the composition of each neighborhood's avian community should also be associated with local homeowner socioeconomic status (Melles 2005). Unfortunately, many people live in biological poverty (Turner et al. 2004). Their ability to access biodiversity exists as a function of the intrinsic constraints or privileges related to their available financial resources, which allow them to modify their surroundings and create their ecological

ideal (Lerman and Warren 2011; Martin et al. 2004; Melles 2005). For these reasons, I ran hierarchical multiple regressions and used both urban-rural as well as socioeconomic gradient analyses to reveal a more nuanced picture of urban biodiversity patterns.

When exploring the predictability of canopy cover from urban-rural and socioeconomic variables, the following patterns emerged. Higher percentages of canopy cover in Lubbock neighborhoods were associated with older neighborhoods that were located farther from the city center (Table 3.4). Human population density had a negative relationship with canopy cover. Although it was retained in the final model (Model 4), as the traditional gradient measures were not removed using stepwise selection, this variable was not statistically significant. Furthermore, only income and house price were retained as significant predictors, and each had a positive relationship with the dependent variable. Education was not included in the final model.

For my traditional urban-rural gradient measures, my prediction that neighborhood age would be positively associated with canopy cover was supported. Urban age is related to vegetation composition (Whitney and Adams 1980), diversity (Hope et al. 2003), and abundance (Martin et al. 2004). It is often used as a time stamp representing the number of years elapsed since neighborhood vegetation was first planted during construction. Neighborhood age can act as a surrogate for more progressed and varied vegetation structure, as plantings need time to grow and mature (Gagne et al. 2016; Palomino and Carrascal 2006; Vale and Vale 1976; Whitney and Adams 1980).

My prediction that neighborhoods located closer to the city center would have less canopy cover was not supported. My hypothesis was based on previous research, which suggests that the habitat loss gradient steepens from the periphery towards the urban core,

resulting in increased habitat fragmentation and patchiness (McKinney 2002) as well as the loss of vegetation (Blair 1999; Marzluff and Ewing 2001; Munyenyembe et al. 1989). For many cities, canopy cover tends to be reduced in the most urbanized commercial and business districts, which are typically located in the city center (Chace and Walsh 2006), while vegetation volume (Mills et al. 1989) and quality (Sandstrom et al. 2006) increase in the direction of the periphery where less anthropogenic disturbance exists. However, it is important to note that Lubbock is embedded within an agricultural matrix. My results are in alignment with other studies, which revealed the lowest amount of tree cover at the highest distance from the urban core, perhaps explained by the relative scarcity of trees existing in the surrounding agricultural and natural landscapes (Dallimer et al. 2012).

For my socioeconomic indicators, my prediction that higher homeowner income would be positively related to canopy cover was affirmed. Previous research suggests that canopy cover (Mills et al. 2016; Schwarz et al. 2015) and plant species diversity (Hope et al. 2003; Kinzig et al. 2005; Martin et al. 2004) are associated with higher neighborhood income levels. Lawn maintenance decisions are often a function of homeowners' economic empowerments or constraints; people residing in higher-income neighborhoods may landscape based off their preferences and desires for vegetation plantings, while lower-income families might only be able to afford a few trees and shrubs (Lerman and Warren 2011). The allocation of critical resources, whether they are natural, socioeconomic, or cultural, is seldom distributed equally across social groups of different types, resulting in more affluent communities having access to areas with green space that less fortunate neighborhoods lack (Grove and Burch 1997).

My next prediction that house list prices would be positively related to canopy cover was supported by the results. I based this prediction off of previous hedonic pricing model research which assessed the benefits and values of urban green space associated with human presence, inferring how people value certain environmental attributes without asking them directly (Bark et al. 2009; Farmer et al. 2013; Jim and Chen 2006; Luttik 2000; Mansfield et al. 2005; Morancho 2003). Rather, homeowners' revealed preferences are found using house sales prices as a function of the value of environmental characteristics and resources related to the home or neighborhood. Higher priced homes have been associated with a view of green space (Jim and Chen 2006), closer proximity to forested areas (Mansfield et al. 2005), and higher vegetation richness and abundance (Mills et al. 2016). Furthermore, some research has explored whether urban residents can distinguish between the simple existence of green space and habitat containing biologically significant vegetation characteristics. For example, Bark et al. (2009) discovered that homebuyers were willing to pay premiums not just for greenness, but also for the quality and type of nearby habitat (Bark et al. 2009). My research is an extension of the work by Farmer et al. (2013), which aimed to apply hedonic pricing models to non-public green space, as little research had been done on how ecological characteristics of urban residential yards might be related to house value. My results indicate that in Lubbock, yards located in higher-priced neighborhoods tend to provide more canopy cover than those in less affluent areas of the city.

My second hierarchical regression investigated the predictability of bird diversity from traditional urban-rural and socioeconomic variables. The final model (Model 5) in Table 3.5 indicated that all six predictor variables could help explain the variance in bird

diversity. Higher bird diversity was associated with older neighborhoods, lower population densities, and farther distances from the city center. The socioeconomic variables of income, education, and house price all had positive relationships with bird diversity.

First considering my traditional urban-rural gradient measures, my prediction that neighborhood age would be positively related to bird diversity was supported. This measure deduces the effects of time on an urban habitat and accounts for the temporal dynamics affecting urban ecosystems (Gagne et al. 2016). For instance, disturbance created during building and road construction at the commencement of urban development typically results in the replacement of native vegetation with more impervious surfaces and exotic plantings, so neighborhood age measures the amount of time elapsed since disturbance originally occurred (Martin et al. 2004; Melles 2005). This is important because neighborhood age can act as a proxy for more progressed and varied vegetation structure, as residential plantings need time to mature fully (Gagne et al. 2016; Palomino and Carrascal 2006; Vale and Vale 1976; Whitney and Adams 1980). Previous research has also suggested that urban age is also positively associated with avian species richness (Gagne et al. 2016; Munyenyembe et al. 1989; Palomino and Carrascal 2006; Vale and Vale 1976). This relationship is intuitive, because vegetation is widely accepted as the most important driver of changes in bird communities (Macarthur and Macarthur 1961; Mills et al. 1989). Therefore, urban areas that more readily provide vegetation characteristically have the higher species diversity as well (Blair 1999; Marzluff 2001; McKinney 2002).

Next, the multiple regression analysis results bolstered my prediction that human population densities would be negatively related to bird diversity. This urban-rural gradient measure is often used to represent the level of urban development intensity (Gagne et al. 2016; Loss et al. 2009; Martin et al. 2004; Strohbach et al. 2009). For example, increased human habitation is associated with disturbance regimes such as habitat fragmentation, pollution, and increased road density (Kinzig et al. 2005; McKinney 2002; 2008). Previous research has suggested that the most densely populated neighborhoods often contain below-average species richness (Strohbach et al. 2009) and abundance (Melles 2005). This can be attributed to the fact that human development contributes to the loss of native and total vegetation available (McKinney 2002), and highly populated areas tend to retain few remaining patches of undeveloped land (Loss et al. 2009).

My final urban-rural gradient measure, distance from the city center, had a positive relationship with bird diversity. This lent credence to my prediction for this variable. Previous research suggests that avian species richness varies with proximity to the city center (Chace and Walsh 2006; Dallimer et al. 2012; MacGregor-Fors et al. 2011; McKinney 2008). Fluctuations in bird diversity across the cityscape can be understood as a function of such factors as pedestrian traffic and seclusion from native habitat (Leveau and Leveau 2016). For instance, habitat loss tends to accelerate towards the urban center, and the resulting increase in fragmentation and patchiness permits exotic biota to exploit human-subsidized resources found in heavily built-up and modified areas (Marzluff 2001; McKinney 2002). Moreover, vegetation complexity tends to decrease from the city

outskirts towards the center (Sandstrom et al. 2006), partly illuminating why bird diversity is typically lowest in the most intensely urbanized areas (Blair 1996; 1999).

When considering how homeowner socioeconomic characteristics drive urban biodiversity patterns, I found that neighborhood income had a positive impact on bird diversity as I expected. There can be significant variation in biodiversity from one urban area to the next contingent upon the socioeconomic and cultural characteristics of the local residents. Previous research suggests that there are substantial associations between homeowner income and plant diversity (Hope et al. 2003; Kinzig et al. 2005; Martin et al. 2004) as well as bird diversity (Kinzig et al. 2005; Lerman and Warren 2011; Melles 2005). Given that birds are highly associated with vegetation coverage (Macarthur and Macarthur 1961; Niemi and McDonald 2004), it is easy to understand how the composition and abundance of available vegetation can affect breeding bird populations in urban habitats (Chace and Walsh 2006; Gavareski 1976; Mills et al. 1989). Humans are the primary dispersers of vascular plants in the world (Mack and Lonsdale 2001). Yet an individual's capacity to create their ecological ideal on their property appears to be limited in part by their dispensable income (Kinzig et al. 2005; Martin et al. 2004). The unequal distribution of wealth in urban areas can, therefore, illuminate the spatial variation of avian diversity across the cityscape (Melles 2005).

Previous research suggests socioeconomic status is a significant predictor of biodiversity patterns in urban residential areas (Hope et al. 2003; Grove and Burch 1997; Martin et al. 2004; Melles 2005; Whitney and Adams 1980). My prediction that education would be positively associated with bird diversity was supported. Homeowner income and education are often highly correlated with one another. Some researchers will

choose to include only income in their analyses (Hope et al. 2003; Kinzig et al. 2005), while others have used both to represent socioeconomic gradients (Grove et al. 2006; Kinzig et al. 2005; Schwarz et al. 2015). Although attaining a higher level of education often results in a higher paying job, not all well-paid individuals attended college (Luck et al. 2009), and some well-paid individuals choose to live in new neighborhoods with very low levels of tree cover (Kendal et al. 2012). Yet people with one or more university degrees may be more informed about land management practices and environmental issues, and therefore more likely to engage in pro-environmental behavior such as tree planting (Luck et al. 2009; Luck et al. 2013). Although canopy cover could not be predicted from education in the first hierarchical multiple regression I ran (Table 3.4), the relationship between educational attainment and bird diversity may be attributed to other factors. For instance, Clucas et al. (2015) found that educational attainment was positively associated with bird food expenditures in Seattle; people with higher education levels may participate in a range of other bird-supporting activities that are beneficial to urban wildlife.

House prices were positively associated with bird diversity in the way I anticipated. The study upon which this research is based incorporated an avian ecological indicator into their exploration of the relationships between house values, bird diversity, and canopy cover in Lubbock neighborhoods. Farmer et al. (2013) found home prices in their hedonic pricing model increased by \$32,028 with the addition of one less ubiquitous bird species near a neighborhood site. The increased canopy cover provided in higher priced neighborhoods might explain this relationship; not only are birds typically good indicators of environmental health, but they are also highly associated with vegetation

(Macarthur and Macarthur 1961; Niemi and McDonald 2004). Furthermore, inexpensive urban housing is often restricted to deserted commercial and industrialized areas, which inherently contain more impervious surfaces and less green space (Melles 2005). Given that birds respond negatively to intense levels of urbanization (Blair 1999; Marzluff and Ewing 2001; McKinney 2002), it is not surprising to find lower bird diversity in lower-priced neighborhoods.

Conclusions

Urbanization is influencing the structure and function of natural ecosystems worldwide through the continuous expansion of “human-dominated ecosystems” (Vitousek et al. 1997). Urban development poses as the longest-lasting contributor to habitat loss (McKinney 2002), and habitat loss is considered the primary reason for world-wide species endangerment (Tilman et al. 1994). Human population growth is expanding at unprecedented rates (United Nations 2014). It would be illogical to expect that the process of global urbanization will abate in the future, and so establishing ways to promote biodiversity in fragmented landscapes is of the utmost importance (Marzluff and Ewing 2001). One way researchers have attempted to quantify the interactions between urbanization and disturbance regimes is the urban-rural gradient paradigm (McDonnell and Pickett 1990). However, traditional urban-rural gradients do not account for the ways in which human socioeconomic and cultural attributes influence the interplay between humans and the environment (Kinzig et al. 2005). A more nuanced understanding of urban ecosystems can be achieved by examining not only the structural components of the environment, but also the characteristics of the human inhabitants.

A significant portion of the urban ecosystem is comprised of residential yards (Lerman and Warren 2011). Patterns of urban biodiversity can be explained by local variations in landscaping practices, which can have implications for flora and fauna across the cityscape (Bergey and Figueroa 2016). It is important to understand how human perception, choice, and behavior direct socioeconomic and cultural decisions made by homeowners, who in turn modify the environment around them in ways that can either create their ecological ideal or further sink them into biological poverty (Kinzig et al. 2005; Melles 2005; Turner et al. 2004). People value the nature they are familiar with, so as future generations are raised in more impoverished ecological conditions, they may dissociate from the importance of biodiversity and be less likely to support conservation initiatives (Melles 2005). This is a troubling thought, as social and environmental health are intertwined. Urban green spaces are inherently valuable for their ability to enhance aesthetics, reduce radiation, runoff, heat, and urban noise, and improve air quality, human health, and physiological distress (Mansfield et al. 2005). Therefore, it is imperative for researchers, managers, policy makers, and educators to find solutions that preserve habitats, protect wildlife diversity, and increase the quality of life for humans from all socioeconomic, cultural, and ethnic backgrounds.

References

- Adams CE. 2016. Urban wildlife management. Third Edition. Boca Raton (FL): CRC Press Taylor & Francis Group.
- Bark RH, Osgood DE, Colby BG, Katz G, Stromberg J. 2009. Habitat preservation and restoration: Do homebuyers have preferences for quality habitat? *Ecological Economics*. 68(5):1465-1475.
- Belaire JA, Whelan CJ, Minor ES. 2014. Having our yards and sharing them too: The collective effects of yards on native bird species in an urban landscape. *Ecological Applications*. 24(8):2132-2143.
- Bergey EA, Figueroa LL. 2016. Residential yards as designer ecosystems: Effects of yard management on land snail species composition. *Ecological Applications*. 26(8):2536-2545.
- Bibby CJ, Hill DA, Burgess N. 1992. Bird census techniques. San Diego (CA): Academic Press Inc.
- Blair RB. 1996. Land use and avian species diversity along an urban gradient. *Ecological Applications*. 6(2):506-519.
- Blair RB. 1999. Birds and butterflies along urban gradients in two ecoregions of the united states: Is urbanization creating a homogeneous fauna? *Biotic Homogenization*. 9(1):33-56.
- Chace JF, Walsh JJ. 2006. Urban effects on native avifauna: A review. *Landscape and Urban Planning*. 74(1):46-69.
- Clucas B, Rabotyagov S, Marzluff JM. 2015. How much is that birdie in my backyard? A cross-continental economic valuation of native urban songbirds. *Urban Ecosystems*. 18(1):251-266.
- Czech B, Krausman PR, Devers PK. 2000. Economic associations among causes of species endangerment in the united states. *Bioscience*. 50(7):593-601.
- Dallimer M, Rouquette JR, Skinner AMJ, Armsworth PR, Maltby LM, Warren PH, Gaston KJ. 2012. Contrasting patterns in species richness of birds, butterflies and plants along riparian corridors in an urban landscape. *Diversity and Distributions*. 18(8):742-753.
- Douglas I, James P. 2015. Urban ecology: An introduction. New York (NY): Routledge.

- ESRI (Environmental Systems Resource Institute). 2016. ArcMap 10.4.1. ESRI, Redlands, California.
- Farmer MC, Wallace MC, Shiroya M. 2013. Bird diversity indicates ecological value in urban home prices. *Urban Ecosystems*. 16(1):131-144.
- Gagne SA, Sherman PJ, Singh KK, Meentemeyer RK. 2016. The effect of human population size on the breeding bird diversity of urban regions. *Biodiversity and Conservation*. 25(4):653-671.
- Gavareski CA. 1976. Relation of park size and vegetation to urban bird populations in seattle, washington. *The Condor*. 78(3):375-382.
- Grove JM, Troy AR, O'Neil-Dunne JPM, Burch WR, Cadenasso ML, Pickett STA. 2006. Characterization of households and its implications for the vegetation of urban ecosystems. *Ecosystems*. 9(4):578-597.
- Grove JM, Burch WR. 1997. A social ecology approach and applications of urban ecosystem landscape analyses: A case study of Baltimore, Maryland. *Urban Ecosystems*. 1:259 - 275.
- Hope D, Gries C, Zhu WX, Fagan WF, Redman CL, Grimm NB, Nelson AL, Martin C, Kinzig A. 2003. Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Sciences of the United States of America*. 100(15):8788-8792.
- IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.
- Jim CY, Chen WY. 2006. Impacts of urban environmental elements on residential housing prices in Guangzhou (China). *Landscape and Urban Planning*. 78(4):422-434.
- Kendal D, Williams NSG, Williams KJH. 2012. Drivers of diversity and tree cover in gardens, parks and streetscapes in an Australian city. *Urban Forestry & Urban Greening*. 11(3):257-265.
- Kinzig AP, Warren P, Martin C, Hope D, Katti M. 2005. The effects of human socioeconomic status and cultural characteristics on urban patterns of biodiversity. *Ecology and Society*. 10(1):13.
- Lerman SB, Warren PS. 2011. The conservation value of residential yards: Linking birds and people. *Ecological Applications*. 21(4):1327-1339.

- Leveau LM, Leveau CM. 2016. Does urbanization affect the seasonal dynamics of bird communities in urban parks? *Urban Ecosystems*. 19(2):631-647.
- Loss SR, Ruiz MO, Brawn JD. 2009. Relationships between avian diversity, neighborhood age, income, and environmental characteristics of an urban landscape. *Biological Conservation*. 142(11):2578-2585.
- Luck GW, Smallbone LT, O'Brien R. 2009. Socio-economics and vegetation change in urban ecosystems: Patterns in space and time. *Ecosystems*. 12(4):604-620.
- Luck GW, Smallbone LT, Sheffield KJ. 2013. Environmental and socio-economic factors related to urban bird communities. *Austral Ecology*. 38(1):111-120.
- Luttik J. 2000. The value of trees, water and open space as reflected by house prices in the Netherlands. *Landscape and Urban Planning*. 48(3-4):161-167.
- Macarthur R, Macarthur JW. 1961. On bird species-diversity. *Ecology*. 42(3):594-598.
- MacGregor-Fors I, Morales-Perez L, Schondube JE. 2011. Does size really matter? Species-area relationships in human settlements. *Diversity and Distributions*. 17(1):112-121.
- Mack RN, Lonsdale WM. 2001. Humans as global plant dispersers: Getting more than we bargained for. *Bioscience*. 51(2):95-102.
- Mansfield C, Pattanayak SK, McDow W, McDonald R, Halpin P. 2005. Shades of green: Measuring the value of urban forests in the housing market. *Journal of Forest Economics*. 11(3):177-199.
- Martin CA, Warren PS, Kinzig AP. 2004. Neighborhood socioeconomic status is a useful predictor of perennial landscape vegetation in residential neighborhoods and embedded small parks of Phoenix, AZ. *Landscape and Urban Planning*. 69(4):355-368.
- Marzluff JM, Ewing K. 2001. Restoration of fragmented landscapes for the conservation of birds: A general framework and specific recommendations for urbanizing landscapes. *Restoration Ecology*. 9(3):280-292.
- Marzluff JM. 2001. Worldwide urbanization and its effects on birds. In: Marzluff JM, Bowman R, Donnelly R, editors. *Avian Ecology and Conservation in an Urbanizing World*. New York (NY): Kluwer Academic Publishers. p. 19-48.
- McDonnell MJ, Pickett STA. 1990. Ecosystem structure and function along urban rural gradients: An unexploited opportunity for ecology. *Ecology*. 71(4):1232-1237.

- McKinney ML. 2002. Urbanization, biodiversity, and conservation. *Bioscience*. 52(10):883-890.
- McKinney ML. 2008. Effects of urbanization on species richness: A review of plants and animals. *Urban Ecosystems*. 11(2):161-176.
- Melles SJ. 2005. Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats*. 3(1):25-48.
- Mills GS, Dunning JB, Bates JM. 1989. Effects of urbanization on breeding bird community structure in southwestern desert habitats. *The Condor*. 91(2):416-428.
- Mills JR, Cunningham P, Donovan GH. 2016. Urban forests and social inequality in the pacific northwest. *Urban Forestry & Urban Greening*. 16:188-196.
- Morancho AB. 2003. A hedonic valuation of urban green areas. *Landscape and Urban Planning*. 66(1):35-41.
- Munyenye F, Harris J, Hone J, Nix H. 1989. Determinants of bird populations in an urban area. *Australian Journal of Ecology*. 14(4):549-557.
- Niemi GJ, McDonald ME. 2004. Application of ecological indicators. *Annual Review of Ecology Evolution and Systematics*. 35:89-111.
- Palomino D, Carrascal LM. 2006. Urban influence on birds at a regional scale: A case study with the avifauna of northern Madrid province. *Landscape and Urban Planning*. 77(3):276-290.
- Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R. 2001. Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics*. 32:127-157.
- Quantum GIS Development Team 2017. Quantum GIS (Geographic Information System). Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>.
- Sandstrom UG, Angelstam P, Mikusinski G. 2006. Ecological diversity of birds in relation to the structure of urban green space. *Landscape and Urban Planning*. 77(1-2):39-53.
- Schneider CA, Rasband WS, Eliceiri KW. 2012. Nih image to imagej: 25 years of image analysis. *Nature Methods*. 9(7):671-675.

- Schwarz K, Fragkias M, Boone CG, Zhou WQ, McHale M, Grove JM, O'Neil-Dunne J, McFadden JP, Buckley GL, Childers D et al. 2015. Trees grow on money: Urban tree canopy cover and environmental justice. *Plos One*. 10(4):17.
- Strohbach MW, Haase D, Kabisch N. 2009. Birds and the city: Urban biodiversity, land use, and socioeconomics. *Ecology and Society*. 14(2):15.
- Tilman D, May RM, Lehman CL, Nowak MA. 1994. Habitat destruction and the extinction debt. *Nature*. 371(6492):65-66.
- Turner WR, Nakamura T, Dinetti M. 2004. Global urbanization and the separation of humans from nature. *Bioscience*. 54(6):585-590.
- United Nations Department of Economic and Social Affairs. 2014. World urbanization prospects, The 2014 revision. New York, New York.
- U.S. Census Bureau. 2016. State and county quick facts: Lubbock, Texas. Data derived from Population Estimates, American Community Survey, Census of Population and Housing, County Business Patterns, Economic Census, Survey and Business Owners, Building Permits, Census of Governments.
<https://www.census.gov/quickfacts/fact/table/lubbockcitytexas,US#viewtop>
- Vale TR, Vale GR. 1976. Suburban bird populations in West-Central California. *Journal of Biogeography*. 3(2):157-165.
- Vitousek PM, Mooney HA, Lubchenco J, Melillo JM. 1997. Human domination of earth's ecosystems. *Science*. 277(5325):494-499.
- Whitney GG, Adams SD. 1980. Man as a maker of new plant-communities. *Journal of Applied Ecology*. 17(2):431-448.

Tables

Table 3.1. Hypotheses for Relationships of Structural Characteristics of the Urban Environment and Homeowner Socioeconomics with Bird Diversity and Canopy Cover During Summer 2017 in Lubbock, TX.

	<i>Neighborhood Age</i>	<i>Distance to City Center</i>	<i>Human Population Density</i>	<i>House Price</i>	<i>Income</i>	<i>Education</i>
<i>Bird Diversity</i>	Positive	Positive	Negative	Positive	Positive	Positive
<i>Canopy Cover</i>	Positive	Positive	Negative	Positive	Positive	Positive

Table 3.2. Neighborhoods Selected for Bird Point Count Surveys During Summer 2017 in Lubbock, TX.

Neighborhood Name	Category	
	<i>Age</i>	<i>Price</i>
Kuykendall Heights	1959 – 1976	\$81,024 – 120,502
Oakwood	1959 – 1976	\$120,503 – 159,980
Monterey Park*	1959 – 1976	\$159,981 – 199,455
Richland Hills	1977 – 1994	\$81,024 – 120,502
Leftwich Monterey	1977 – 1994	\$120,503 – 159,980
Quaker Heights	1977 – 1994	\$159,981 – 199,455
Cedar Meadows	1995 – 2013	\$81,024 – 120,502
Monterey	1995 – 2013	\$120,503 – 159,980
Fox Ridge	1995 – 2013	\$159,981 – 199,455
<i>Replication Sites</i>		
Overton	1968	\$85,658
Whisperwood	1996	\$183,109
Melonie Park South	1990	\$190,111
Pheasant Run	1997	\$190,894
Farrar Estates	1992	\$191,077

* *Monterey Park* was randomly selected, as no other neighborhood fit the 1959-1976 and \$159,981-199,455 category

Table 3.3. Simple Linear Regression Analyses Predicting Canopy Cover and Bird Diversity from Human Population Density, Distance to City Center, Neighborhood Age, House Price, Income, and Education During Summer 2017 in Lubbock, TX.

Variable	Canopy Cover		Bird Diversity	
	R ²	p-value	R ²	p-value
Sample Round				
Population Density	0.196	0.000	0.393	0.000
City Center	0.346	0.000	0.201	0.000
Neighborhood Age	0.319	0.000	0.410	0.000
House Price	0.006	0.228	0.042	0.000
Income	0.011	0.071	0.000	0.871
Education	0.009	0.115	0.040	0.000

Note: $N = 350$

Table 3.4. Hierarchical Multiple Regression Predicting Percent Canopy Cover From Sample Round, Neighborhood Age, Human Population Density, Distance to City Center, Income, and House Price During Summer 2017 in Lubbock, TX.

	Model 1	Model 2	Model 3	Model 4
Variable	β	β	β	β
Constant				
Sample Round	0.037	0.037	0.037	0.037
Neighborhood Age		0.257**	0.602**	0.635**
Human Population Density		-0.294**	-0.092*	-0.007
Distance to City Center		-0.293**	-0.381**	-0.375**
Income			0.528**	0.360**
House Price				0.238*
R^2	0.001	0.448	0.553	0.563
F	0.482	69.906**	85.259**	73.694**
ΔR^2	0.001	0.446	0.106	0.010
ΔF	0.482	92.920**	81.459**	7.642*

Note: $N = 350$. * $p < .01$, ** $p < .001$

Table 3.5. Hierarchical Multiple Regression Predicting Bird Diversity From Sample Round, Neighborhood Age, Human Population Density, Distance to City Center, House Price, Income, and Education.

	Model 1	Model 2	Model 3	Model 4	Model 5
Variable	β	β	β	β	β
Constant					
Sample Round	0.000	0.000	0.000	0.000	0.000
Neighborhood Age		0.797**	1.196**	1.272**	1.116**
Human Population Density		-0.540**	-0.124**	-0.154**	-0.227**
Distance to City Center		0.354**	0.292**	0.256**	0.122*
House Price			0.664**	0.391**	0.264**
Income				0.368**	0.378**
Education					0.152**
<i>R</i> ²	0.000	0.689	0.848	0.873	0.883
<i>F</i>	0.000	191.35**	384.415**	392.241**	367.421**
ΔR^2	0.000	0.689	0.159	0.025	0.01
ΔF	0.000	255.134**	360.067**	66.332**	28.667**

Note: $N = 350$. * $p < .05$, ** $p < .001$

CHAPTER IV

CONCLUSIONS

My research aimed to understand both the structural and socioeconomic correlates of urban biodiversity patterns in West Texas by examining not only urban-rural gradient metrics in Lubbock neighborhoods, but also homeowner characteristics, which contribute to the choices people make on their properties. In terms of the structural characteristics of the urban environment, adapter, avoider, and exploiter bird species all had variable responses to neighborhood age, distance to the city center, human population density, and canopy cover. When the predictor variables were considered together in multiple regression analyses, adapter bird species richness had statistically significant relationships with all metrics. However, neighborhood age emerged as the only predictor variable that could explain the variance in the three individual categories of bird species. Exploiter and avoider bird diversity, interestingly, did not have a statistically significant relationship with canopy cover, and human population density was the only other statistically significant predictor of avoider bird species richness.

Next, I determined how the combination of both structural and socioeconomic variables related to two urban biodiversity patterns of canopy cover and bird diversity. Beyond the statistically significant indicators of neighborhood age, distance to the city center, and human population density, the socioeconomic variables of neighborhood income and house list prices predicted canopy cover. Using a similar analysis for bird diversity, income, house list prices, and education were all retained in the final model as significant predictor variables above and beyond the traditional urban-rural gradient measures. The results of my research indicate that the structure of the urban environment

is important for understanding patterns of biodiversity across the cityscape. Furthermore, the patterns and processes in cities are also driven in part by human behavior, as people can act as extremely influential agents of change (Melles 2005).

A better understanding of how urban homeowners' behaviors, preferences, and perceptions culminate in their front and back yards can be achieved through social and ecological research. Residential landscapes in the southwest region of the United States often replace native habitats with an "urban oasis" (LTER 2016). For example, in Phoenix, Arizona, yards encompass both verdant lawns as well as yard designs reminiscent of the neighboring Sonoran desert (LTER 2016). The Long Term Ecological Research Network proposes that landscaping choices can be understood through a decision framework comprised of individual preferences, ecological constraints, cost, and laws (Yabiku et al. 2008).

Efforts made to reduce human impacts on the environment should account for the aesthetic and lifestyle factors that drive people's preferences (Larson et al. 2009). Homeowners may choose a more environmentally friendly landscape design for a variety of reasons. For instance, residents may select xeric lawns if they understand that these yards offer environmental benefits, that the perceived dangers of desert plants and rocky landscapes to children and pets can be ameliorated, and that reduced watering regimes needed by native plants, as well as the associated wildlife they attract, can improve aesthetics (Yabiku et al. 2008). Advocating for biodiversity or water conservation in urban ecosystems may be more successful, therefore, by marketing the benefits of alternative landscaping practices, such as lower maintenance and increased aesthetics

(Larson et al. 2009), the appeals of which often carry more weight in a homeowner's decision making process than environmental concerns (Larson et al. 2009).

Landscape choice may also be limited by ecological constraints. For example, local climate may not be conducive to the survival of certain species of plants. Lubbock is a semi-arid environment with a scarce amount of average annual rainfall. Turf grasses from more temperate zones and nonnative garden plantings do not flourish in this kind of environment, and higher mortality rates for these types of vegetation would require regular replacement, leading to higher landscaping costs, which pose as the next factor in the decision framework (Yabiku et al. 2008).

Financial resources must be taken into consideration when assessing the choices people make on their properties. Hope et al. (2003) described the positive relationship between socioeconomic wherewithal and plant diversity as the "luxury effect," by which people's affluence permits them to inhabit more diverse urban environments. More affluent homeowners may be able to actively landscape their yards in ways that attract a more varied assemblage of bird species, perhaps by providing native vegetation or bird feed (Lerman and Warren 2011). Aside from vegetation species composition, it is well-accepted that birds also respond positively to additive layers of foliage (Macarthur and Macarthur 1961). Even if some homeowners are not actively selecting or avoiding certain plant species, they may choose to include a lower total abundance of vegetation in their yard designs in order to create a simpler, more easily managed landscape. For instance, members of underprivileged communities, potentially limited by economic constraints, may choose to allocate their disposable financial resources to other more pressing expenses (Lerman and Warren 2011). The unequal distribution of environmental

amenities, therefore, subjects certain social groups to higher levels of biological poverty (Turner et al. 2004).

Discrepancies in biodiversity across neighborhoods of different types can also be explained, and perhaps remedied, by city laws and ordinances. Many United States residents are legally obligated to abide by certain limitations beyond local, state, and federal laws (Yabiku et al. 2008). Homeowners' Associations often impose regulations on landscaping, such as mandated turf grass or guidelines for plant species that may be grown (Yabiku et al. 2008). These types of rules can limit the actions of residents who would otherwise engage in pro-environmental behavior. Moreover, ethnic and economic segregation occurs in many cities across the globe, and certain neighborhoods are ignored by city officials in terms of planning, zoning, and improvement efforts such as tree plantings and parks (Melles 2005). Top-down endeavors to make urban development more harmonious with biodiversity will therefore be crucial for conserving biota.

Finding ways to meet the needs of an ever-expanding human population while conserving global biodiversity poses one of the greatest challenges of the century. Urban-rural gradients have unveiled the impacts of anthropogenic disturbance on biota in human-dominated systems. My study examined the effects of human population density, neighborhood age, and distance from the city center, which represented the level of disturbance, the time elapsed since disturbance, and the habitat loss gradient, respectively. In order to understand the socioeconomic gradients in Lubbock neighborhoods, I also measured income, education, and house prices. These variables were used to investigate whether people's wealth, degree attainment, and home value could explain variations in canopy cover and bird diversity in their community. Having a

well-paying job and living in a more affluent neighborhood allows certain individuals to afford more developed residential landscapes (Farmer et al. 2013), and holding a university degree may also be positively associated with people's willingness to participate in pro-environmental activities that benefit bird diversity (Clucas et al. 2015). Future work in Lubbock neighborhoods could include urban-rural metrics such as impervious surface percentages, road traffic, or noise levels. In order to better understand the choices homeowners make, a potential human dimensions study might assess cultural attributes of homeowners, including variables such as race or religious affiliation. Furthermore, I only used publicly available socioeconomic data, and so future research could include surveys that ask residents directly about their preferences and choices. It is paramount for researchers, managers, and educators to consider the structural characteristics of the urban environment, as well as the drivers of human behavior.

References

- Clucas B, Rabotyagov S, Marzluff JM. 2015. How much is that birdie in my backyard? A cross-continental economic valuation of native urban songbirds. *Urban Ecosystems*. 18(1):251-266.
- Farmer MC, Wallace MC, Shiroya M. 2013. Bird diversity indicates ecological value in urban home prices. *Urban Ecosystems*. 16(1):131-144.
- Hope D, Gries C, Zhu WX, Fagan WF, Redman CL, Grimm NB, Nelson AL, Martin C, Kinzig A. 2003. Socioeconomics drive urban plant diversity. *Proceedings of the National Academy of Sciences of the United States of America*. 100(15):8788-8792.
- Larson KL, Casagrande D, Harlan SL, Yabiku ST. 2009. Residents' yard choices and rationales in a desert city: Social priorities, ecological impacts, and decision tradeoffs. *Environmental Management*. 44(5):921-937.
- Lerman SB, Warren PS. 2011. The conservation value of residential yards: Linking birds and people. *Ecological Applications*. 21(4):1327-1339.
- Macarthur R, Macarthur JW. 1961. On bird species-diversity. *Ecology*. 42(3):594-598.
- Melles SJ. 2005. Urban bird diversity as an indicator of human social diversity and economic inequality in Vancouver, British Columbia. *Urban Habitats*. 3(1):25-48.
- Turner WR, Nakamura T, Dinetti M. 2004. Global urbanization and the separation of humans from nature. *Bioscience*. 54(6):585-590.
- Yabiku ST, Casagrande DG, Farley-Metzger E. 2008. Preferences for landscape choice in a southwestern desert city. *Environment and Behavior*. 40(3):382-400.

APPENDIX A**BIRD SPECIES OBSERVED IN LUBBOCK, TX DURING SUMMER 2017**

Common Name	Scientific Name	Category	Total Individuals
Eurasian Collared Dove	<i>Streptopelia decaocto</i>	Exploiter	751
European Starling	<i>Sturnus vulgaris</i>	Exploiter	219
Great Tailed Grackle	<i>Quiscalus mexicanus</i>	Exploiter	1429
House Sparrow	<i>Passer domesticus</i>	Exploiter	1383
White-winged Dove	<i>Zenaida asiatica</i>	Exploiter	1036
American Robin	<i>Turdus migratorius</i>	Adapter	452
Blue Jay	<i>Cyanocitta cristata</i>	Adapter	315
Mourning Dove	<i>Zenaida macroura</i>	Adapter	273
Northern Mockingbird	<i>Mimus polyglottos</i>	Adapter	205
Western Kingbird	<i>Tyrannus verticalis</i>	Adapter	192
Barn Swallow	<i>Hirundo rustica</i>	Less Common	175
Burrowing Owl	<i>Athene cunicularia</i>	Less Common	1
Chimney Swift	<i>Chaetura pelagica</i>	Less Common	116
Cassin's Sparrow	<i>Peucaea cassinii</i>	Less Common	5
Cedar Waxwing	<i>Bombycilla cedrorum</i>	Less Common	1
Canyon Wren	<i>Catherpes mexicanus</i>	Less Common	1
Chipping Sparrow	<i>Spizella passerina</i>	Less Common	1
Common Nighthawk	<i>Chordeiles minor</i>	Less Common	1
Curve-billed Thrasher	<i>Toxostoma curvirostre</i>	Less Common	5
Eastern Meadowlark	<i>Sturnella magna</i>	Less Common	1
House Finch	<i>Haemorhous mexicanus</i>	Less Common	229
Inca Dove	<i>Columbina inca</i>	Less Common	4
Ladder-backed Woodpecker	<i>Dryobates scalaris</i>	Less Common	3
MacGillivray's Warbler	<i>Geothlypis tolmiei</i>	Less Common	2
Mississippi Kite	<i>Ictinia mississippiensis</i>	Less Common	6
Northern Cardinal	<i>Cardinalis cardinalis</i>	Less Common	52