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Examining the Relationship between Avifauna and Green Roofs in Mississippi's Humid-Subtropical Climate

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Examining the relationship between avifauna and green roofs in Mississippi's humid-subtropical climate

By

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Human settlement displaces and fragments natural habitats. Design choices in the landscape directly affect both local diversity and extinction rates. This study seeks to understand how avifauna are responding to this new technology in Mississippi.

DEDICATION

This thesis is dedicated to the loving memory of Dr. Samuel K. Riffell. Thank you for introducing me to the field of Ornithology. Over the past two years, your guidance shaped my work and my perspective of the natural world. You said to me one time that it would be significant if I saw a *Sturnella magna* land in “one of those things.” Well, it did--7 times. I wish I could share with you the results and get your take on everything. I barely have words, but I know that things would be so much better if you were still here.

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CHAPTER I

INTRODUCTION

Purpose of Study

Studying green roofs in respect to biodiversity is an increasingly popular research topic (Blank et al., 2013) as researchers, designers, and other allied professionals scramble to unlock the potential in this green infrastructure type. The purpose of this study is to establish baseline data on the relationship between avifauna and green roofs in Mississippi's humid subtropical climate. The study seeks to answer two main questions. First, is there a significant difference between the *Sedum* and prairie vegetative roof types at GIRA with respect to mean number of birds landing? The second question the study seeks to answer is whether the presence of vegetation on a roof in the humid subtropical climate impacts local bird habitat?

Organization of Thesis

This thesis is organized into five chapters. Following this introduction chapter is a comprehensive literature review, then the methodology chapter comes next. The results and statistics are presented in chapter four and the final chapter includes the discussion and conclusions. The literature review defines the underlying issues and focuses primarily on problems associated with urbanization. The literature review introduces green roofs and then details their component parts, classification, cited benefits, a brief history of the technology, and a research overview. The methodology chapter explains the selected sites and the intended experimental process. The results chapter includes the data overview, statistical analysis, and a descriptive data overview. The final chapter presents the conclusions, discusses the findings, and offers suggestions towards future research and advancement in the field of Landscape Architecture.

CHAPTER II

LITERATURE REVIEW

Introduction

The following literature review is organized into three main sections. The first section discusses urbanization, addressing related issues, associated problems, and contemporary ameliorations. The second section offers a glimpse into the sphere of biodiversity and the use of avifauna research for ecological consideration. The final section focuses on the primary subject of this study: green roofs.

Urbanization

Defining the Issue: from Population Growth to Impervious Surfaces

Human population growth has exploded over the last few hundred years. In 1800, there were fewer than a billion people on the planet. By 1900, the population was roughly 1.5 billion, and by 1950, the number had climbed to around 2.5 billion people (United States Census Bureau, 2013). As of 2012, the population grew beyond 7 billion people and projections from the United Nations estimated growth to near or to surpass 10 billion people by 2050 (Department of Economic and Social Affairs, Population Division, 2013). Since 1990, the number of people living in urban areas has risen from 40% to 51% (World Health Organization, 2014). This figure is expected to increase where 70% of the world population will live in urban centers by 2050, which implies that the total current population today will be the urban population in about 35 years (United Nations, 2014a; World Health Organization, 2014). The growing population of the planet means increasing demand for natural resources and space (Abdul-Wahab & Al-Arairni, 2004; Benfield et al., 1999; Meyer & Turner, 1992). The population shift towards urban areas will include increasing densities in urban population centers as well as new development in surrounding rural areas (Department of Economic and Social Affairs, Population Division, 2013). Most of this growth is expected to occur in developing countries although developed countries will also experience growth (United Nations, 2014b; World Health Organization, 2014).

It is widely accepted that anthropogenic activity, driven by urbanization and social factors (Burchell & Mukherji, 2003), is impacting global climate and is projected to have continuous and cumulative effects going forward (Houghton et al., 1996). These effects will manifest in increasing mean global temperatures which have already risen at an average rate of about 0.2°C each decade over the past several decades and will bring changes in weather due to the massive thermal inertia of the world's oceans (Hansen et al., 2006). These weather patterns impact which species may exist in a given area (Pain & Donald, 2002) and are already beginning to manifest through the pole-ward shift in certain species' ranges (Parmesan et al., 1999).

The Intergovernmental Panel on Climate Change (IPCC) cites the primary causes of climate change have arrived due to the burning of fossil fuels, deforestation, and processes which have increased the number and distribution of greenhouse gases, and altering the surface of the planet (2014). These causes arrive through urban expansion, industrial development, and road traffic. These activities result in a medley of problems related to waste disposal, spread of disease, pollution or depletion of natural resources, desertification, emissions from road traffic and industry, creation of industrial byproducts, noise pollution, and damage to the atmosphere and ozone layer (Abdul-Wahab & Al-Arairni, 2004).

Costanza et al. (1997) attempted to quantify the value of ecosystem services on the planet. First, they identified seventeen ecosystem services (and goods) provided by natural biota: gas, climate, water, disturbance regulation, water supply, erosion control and sediment retention, soil formation, nutrient cycling, waste treatment, pollination, biological control, refugia, food production, raw materials, genetic resources, recreation, and cultural opportunities. Ecosystem services contribute to the well-being of all living creatures on Earth and they provide services directly without having to move through a tangible economy at all. Examples include clean air and water, soil formation, climate regulation, waste treatment, aesthetic values, and good health (Costanza et al., 1997). Many of these services cannot be replaced and substitutions, if available, have extremely high costs when artificially produced.

Of the seventeen ecosystem services identified by Costanza et al. (1997), six are recognized by Bolund and Hunhammar (1999) for their contributions to stressed urban ecosystems. In their case study of Stockholm, they describe six ecosystem types which can be found in the urban fabric: street trees, lawns and parks, urban forests, cultivated lands, wetlands, lakes and seas, and streams. Each of these ecosystem types performs ecological services at varying scales, and these services all directly benefit human well-being. These services are atmospheric regulation, climate regulation, water regulation, and disturbance regulation. Ecosystem services also exist as opportunities for recreation and may be cultural in nature where both the customs and the artifacts of a people's lifestyle is directly related to the health of the environment. For instance, low-lying island nations have different natural capital and values than nations which exist in arid, mountainous locations. As lands are converted to a more urban character, their functions or associated ecosystem services change. Despite disturbance, ecosystems may still retain some of their services even though they may be more difficult to recognize in a more urban context.

Land-use and land cover can be characterized into five basic categories: cultivated land, forest/tree cover, grassland/pasture, wetlands, and settlement. Land cover change occurs when one type is converted to another or through altering the characteristics of a category (Meyer & Turner, 1992). An example of this would be the conversion of a swamp to a settlement or developing a village into a city. Expanding settlement (urbanization) has been dubbed a somewhat derogatory moniker by many: sprawl (Alberti et al., 2003; Benfield et al., 1999; Burchell & Mukherji, 2003; Kunstler, 1993). Sprawling development patterns are defined by independent, disassociated nodes of human institutions and housing where goods and services are dispersed without reason across the landscape and often require an automobile for access because the urban fabric is connected with miles of roadway and impervious surface (Duany et al., 2000). How we use the landscape and alter its cover directly affects heat and ambient air temperatures, microclimate, and air quality (Akbari & Rose, 2001). Impervious surfaces are characteristic of urbanization and exacerbate the Urban Heat Island (UHI) effect, damage hydrology, collect pollutants, and conversely, provide opportunities for relief of these ailments (Lee & French, 2009).

Urban Heat Islands

A widely recognized effect of urbanization is the Urban Heat Island (UHI) effect: the phenomenon where higher temperatures exist in urban areas because of the thermal characteristics of the built environment (Sailor, 2002; Taha, 1997). Sailor (2002) defines five causes of the UHI effect as: latent heat flux, long and short wave radiative exchanges, anthropogenic heat flux, convective heat flux, and thermal storage. Latent heat flux refers to a city's high thermal inertia where heat gains during the day are not fully released at night. Solar radiation is absorbed and reflected naturally by the surface of the planet, but in built up areas, these exchanges are influenced by building materials and surface reflectivity, or albedo. Sources of anthropogenic heat flux come from the release of heat due to human activities: emissions from air conditioning and vehicles; while convective heat flux refers to the relationship between wind and urban geometry and how relative temperatures act upon each other and the UHI. Impervious surfaces and buildings act as thermal mass and store solar and other sources of heat energy, the sheer volume of thermal mass in cities exacerbates problems with UHI (2002). Heat islands can vary in scale from a single structure to a megacity, and are driven by factors which include albedo, evapotranspiration, and heat produced from human activities (Taha, 1997). When solar energy is captured and stored in impervious surfaces, ambient temperatures increase during the daytime and stay elevated during the night (Lee & French, 2009; Taha, 1997).

Consequences of UHI include degradation of air quality through emissions, increased energy usage and emissions due to heating and cooling requirements, and potential for heat-related injuries or death from smog or elevated temperatures (Sailor, 2002). Taha (1997) calls for large scale urban forestation to mitigate the effects of UHI because vegetation offers shading and relief through evapotranspiration, making vegetation behave like a heat sink during the day and at night, are locations of heat islands; vegetation behaves as a quintessential oasis in the urban context. In response to this trend, the U.S. Environmental Protection Agency developed a Heat Island Reduction Initiative (HIRI) which is a compendium of strategies to improve energy savings, economic benefits, and air quality in built up areas. It is recognized vegetation reduces ambient temperature and reduces ozone concentrations in the city due to shading and evapotranspiration (Akbari et al., 2003; Akbari & Rose, 2001). In a study designed to estimate impervious surface, Lee and French (2009) also propose UHI mitigation strategies: utilization of lighter and reflective materials for roofing, replacing asphalt with lighter colored paving, the planting of trees and vegetation, and raising concerns about the impact of impervious surfaces on collective water resources.

Urban Stormwater

Impervious refers to the quality of surface or material where water flow is restricted and not allowed to pass through (Chesapeake Bay Program, 2012). An increase in impervious surfaces translates into an increase in stormwater runoff problems in urban areas. These problems all ultimately result in impaired stormwater uptake into the soils and include compaction, loss or removal of topsoil, and conversion of surface (Booth et al., 2002). Barbosa et al., (2012) identify suspended solids, heavy metals (Cu, Zn, Cd, Pb, Ni, Cr), biodegradable organic matter (vegetation, fecal matter, corpses), organic micropollutants (endocrine disrupting chemicals), pathogenic microorganisms (coliforms, E. *coli*), and nutrients (nitrogen, phosphorous) as the six major sources of pollution in stormwater runoff. They also point out the fact that the volume and intensity of pollutions from the same site will vary between rainfall events due to variations in the rainfall events themselves and factors related to the preceding dry periods and argue for Best Management Practices (BMPs) which act to offset pollution loads and peak flows (Berndtsson, 2010).

Sabin et al. (2005) drew conclusions about the influence of dry deposition of trace heavy metals in stormwater samples taken from catchments in Los Angeles. The study, which used two detection methods to test the presence of Cr, Cu, Ni, Pb, and Zn measured once a month for the duration of a year. The site was chosen for its lack of vegetation and isolation from green space within the urban fabric. The plate catchment detection method resulted in 100% frequency for all metals except chromium which had a frequency of 92%. The frequency for all metals was 100% from stormwater samples. Without vegetation, sinks, or opportunities for heavy metals or other pollutants to become sequestered elsewhere, they travel to the next logical place: receiving waters (Berghage et al., 2009).

Impervious surfaces also affect runoff temperature and influence temperature-dependent cold aquatic ecosystems. Sabouri et al. (2013) sampled four watersheds in Canada and collected data across a gradient of vegetation and impervious from the uplands, through inlets, holding ponds, and finally to the receiving water body. They discovered certain landscape features which influence stormwater temperature: pipe lengths, maximum storm intensity, % impervious cover in the drainage area, rainfall depth, initial impervious temperature, pipe network density, and rainfall duration. For one scenario, increasing impervious area from 20% to 50% increased the stormwater temperature by 3°C.

A 2002 case study of the King County, Washington area (which includes the city of Seattle) highlights the many successes and failures in addressing stormwater management issues. Across the watershed BMPs were deployed to stem the tide of impervious impacts, but as many of these failed due to inadequate planning, they still contributed to the degradation of stream and water body systems. The study suggests for the Pacific Northwest region that an area above 10% imperviousness will cause deterioration which manifests in new hydrological regimes, increased erosion, and habitat simplification (Booth et al., 2002).

Habitat Loss and Fragmentation

A review by Fahrig (2003) defines habitat fragmentation as the loss and breaking apart of habitat at the landscape scale. Habitat loss results from the removal of available habitat through land-use and cover change. Fragmentation is simply a remodeling of habitat configuration (Fahrig, 2003) Fahrig goes on to explain how biodiversity is weakly impacted by habitat fragmentation compared to habitat loss, which completely removes biota from a given area rather than altering the species mix.

Human development not only fragments habitat but also results in habitat loss because the construction of buildings and impervious surfaces become unnatural barriers in the landscape. This creates additional challenges for wildlife and influences evolutionary processes through accelerated local extinction rates and introduction of non-native species (Alberti et al., 2003). In these ways, urbanization pressures the habitat of both mobile and sessile species.

McKinney suggests modern landscaping practices degrade habitat by reducing the overall vegetative volume and the quality of remnant vegetation “due to erosion, trampling, pollution, invasion, [and] cultivation of non-natives” (2002). Human development is habitat-fragmenting disturbance and causes extinctions on scales which range from local to global (Bennett et al., 2001; Opdam & Wiens, 2002; Vitousek et al., 1996). Some argue habitat fragmentation is a threat to biodiversity where the magnitude of impact to an affected ecosystem depends on what species are going extinct (Cardinale et al., 2006).

In a study concerned with extinction and speciation of avifauna, Bennett et al. (2001) calls fragmentation both pattern and process: spatially, as fragmentation increases due to disturbance, distances between viable habitat patches increase. In response, habitat quality is decreased as the landscape matrix is no longer spatially continuous (Bennett et al., 2001). Species respond differently to habitat disturbance (Opdam & Wiens, 2002) because each has its own set of requirements and conditions needed to thrive (Renton et al., 2012). If habitat becomes compromised, a species may be forced to either adapt, migrate (Renton et al., 2012), or become extinct (Bennett et al., 2001; Webb et al., 2001).

Biotic Homogenization

A direct byproduct of urbanization is biological homogenization, which refers to the simplification of functional and biological systems. Correlated with homogenization is an increased extinction risk (McKinney & Lockwood, 2001). Biotic homogenization is the result of many inputs, all of which are related to anthropogenic activities, such as resource withdrawal or structural development (creation of impervious surfaces and constructs to further social or recreational pursuits) (Blair, 2001).

While scientists generally accept that the Earth's climate has been in a warming trend since the turn of the 20th century, there are still many who challenge the established notion that human activity impacts climate (Houghton et al., 1996), alters climate patterns (IPCC, 2014), and accelerates change. The major contributor to global warming has been the increase in concentration of greenhouse gasses in the atmosphere from the anthropogenic burning of fossil fuels. Human prosperity and population growth inevitably require more resources and therefore generate more opportunities to disrupt natural cycles (Meyer & Turner, 1992). The Intergovernmental Panel on Climate Change (IPCC) recognizes climate change will occur at different rates of intensity and will manifest in different ways globally (IPCC, 2014). Green et al. (2001) cite an expected temperature increase of 1.5°C to 3°C which will be both altitude and latitude dependent and supports theory of a shrinking "equator-to-pole and sea-level-to-mountain-top gradients." Based on this temperature increase, they created a model to observe trends in how species will react over time to climate change. Their model predicted sessile species would suffer greater losses than mobile species and that the greatest species loss would be at the poles due to loss of ice and biological invasion due to species migrating towards more tolerable temperatures.

This trend is already being observed in certain species. In order to observe trends in species associated with regional warming, Parmesan et al. (1999) monitored non-migratory butterfly species with ranges between northern Europe and northern Africa and compared species borders with historical data. Analyses were conducted on the selected species based on the conclusions of a collection of population-dynamic studies which indicate “butterflies, and insects in general, are sensitive to temperature” (Parmesan et al., 1999). In a whole-range analysis of thirty-five species, 63% shifted northwards, 29% were stable at both northern and southern boundaries, 6% shifted to the south, and 3% extended at both ends. A second analysis of thirty-eight species with non-migratory borders within Great Britain focusing on species whose habitats are impacted by human development found 47% of species that had extended northwards and 8% that experienced southern retraction (Parmesan et al., 1999). Their study provided evidence temperature caused the shifts in range and not land use as these extensions and retractions correlated with regional temperature fluctuations. Their analysis also revealed some species disappeared entirely from parts of the region. What these results imply is that climate change and fluctuations in temperature are going to play a large role in determining which species may continue to persist in an area (Green et al., 2001).

Evidence in the fossil record indicates the planet has undergone multiple extinction events and periods of biotic homogenization in addition to other trends. So the trend towards biotic homogenization is not alarming except that it is occurring globally at an unprecedented rate (Maurer et al., 2001; Pain & Donald, 2002). McKinney and Lockwood (2001) offer two basic causes of biotic homogenization: disturbances that upset habitat heterogeneity and increasing distance between similar habitat types. Compounding this dilemma, people move species and do so without regard or comprehension of the potential repercussions which have been damaging both ecologically and economically (Vitousek et al., 1996). In doing this, humans create pockets of biodiversity while simultaneously degrading regional and global diversity (McKinney & Lockwood, 2001).

Based on the premise that land-use and cover change leads to sweeping endangerment and extinction of species, Blair (2001) conducted a study examining birds and butterflies in California and Ohio to determine the relationship between biotic homogenization and urbanization. Land uses defined in the study included the business district, office parks and apartments, residential areas, golf courses, open-space reserve and biological preserve. Species diversity did not decrease steadily as urbanization increased, but appears to decline dramatically somewhere between golf courses and open-space reserves: the threshold between the natural and the manipulated (Blair, 2001).

As easily as landscapes can be classified by general characteristics, McKinney (2002) divides species into three basic types based on how they respond to development: urban exploiters, urban adapters, and urban avoiders. Urban exploiters are entirely dependent on humans for survival, urban adapters take advantage of human resources but also seek resources from the wild as well, and urban avoiders tend to rely on natural resources only and have a tendency to avoid urban contexts (M. L. McKinney, 2002).

Maurer et al. (2001) examined the difference between species whose populations have been impacted on 10-30 year timescales and focused specifically on the expansion of two bird species which were introduced to eastern North America. The European starling (*Sturnus vulgaris*) and house finch (*Haemorhous mexicanus)* were introduced in the New York City area in the 1890's and 1960's, respectively (Maurer et al., 2001) and today inhabit nearly every ecoregion and biome in North America (Peterson, 2010). Interestingly, these species did not assimilate into the undisturbed landscape matrix, but made their homes in the wake of human settlement and urban development. Analysis for both species produced similar results: expansion shadowed human development patterns. Their results suggest human dominated ecosystems not only cause widespread homogenization of biota but also that the landscape changes have distinct characteristics which appear to follow and favor sprawl.

Green Infrastructure

Green infrastructure refers to natural areas or engineered systems which are aimed towards better resource management and advancing gains toward healthy urban ecosystems. Green infrastructure elements can range in scale from the site to the watershed and includes, but is not limited to, structures or elements which slow stormwater such as downspout disconnection, rainwater harvesting, rain gardens, planter boxes, wet-, dry-, and bioswales, permeable paving, green roofs, urban tree canopy, green parking, streets, and alleys, and other measures which support land conservation (U. S. Environmental Protection Agency, 2014a, 2014b, 2014c).

Green roofs are a type of stormwater Best Management Practice (BMP) and type of green infrastructure defined by the EPA as a part of a compendium of strategies for ameliorating or mitigating impacts from urban development (U. S. Environmental Protection Agency, 2014b). BMPs are anthropogenic installments, management and maintenance activities, practices, or regimes which stop or restrict pollution from nonpoint sources from being introduced into a watershed ("Drinking Water Glossary: A Dictionary of Technical and Legal Terms Related to Drinking Water," 1994, "Handbook for Developing Watershed Plans to Restore and Protect Our Waters," 2008, "NPDES General Permit for Storm Water Discharges From Construction Activities," 2005).

Green Roofs

Introduction

As knowledge in the study of green infrastructure has progressed, terms such as eco-, living-, brown-, and vegetated- have all evolved under the parent term: *green roof* (Berndtsson et al., 2009; Emilsson, 2008; Gedge, 2003). The terms “living” and “vegetated” are straightforward in name and function. “Eco-“describes a roof type where “green” technologies and vegetation are paired and “brown-“describes a roof type where loose material is gathered and is often allowed to be spontaneously colonized. The term *green roof,* however, has been called a misnomer because some roof types may be dry, support brown vegetation, or be composed of unplanted rubble intended for spontaneous colonization (Dunnett & Kingsbury, 2004). Down to its essence, a green roof is simply an ecosystem on top of a structure. The following section covers green roof components, categories, and benefits. The second portion provides a brief history and green roof research overview.

Components of Green Roofs

Green roofs are constructed ecosystems where layers of growing medium or soil substrate and vegetation are supported on roofs (Oberndorfer et al., 2007). In its most simple construction, a green roof is composed of structural support, soil, and canopy (vegetation) (Barrio, 1998). More sophisticated systems may contain additional layers such as waterproofing, insulation, filtration, drainage, and root barrier layers in addition to planting medium and the vegetation itself (Snodgrass & Snodgrass, 2006). Materials could be natural or artificial, and some designers are specifying the usage of recycled or waste materials like crushed brick, concrete, or subsoils (Dunnett & Kingsbury, 2004).

Categorizing Green Roofs

Green roofs are generally classified by their substrate depth. Extensive green roofs are characterized by shallow substrate (2-15 cm, 0.8-6 in) (Dunnett & Kingsbury, 2004), are often not accessible to the public and are generally lower-costing systems (Peck, 2008). Intensive green roofs have deeper substrate (>15 cm) (Dunnett & Kingsbury, 2004). Intensive green roofs may be referred to as rooftop gardens or parks, are generally accessible to the public or are intended for recreational use and these systems are generally associated with higher maintenance and greater capital costs (Peck, 2008). A combination of both roof types has been referred to in the literature as "semi-intensive," (Peck, 2008) "semi-extensive," (Dunnett & Kingsbury, 2004) and "hybrid" (Werthmann, 2007) although they all describe a similar roof type which blends components of both intensive and extensive green roofs. Blending roof types increases biodiversity and may be favorable as a reduced-cost method of attaining some of the benefits of an intensive roof without having to utilize one over an entire roof area.

Green Roof Benefits

The benefits of green roofs include the restoration of ecosystem services to urban areas, (Bolund & Hunhammar, 1999; Oberndorfer et al., 2007; Wang et al., 2014) which some say define sustainable systems (Costanza, 1998). These services include, but are not limited to stormwater management (Berghage et al., 2009), UHI mitigation (Gago et al., 2013), habitat provisioning (Brenneisen, 2006; Gedge, 2003; Kadas, 2006; Lundholm, 2006), as well as social and cultural benefits due to the restorative qualities of vegetation and the amenities green spaces support. Green roofs also provide economic benefits where they can drastically reduce energy demands because they are good insulators. This translates into reduced costs for heating and cooling ("Reducing Urban Heat Islands: Compendium of Strategies: Green Roofs," 2008). Other services provided by green roofs include increasing urban biodiversity, crop harvesting, visual aesthetics, improved air quality and increased CO_2 sequestering, and general environmental buffering (Renterghem et al., 2013).

Brief History

Legends of the Hanging Gardens of Babylon have captured the imagination of people for centuries. While evidence of this magical place remains elusive in modern times, the concept of integrating landscape into construction dates back to ancient times (Dalley, 2013; Osmundson, 1999). A more recent example of vernacular architecture which employs green roofs can be found in Iceland, a maritime subarctic climate, where sod was a highly incorporated building material up until the World War II era. Traditional Icelandic architecture is characterized by a building envelope of green, growing vegetation (Hoof & Dijken, 2008). Although Germany is credited with utilizing green roofs since the turn of the 20th century, the formation of the German Landscape Research Development and Construction (FLL) group in the 1970's boosted the country's status as leaders in the research, development, and design of green roofs (Oberndorfer et al., 2007). Today green roofs are found all over the world and research projects dedicated to their exploration and understanding are on the rise (Blank et al., 2013).

Research Overview

Green Roofs and UHI

Using a mathematic model designed to analyze green roof structure, substrate, and vegetative canopy conditions, Del Barrio's results (1998) provided support for the employment of green roofs for UHI mitigation. The study addresses the limiting factors associated with substrate and moisture capacity and recommends considering this relationship when designing green roof systems. The author also suggests if one is planning roofs for characteristics which make them most effective in summer (in terms of increased substrate depth and moisture capacity), those same qualities or characteristics may hinder efficiency in winter conditions.

Models have also been used to evaluate the passive cooling properties of green roofs. Temperature and moisture on a green roof in Vicenza, Italy were monitored over the 2002 and 2003 summers and winter of 2004 to develop a predictive model to help understand the thermal properties of green roofs and estimate the potential benefits from evapotranspiration. Measurements were taken on a 1000 m^2 *Sedum* green roof system with 20 cm of substrate over an 11 cm drainage layer. During the summer, green roofs both reflect and absorb more solar radiation than traditional roofs and evapotranspire, which traditional roofs do not, which reduces thermal impacts both indoors and outdoors by considerable amounts. It was also found wet roofs have increased capacity for evapotranspiration, which reduces the amount of accumulated heat and provides for both cooler indoor and outdoor temperatures. During winter, green roofs maintained low surface temperatures due to evapotranspiration (Lazzarin et al., 2005).

Alexandri and Jones (2008) hypothesized greening urban surfaces could impact UHI in different climates differently depending on urban geometry. Through a micro-scale model of three urban canyons, the effects of vapor gradients on temperature gradients were evaluated in four cases: no-green, green-roofs, green-walls, and green-all. Each treatment was examined with two orientations and two directions of wind flow in one of nine cities, each located in a different climate region. Results indicated lowest air temperatures when both walls and roofs are greened across all climates examined, although the best results occurred in the hot arid climate condition. The study included the city of Hong Kong for its treatment of the humid subtropical climate and reported a maximum air temperature decrease of 8.4°C in the canyon and 6.9°C reduction in daytime average temperatures in the green-all case, suggesting similar results could be observed in North American humid subtropical climates under the right conditions. Alexandri and Jones (2008) provide evidence that green infrastructure cools the environment and influences indoor conditions which indicate important energy savings potential.

Green Roof Vegetation

Exploration into suitable green roof vegetation for North American ecoregions was undertaken by Dvorak and Volder (2010) where twenty-eight investigations representing fourteen ecoregions between Mexico and Canada were found to coincide with European research findings. Recommendations for potential plant species are offered in their study for both succulents as well as herbaceous perennials for different ecoregions. This study notes the limiting factor of available moisture in the system and points towards research which utilized fabrics for moisture retention in order to attain more favorable results from vegetation.

Sedum species are a favorite for extensive green roof plantings because of their ability to tolerate the extreme temperature and moisture demands associated with rooftop conditions. In two long term three-year studies by Butler and Orians (2011) designed to study 1.) the effect of *Sedum album* on the performance of two neighboring plant species and 2.) the effects of four *Sedum* species on a single species: *Agastache 'Black Adder."* The results from these experiments suggest *Sedum* species act as both facilitators and competitors in green roof systems. During times when moisture and resources were available, they acted as competitors and when conditions were hot and dry, they acted as facilitators. It was found that *Sedum* species cool the soil which helps nearby plants thrive under difficult conditions. The authors suggest this ability could have important implications for increasing biodiversity on roofs as *Sedum* species could reduce abiotic stress and expand the palette of plants available for utilization in green roofs.

A five-year study observing substrate depth's influence on the establishment of vegetation on an extensive green roof in the United Kingdom hypothesized moisture would be the significant limiting factor for plant establishment (Dunnett et al., 2008). In addition to monitoring planted species, Dunnett et al., evaluated the performance of spontaneous colonizing flora as well. Six test beds were established at either 100 mm or 200 mm substrate depth. Two-thirds of treatments were irrigated. At the end of the study, all species planted remained. However, differences were observed in plant performance across substrate depth and varying moisture regimes. It was found that the 200 mm plots produced-better performing vegetation than plots at 100 mm depth.

Plant studies which explore alternatives to *Sedum* species are also increasing in availability. In a study designed to discover new plants for green roofs, some researchers call for a shift in perspective (Blanusa et al., 2013). Three perennials with broad-leaf characteristics were compared to *Sedum* species in a study to determine if leaf morphology influenced soil temperature and air temperature just above the canopy. Because irrigation was available, this study showed positive results for alternative species, highlighting potential in the genus *Stachys* due to its ability to influence soil temperature fluctuations and the capacity to self-regulate its own temperature.

Wetland systems have also received credit for potential in overall microclimate regulation and stormwater mitigation in research from Seoul National University in Seoul, Korea (Song et al., 20130). Wetlands were hypothesized to make an effective insulator and green roof ecosystem. To study potential advantages, several wetland species were considered in a rooftop tank experiment and through the monitoring of a 2 m x 2 m rooftop constructed wetland. If the waterproofing layer and roof structure are both adequate, wetland roof systems could be used to capture stormwater and hold it--which, if deployed on a large scale, shows potential for flood prevention. In one instance, rooftop temperature was recorded at 38°C and wetland system temperature was recorded at 33.1°C. These results suggest wetlands have potential at being efficient microclimate-regulating green roof systems.

Green Roofs and Runoff

Studies addressing green roof vegetation and stormwater mitigation are also common. Monterusso et al. (2004) conducted a study at Michigan State University to determine nutrient removal capacity of the extensive roofs with four different commercially available drainage systems installed on twelve test roof platforms. The study monitored three vegetative treatments and tested for NO_3 and P, finding nitrate concentrations to be significantly higher on day 314 than on day 140, the study suggests this was due perhaps to the time-release nature of the fertilizer applied. Measured concentrations of phosphorus were lower on day 314 than on day 140. Results indicated systems with *Sedum* plantings started from seed were less effective at point-source pollution removal than the other vegetative types tested. The study also reported monitored roofs retained 49% of the rainfall they received.

The 2004 study (Monterusso et al., 2004) points out the potential for green roofs to pollute stormwater runoff and surface waters from even light fertilization which would be reasonably expected to occur during routine green roof maintenance. This is a concept explored in 2009 runoff quality research on both extensive and intensive roof types in Malmö, Sweden and Fukuoka, Japan (Berndtsson et al., 2009). Runoff pollutant sources were concluded to occur in multiple green roof components which were either structural (i.e. building materials, substrate mix, vegetation) or external (dry deposition, fertilizer additives) (Berndtsson et al., 2009).

A subsequent research review from Berndtsson (2010) concluded there is a need for additional research into green roofs in urban environments as well as long term monitoring studies to inform design and management decisions. Berndtsson identifies the major factors affecting stormwater runoff quantity to be climate (average annual precipitation, length of time since last storm event), design (substrate depth, composition), and age of system (chemical or capacity changes over time). Research addressing the capacity for green roofs to remove pollutants from the local environment in Chicago indicated the capacity for green roofs to sequester pollution is directly related to the amount of vegetation available. (Yang et al., 2008) The study considered NO_2, SO_2, O_3, and PM_{10} and results suggested pollution levels may vary depending on time of year.

Noise Pollution

Another benefit of green roofs is their noise buffering capabilities. Renterghem and Botteldooren (2009) developed a model for anticipating how sounds created from vehicle traffic at different speeds would behave in an urban context and then calculated how the addition of green infrastructure would impact the noise. An increase in shielding was observed, however certain thresholds were observed for sound intensity and distance to structure which suggested green roofs as an unlikely panacea for noise mitigation.

In a successive study, Renterghem et al. (2013) describe impervious surfaces as "acoustically rigid" which allows them to bounce and amplify sound from the urban environment. A case study considering twenty-one green building retrofits (which included green walls as well as green roofs), determined green roofs may have increased potential as a noise barrier. The study also points out buildings with increased infrastructure generally produce lower noise infiltration; green roofs act as sonic insulators in this way.

Green Roofs and Biodiversity

When Blank et al. (2013) performed their bibliometric survey, research trends were observed and included a gap in biodiversity studies. Their findings suggested great potential for future research on green roofs as biological systems and their applications to urban ecology (Blank et al., 2013). Existing research often addresses habitat: general findings indicate the most positive results occur when roofs considered biodiversity issues at design onset (Brenneisen, 2006; Gedge, 2003; Lundholm, 2006). Lundholm (2006) addressed the concept of green building and integrating desired species into design while mitigating damage caused by urbanization. Viewing green roofs from an ecological standpoint, Lundholm (2006) makes the argument for matching the right plant with the right conditions, even on a roof top, by proposing to use plants based on their occurring naturally in hostile, extreme conditions. Ideally, research will help develop habitat templates for the deployment of successful biodiverse green roof systems.

Popular subjects for biodiversity research often include avifauna because they make good social, economic (Melles, 2005), and environmental indicators (Bibby, 2002). Bibby provides four reasons to support this argument: birds are conspicuous and relatively easy to identify, bird taxonomy is relatively agreed upon, birds are widespread in most terrestrial habitats, and birds have both symbolic and cultural value to humans (2002). Avian green roof research is already demonstrating benefits to ecosystems and conservation. In the United Kingdom (UK), Gedge has overseen the comeback of the Black Redstart (*Phoenicurus ochruros*) and the establishment of the Black Restart Action Plan for London where green roofs designed to mimic brownfield sites are established for this threatened species (Gedge, 2003; Gedge & Kadas, 2005; Lee, 2007). Gedge and Kadas (2005) provide helpful design principles for constructing biodiverse roofs: vary substrate depth, provide structural diversity, and vary biomass densities to create a "mosaic of microhabitats" which will encourage colonization of life.

Twelve green roofs across Michigan and Illinois, U.S.A. were monitored between April-July, during times associated with nesting and brood rearing (Eakin, 2012). The objectives of the study were to quantify bird communities associated with the green roofs and surrounding areas, to quantify how vegetation and roof structure impact these bird communities, and to quantify the relationship between birds, structure, and vegetation in addition to offering recommendations for future green roof design. Eakin provided comprehensive vegetative surveys for each roof and conducted point count surveys to detect bird species on the roofs. Twenty-nine of the sixty-nine species observed over the duration of the study were found on green roofs. It is notable that three of the twenty-nine were found only on green roofs and not in the surrounding landscape (Eakin, 2012). Eakin observed birds and a variety of behaviors: feeding, bathing, perching, nesting, defending territory. Ground-nesting birds were observed on the roofs, a phenomenon which has been observed in other studies (Baumann, 2006). The presence of ground-nesting birds on a rooftop suggests species with a penchant for nesting on the ground might utilize green roofs at any height--or--that there may be a threshold at which green roofs may no longer be discoverable by certain species.

In another study addressing bird conservation concerns in the UK, Burgess (2004) observed six species of moderate or high conservation concern on two roofs (one rural, one suburban) between January and April of 2004. Observed behaviors were both active and passive, including foraging for food, collecting nest materials, and resting or perching. At the time of Burgess' research, the Rolls-Royce factory in West Sussex was newly established and so even with such a large area (33,000 m^2) and rural location, the author noted sparse resource availability due to roof age. In addition, only an estimated

7,500 m² of Rolls-Royce roof area was visible for observation. The suburban observation site monitored a group of green roofs on an apartment complex in the outskirts of Brighton, established between 1992 and 1994. For both contexts, observation of the roofs was from a remote location.

On designing for biodiversity in Basel, Switzerland, Brenneisen (2006) notes a very biodiverse, ninety year-old roof at the Wollishofen water plant in Zurich which hosts one hundred and sevety-five plant species, including many rare or endangered species. This is important because the success of the Wollishofen plant communities is dependent on the roof's poor drainage, which allowed the diverse wet meadow to develop. This supports the notion that while "technical substrates have many practical advantages in terms of weight, consistent drainage, and efficient installation, they are generally suboptimal where biodiversity is concerned" (Brenneisen, 2006). Brenneisen's recommendation for achieving successful urban habitat is to thoroughly research a given roof's target species in order to tailor habitat to fit their needs. Brenneisen offers several limitations of green roofs for biodiversity conservation: limited mobility keeps some species from accessing rooftops, stressors from extreme rooftop conditions make it difficult for some species to successfully adapt to them, and total habitat (roof) size. This suggests for any given climate type, successful habitat could be created for certain species with the capacity to adapt to rooftop conditions.

Bauman (2006) provides evidence of avian habitat requirements being fulfilled under rooftop conditions. Five study sites were selected because on them observations of endangered species had been previously recorded. The northern lapwing (*Vanellus vanellus)* and little ringed plover *(Charadrius dubius)* were these species. During the study, birds were observed mating, brooding, laying eggs, and hatching on the roofs, although no chicks survived. This is important because it shows significant promise for the role of green roofs and conservation.

While there is significantly more research available on avifauna and green roofs than any other taxa, other studies do exist. A well-known study by Kadas (2006) studied invertebrate populations on existing green roofs in London. Interestingly, the study revealed some cases where more invertebrates were present under roof conditions than ground-level brown field sites. Overall, the results indicated abundant populations of invertebrates on rooftops and Kadas suggests green roofs could focus habitat development to promote "species of interest that are rare or scarce in other habitats" (Kadas, 2006). This concept supports the potential for green roofs to function as habitat islands in fragmented urban contexts.

Green Infrastructure Research Plots

The Green Infrastructure Research Area (GIRA) at South Farm (SF) was established in 2010 to study how certain BMPs perform in Mississippi's humid subtropical climate region.

Arnold (2011) found green roofs reduced average daily high surface temperatures by 1.7°C and reduced average daily high interior temperatures by 1.92°C. During winter, temperature improvements were 2.6°C and 0.95°C respectively. His findings showed green roofs reduce a structure's temperature fluctuation by acting as an insulating element and showed they also provided relief from peak daily temperatures.

In a study designed to assess the effect of slope and media on sedum growth performance, Kordon (2012) measured percent (%) coverage for four sedum species:

Sedum album, Spurium "John Creech," Sedum sexangulare, and Sedum rupestre "Angelina" on twelve roofs at GIRA. The roofs were planted the last week of July 2010 (Anders, 2012). The twelve test roofs monitored represent three replications of four types: 6 in depth 2% slope roofs, 4 in depth 2% slope roofs, 6 in depth 33% slope roofs, and 4 in depth 33% slope roofs. Because plant survival was threatened, supplemental irrigation had to be provided once during a drought which occurred shortly after planting. At the end of the study, plant cover measured on the 4 in substrate, 2% slope and 6 in substrate, 33% slope treatments were not statistically different and reached mean % plant cover values of 26.02% and 32.37%, respectively. Evidence from this study suggests it is substrate depth, and not slope, which is more critical on plant cover development (Kordon, 2012). This is probably due to the increased moisture capacity of deeper soils. Similar results have been achieved in a long term study in Sheffield, UK to monitor the influence of substrate depth on plant performance (Dunnett et al., 2008).

The GIRA has also recorded baseline data for stormwater retention capacity and performance (Anders, 2012). Anders monitored eighteen roofs: all twelve of the *Sedum* roofs as well as the six controls: 3-2% slope roofs finished with an impervious waterproofing layer and 3-33% slope asphalt shingle roofs. This research found slope impacts stormwater retention with reduced water capacity at steeper slopes. Interestingly, this research found no statistical difference between the 4 in substrate depth 2% slope roofs and the 6 in substrate depth 33%, the same finding Kordon (2012) arrived with. This observation suggests designers may capitalize on slope-substrate depth relationships by increasing soil depths in steep slope conditions in order to produce more established vegetative cover (Anders, 2012).

There is one more study which has been conducted at the GIRA on the green roof test plots but at the time of writing of this thesis it was not yet published. A rough description of the research will be provided, however no results can be shared as they have not been released. A study to compare two prairie green roof types against the *Sedum* roofs was undertaken. Ten green roof platforms were constructed: five control prairie roofs with the same substrate mix as the other treatments and five prairie roofs with the same mix plus an additional 11% native chalk added to the substrate mix (Lackey, unpublished data). They were then established with prairie species and have been allowed to compete with each other and local invaders. The roofs undergo no maintenance and have not been weeded. It is expected they will undergo a controlled burn in the fall of 2014.

CHAPTER III

METHODOLOGY

Introduction

The methodology chapter is organized into four sections. First, the research area is defined, followed by a description of the research area climate. Detailed site descriptions come next for each of the research areas. An explanation of the experimental design concludes the chapter and covers the development of the study and the statistical methods.

Site Selection

As green roofs are not common yet in the southern United States, and accessibility is an issue, only two sites were chosen for this study. Limited access to study sites is an issue recognized in the literature (Kadas, 2006). The first site, the Green Infrastructure Research Area (GIRA), is located off Agronomy Road adjacent to the Mississippi Agricultural and Forestry Experiment Station (MAFES) research area housed within Mississippi State University's H.H. Leveck Animal Research Center, also known as South Farm (SF). The area can be described as a variety of agricultural research plots and fields. The second site studied is the green roof located at the Oktibbeha County Heritage Museum (OCHM) in Starkville, MS. Both sites are located in Oktibbeha County in northeast Mississippi in the Blackland Prairie Region of the Southeastern Plains

Ecoregion. The Blackland Prairie is defined by the layer of "Cretaceous-age chalk, marl, and calcareous clays" (Chapman et al., 2004) which is alkaline in pH and is a determining factor for the study of ecosystems in the region.

Climate

The climate of Oktibbeha county, MS is humid subtropical. Climate data is described based on details provided by the State University, MS US station, station ID: GHCND: USC00228374. Latitude/Longitude coordinates for the station are 33.4691°, -88.7822° and its elevation is 56.4 m. The annual mean temperature is 62.5°F with its coldest month being January with a mean temperature range of 30.8°F to 53.4°F and the hottest month, July, has a mean temperature range of 70.7°F to 91.5°F. The wettest month is February with a mean precipitation of 5.70 in. The driest month is September with a mean precipitation of 3.41 in. In regard to the seasons, winter (December, January, February) is both the wettest and coldest season experienced with a mean temperature of 44.3°F and a mean precipitation of 5.26 in. The hottest and driest season is summer (June, July, August) with a mean temperature of 79.7°F and a mean precipitation of 4.13 in (National Climatic Data Center, 2014).

Site Descriptions

Green Infrastructure Research Area

The study site location is at approximately 33°25'25.66" N, 88°47'32.08" W with an elevation of approximately 99 m. The Green Infrastructure Research Area (GIRA) consists of twenty-eight test roofs, eighteen of which are coupled to related green infrastructure which include: stormwater catchments, rain gardens, and subsurface storage. The GIRA footprint is about 12 m x 30 m (approximately 30 ft x 90 ft) and covers an area of approximately 360 m^2 (3875 ft^2). A 400-m (0.25 mi) radius around the GIRA is contained entirely within the H.H. Leveck Animal Research Center. The closest residential neighborhood is located approximately 640 m (0.40 mi) due west. Separating the neighborhood from the farm is a woodland area buffer that is approximately 130 m wide.

Cumulative research at GIRA has allowed for site expansion and the construction of various additional green roof treatments as well as other research elements. The GIRA array is composed of twenty-eight test roofs. Roofs 1-18 were constructed in the spring and summer of 2010 (Anders, 2012) and are coupled other best management practices (BMPs). Roofs 19-28 were added in June 2011 (Lackey, unpublished data) and have not been retrofitted with the additional green infrastructure technologies. For the duration of the study, one 10.16 cm soil depth, 33% slope *Sedum* roof was out of service. For the purpose of this study, the test roofs have been numbered 1-27. The green roof configuration for the duration of the study can be found in Figure 3.1.

Green roof treatments are all extensive and can be broken into eight basic groups which are as follows: 1-3, 4-6, 7-9, 10-12, 13-15, 16-18, 19-23, and 24-28. Roofs 1-3 and 7-9 are supported by structures measuring 0.9525 m x 0.9525 m x 1.0414 m (3.125 ft x 3.125 ft x 3.416 ft) (Arnold, 2011). All other test roofs are supported by 4-4 in x 4 in posts with 2 in x 4 in braces. All test roofs are elevated 1.8 m (6 ft) off the ground, and constructed with a 1.27 cm (0.5 in) gap on the low end for stormwater discharge, and are of a southern aspect (Anders, 2012).

Figure 3.1 GIRA model green roof configuration and individual roof classification

Note: Large numbers refer to the roof ID number, 6" or 4" refers to soil substrate depth, 2% or 33% refers to slope, and *Sedum*, Prairie, or Control refer to roof cover class.

Note: *Waterproofing layer on 2% Control Roofs is Sopralene FLAM180 and FLAM 180 GR (Arnold, 2011).

Test roofs are either control roofs or living roofs. Roof numbers 1-6 all represent control roofs which have been constructed with conventional impervious materials. Tests roofs have a surface area of 1.4864 m² (16 ft²). Roofs 1-3 are "flat" with 2% slope and roofs 4-6 have a slope of 33%. Roofs 7-28 are living roofs upon which either a *Sedum* or prairie plant community is established.

The living roofs are all composed of the same basic layers from the bottom up: plywood roof structure, a waterproofing membrane, a drainage layer, soil media, and vegetation. 20.32 cm (8 in) sidewalls frame all living roofs. *Sedum* species grown over two soil media depths (10.16 cm and 15.26 cm; 4 in and 6 in) and two slopes (2% and 33%) are replicated three times each on roofs 7-18.

Roofs 7-12 represent treatments with 2% slope, and have two layers of Sopralene FLAM 180 and FLAM 180 GR (Soprema, Wadsworth, OH) waterproofing, Enka Retain & Drain3211 (Colbond Inc., Enka, NC) drainage and water retention layer, and ERTH Hydrocks Lightweight Soil Media-Extensive (ERTH Products, Peachtree City, GA) as the substrate layer. Roofs 7-9 have a soil media depth of 15.26 cm (6 in) and roofs 10-12 have a soil media depth of 10.16 cm (4 in). Roofs 13-18 represent treatments with 33% slope and in addition to the same component layers as roofs 7-12, have a Enka Mat 7010 (Colbond, Inc. Enka, NC). Roofs 13-15 and 16-18 have substrate depths of 15.26 cm (6 in) and 10.16 cm (4 in), respectively (Anders, 2012).

All prairie roof treatments (roofs 19-28) have a soil media depth of 15.26 cm (6 in) and a slope of 2%. Roofs 19-28 were constructed using a double layer of Sopralene FLAM GR (Soprema, Wadsworth, OH) for a waterproofing membrane. The drainage layer consists of three layers with a root-resistant filter fabric, a plastic dimpled drainage core, and protection fabric sandwiched between the waterproofing membrane and the soil media. Roofs 19-23 represent the control prairie simulations and utilize the same soil substrate as the other test roofs (ERTH Hydrocks Lightweight Soil Media-Extensive, ERTH Products, Peachtree, GA). Roofs 24-28 contain an 11% by weight addition of native prairie soils harvested from two local Blackland Prairie relics (Lackey, unpublished data).

Sedum roofs, numbers 7-18, were planted in July 2010. Plugs of four *Sedum* species: *Sedum rupestre 'Angelina,' Sedum album, Sedum spurium 'John Creech,' and Sedum sexangulare* (Anders, 2012) were planted 6 in on-center in each test roof (Anders, 2012). Prairie roofs, numbers 19-28, were sown with seed sourced from Native American Seed (Junction, TX) and planted with plugs in June 2011. Plug species include sideoats grama (*Bouteloua curtipendula),* purple coneflower *(Echinacea purpurea),* yellow coneflower *(Ratibida pinnata),* and heath aster *(Symphotrichum ericoides)* from Prairie Moon Nursery, Inc. (Winona, MN) (Lackey, unpublished data). The seed mixture, composed of twenty-one prairie species and *Helenium amarum* (sourced locally), were introduced in a seed-sand mixture to roofs 19-28 (Lackey, unpublished data). In April 2014, the prairie roofs were surveyed for dominant species which resulted in the following list: cutleaf geranium (*Geranium dissectum*), early buttercup (*Ranunculus fascicularis*), dropseed (*Sporobolus spp.*), common chickweed (*Stellaria media*), white and Persian clover (*Trifolium repens, -resupinatum*), narrowleaf vervain *(Verbena simplex*), winter vetch (*Vicia vilosa),* early coreopsis (*Coreopsis auriculata*), and beebalm *(Monarda spp.*).

Heritage Museum Green Roof Pavilion

The Oktibbeha County Heritage Museum (OCHM) pavilion is a repurposed gas station awning which supports an extensive green roof. The study site is located at approximately 33°27'35.45" N, 88°48'26.33" W with an approximate elevation of 118 m in Starkville, MS. A 400-m radius (0.25 mi) around OCHM can be characterized by a collection of diverse properties including green spaces, public amenities and services, residences, and places of businesses. Residential units include low-density apartments, single family homes, and duplexes. Commercial properties include restaurants, service stations, and two small strip malls. two small urban parks and a cemetery (approximately 550,000 ft^2), a fire station, and a small church are located within this radius. Starkville is approximately 25 mi^2 in area with an estimated density of about 934 people per mi^2 (United States Census Bureau, 2014).

Constructed in June 2012, the green roof, approximately 9.44 m x 6 m (31'6" x 20'4-1/2"), is roughly 59.644 m^2 (642 ft^2) in area and has 43.664 m^2 (470 ft^2) in available planting space. American Hydrotech (Chicago, IL) donated the green roof materials and component layers. From the structural decking up, the extensive Garden Roof® Assembly is composed of a MM 6125 EV-FR roofing membrane, Hydroflex 30 root stop, Dow Chemical's STYROFOAM® insulation, Moisture Mat and Hydodrain layers, Gardendrain® Retention/Drainage/Aeration Component (GR15 or GR 30), Systemfilter, and Litetop® Engineered Lightweight Growing Media ("Garden Roof® Planning Guide: from Concept to Completion," 2013).

The roof is divided into two planes with a high point in the center, sloping away to the north and south at 7.5% to drain around the edge. Buffering the planted space from the edge are 18 in gravel borders on its east and west sides and 30 in gravel borders on its north and south sides. The green roof was designed without irrigation and drainage occurs through a singular outlet in the center of its western edge.

Vegetation was donated by ItSaul Plants (Alpharetta, GA). Plugs in eighteen species were planted in November 2012: *Allium schoenoprasum, Delosperma cooperi, Opuntia humifusa, Phlox subulata* "*Emerald Blue*", *Portulaca pilosa, Santolina virens, Sedum album* "Jellybean", *Sedum album* "*Murale*", *Sedum* "*Bertram Anderson*", *Sedum* *kamtschaticum, Sedum moranense, Sedum reflexum* “*Blue Spruce*”, *Sedum rupestre* “*Angelina*”, *Sedum takesimense, Sporobolus heterolepsis, Talinum calycinum, Teucrium chamaedrys, and Thymus vulgaris* “*Aurea*.” Since the roof’s establishment, some spontaneous colonization has been allowed to occur. It is periodically maintained and cleared of any undesirable weedy species.

Experimental Design

This section focuses on the methods and materials used to conduct this study. First, the study timeline is discussed. Next is a description of how the observation schedule was determined and subsequently created. Site observations at GIRA are described, followed by a description of the OCHM site observations. A description of the statistical methods rounds out the end of the chapter and includes a stepwise explanation of how the data from GIRA was analyzed.

Observation Protocol

Stretching from mid-February to the 1st of August, the twenty-four week study monitored interactions between avifauna and green roofs at both sites. A two week pilot study was conducted at both sites in the beginning of February 2014 so the observation methods could be practiced and refined. This time period was chosen to sync with the basic annual cycle of birds which coincides with the seasons and months with greatest food availability (Gill, 2007). Figure 3.2 juxtaposes general avian life cycle seasons against the experimental design.

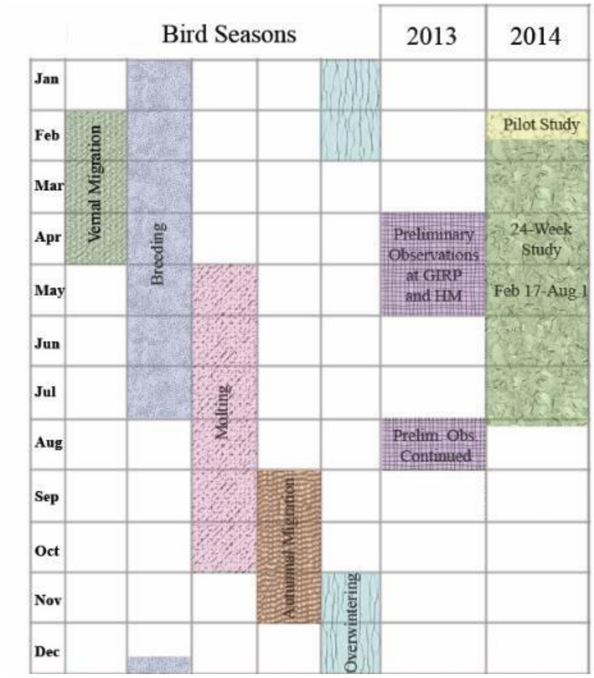

Figure 3.2 Timeline of bird seasons and experimental design

Note: Graphic after Jacobs & Wingfield, 2000 and Gill, 2007.

It was determined before the onset of the study that the OCHM and GIRA sites would be visited 40% and 60% of the time, respectively. GIRA was monitored more frequently because it is the primary research area. Monitoring bird visits and flyovers at both sites should produce results which can be qualitatively compared. Observations at both sites provided information about what species are responsive to green roofs in the humid subtropical climate region.

Robbins (1981) summarized all North American Breeding Bird Survey (BBS) data from 1965-1979 in order to determine what effect time of day had on bird activity. Even though each species exhibits different behavioral patterns, this analysis produced general trends and pointed to the time frame of about half an hour before sunrise to 3.5 or 4.5 hours after sunrise as the time of day with the most activity. Robbins also conducted twenty minute point count surveys over five days in July of 1980 and found the hours between 5 and 7 AM to be the time frame within which peak singing activity occurs with the peak number of species recorded in the 6 AM hour. During winter, Robbins found behaviors to be consistent, except most birds were more active earlier in the day. A study in the United Kingdom of bird activity on green roofs conducted by Burgess (2004) set observation times between 7 and 10 AM for the same reason. Eakin (2012) also set observation times between dawn and 10 AM to capture the same period of high activity. Due to time of day bias and variation in bird activity (Bibby et al., 2000), observation times were generated for this study between 6 and 9 AM in order to observe birds during the early morning peak activity period (Robbins, 1981).

The observation schedule was randomly defined in Microsoft Excel using a random number generating function to minimize bias. The formula to generate site selection in =randbetween(1,5), which produces a number 1 through 5 at random. The GIRA was coded with the numbers 1, 3, and 5, and the OCHM site was coded with the numbers 2 and 4. This numbering system was selected because it would theoretically produce a 60/40 ratio for GIRA and OCHM site visits. The results generated from that function dictated the observation schedule for each day of the study.

Five site visits per week between both the OCHM and GIRA were scheduled between 6 and 9 AM. A random number generating function was used to define the times for each observation session. Observation times were limited on Monday, Wednesday, and Fridays for the first eleven weeks of the study as the researcher had a time conflict on these days for the time frame between 9 and 10 AM. On those days, times were randomly selected in Microsoft Excel using the function =randbetween(6,8) in order to produce site visit times at 6, 7, or 8 o'clock AM. Starting on week 12 and continuing through the end of the study, times randomly selected for Monday, Wednesday, and Friday were expanded to include observation periods starting at 9 AM. Observation times generated for Tuesday and Thursday site visits were created using the function =randbetween(6,9) to produce site visit times at 6, 7, 8, or 9 o'clock AM. The observation schedule also included times generated for Saturday and Sunday observations, as needed.

Site visits consisted of a series of four observation sessions. Each site visit began with a fifteen minute settling period after the researcher arrives. An observation session lasted for the duration of ten minutes and was immediately followed by a five minute period for the researcher to note any additional observations and relax before beginning the next observation session. This pattern of a ten minute observation session followed by five minute resting period was repeated three times until a total of four observation sessions were conducted over the course of the site visit.

During each session, data was recorded onto standardized forms designed to describe the study sites in plan view. Information recorded onto the forms include the species and number of avifauna sighted interacting with the green roofs, the roof type interacted with, and any associated behavior. The researcher recorded the following behaviors: nesting, resting, calling or singing, foraging, breeding, grooming, and defensive or aggressive territorial behaviors. Green roof flyovers were recorded by species and quantity.

At the GIRA, the array was scanned methodically, with the researcher resting their eyes briefly on each roof until each unit has been the subject of focus. The researcher repeated this continual scanning of the array until movement was detected, at which point observations were then recorded. Observations were made with the help of 10x42 field glasses from one of two vantage points selected for viewing at both sites. At SF, vantage point one was approximately 36 m (119 ft) (Figure 3.3) and vantage point two (Figure 3.4) was approximately 9.5 m (30 ft) away from the GIRA array.

Figure 3.3 View of GIRA from vantage point one, approximately 36 m southeast of array

Figure 3.4 View of GIRA from vantage point two, approximately 9.5 m south of array

At the OCHM site, observations occurred in the same way except they were also layered with a video component. Since there is no vantage point from which to view the OCHM roof directly, a Sony HDR-PJ430 Handycam was mounted on a tripod and used to capture video of the roof during the observation sessions. The tripod was placed on the roof two weeks before the pilot study began in early February 2014. For each site visit, the video camera was placed on the roof and allowed to record for fifteen minutes before observations began in order to accommodate the requirement for a settling period. The researcher watched the recordings to discover any green roof-avifauna interactions on the rooftop which could not be directly observed from the ground. Two vantage points were also selected for observation of the OCHM site. The first was approximately 26.5 m (87 ft) (Figure 3.5) from the green roof and vantage point two was approximately 34 m (112 ft) away from the green roof (Figure 3.6).

Figure 3.5 View of OCHM from vantage point one, approximately 26.5 m north of roof

Figure 3.6 View of OCHM from vantage point two, approximately 34 m east of roof

Statistical Methods

All statistical analyses for this study were generated by the Mississippi State University Statistical Consulting Center and analyses were conducted using SAS ® 9.3 proprietary software. This study seeks to address two main questions. The first: 1.) Is there a significant difference between the two vegetative roof types at GIRA with respect to mean number of birds landing? To discover whether there is a difference between *Sedum* and prairie roof types with respect to mean number of birds landing, an analysis of variance (ANOVA) will be conducted. The landing data for each test roof at GIRA will be averaged and each roof's individual mean will be used for the analysis of variance.

The second question this study seeks to address is: 2.) Does the presence of vegetation on a roof in the humid subtropical climate impact local bird habitat? To determine this, linear contrasts will be run on the three roof types at GIRA. This test will determine whether there is a significant difference with respect to mean number of birds between all three roof types, assuming the null hypothesis is that there is no difference between each of the roof types. A difference would prompt the linear contrasts will test *Sedum* vs prairie, control vs *Sedum*, and control vs prairie models to determine where the noteworthy differences occurred. In this series of tests, the null hypothesis assumed the means for each roof type was the same. A third test, the multiple contrasts, may be performed on the data if the linear contrasts output discovers a significant difference to explore.

CHAPTER IV

RESULTS

Introduction

Altogether, eighty-eight site visits were completed over the twenty-four week study producing three hundred and fifty-two individual observation sessions totaling over one hundred and ten hours in the field birding. The results chapter is organized into three major sections. First, the data overview is presented for both sites, followed by the statistical analysis for GIRA, and finally, the descriptive data analysis is provided. All references to birds in the following chapters will be in terms of the four-letter alpha codes generated by Pyle and DeSante (2014) (Table 4.1).

Table 4.1 4-letter alpha codes used in this thesis

Common Name	**Taxonomic Name**	**4-Letter Alpha Code**
European starling	*Sturnus vulgaris*	EUST
Northern mockingbird	*Mimus polyglottos*	NOMO
barn swallow	*Hirundo rustica*	BARS
mourning dove	*Zenaida macroura*	MODO
red-winged blackbird	*Agelaius phoeniceus*	RWBL
Eastern bluebird	*Sialia sialis*	EABL
unknown sparrow	Emberizidae *(genus, species)*	UNSP
American robin	*Turdus migratorius*	AMRO
cattle egret	*Bubulcus ibis*	CAEG
blue jay	*Cyanocitta cristata*	BLJA
Eastern meadowlark	*Sturnella magna*	EAME
unknown blackbird	Icteridae *(genus, species)*	UNBL
red-headed woodpecker	*Melanerpes erythrocephalus*	RHWO
turkey vulture	*Cathartes aura*	TUVU
house finch	*Haemorhous mexicanus*	HOFI
Eurasian collared-dove	*Streptopelia decaocto*	EUCD
purple finch	*Haemorhous purpureus*	PUFI
Canada goose	*Branta canadensis*	CANG
Killdeer	*Charadrius vociferus*	KILL
northern cardinal	*Cardinalis cardinalis*	NOCA
American crow	*Corvus brachyrhynchos*	AMCR
chimney swift	*Chaetura pelagica*	CHSW
white-winged dove	*Zenaida asiatica*	WWDO
indigo bunting	*Passerina cyanea*	INBU
northern flicker "yellow shafted"	*Colaptes auratus*	NOFL
red-bellied woodpecker	*Melanerpes carolinus*	RBWO
brown thrasher	*Toxostoma rufum*	BRTH
Carolina chickadee	*Poecile carolinensis*	CACH
eastern kingbird	*Tyrannus tyrannus*	EAKI
house sparrow	*Passer domesticus*	HOSP
loggerhead shrike	*Lanius ludovicianus*	LOSH
Mississippi kite	*Ictinia mississippiensis*	MIKI
unknown bird	Aves *(genus, species)*	UNBI
northern lapwing	*Vanellus vanellus*	NOLA
little ringed plover	*Charadris dubius*	LRPL
cedar waxwing	*Bombycilla cedrorum*	CEDW
unknown hummingbird	Trochilidae *(genus, species)*	UNHU

Data Overview

Site 1: Green Infrastructure Research Area

At the Green Infrastructure Research Area (GIRA) site, two hundred and twenty-eight observation sessions were completed during fifty-seven site visits between February 17th and August 1st, 2014. A total of one thousand eight hundred and seventy-three birds were observed visiting or flying directly above the research area. In terms of roof by cover type, the six control roofs experienced thirty-one bird visits, the eleven *Sedum* roofs experienced two hundred and twenty-four bird visits, and the ten prairie roofs experienced one hundred and seventy-nine visits from birds. Table 4.2 represents the overall data related to number of birds that landed on each test *Sedum,* prairie, and control roof at GIRA.

Overall, observations revealed four hundred and fifty-one instances of roofs being visited by birds, where three-hundred and eighty-five individual birds from nine families were counted utilizing the roofs. Birds were identified to the genus and species level with a few exceptions: sparrows and blackbirds were generalized at the family level and birds unable to be positively identified were all lumped together into the unknown bird category (UNBI). Species observed landing on roofs at the GIRA site can be found in Table 4.3. The native to non-native ratio was 13:3 and rarity of species observed ranged from common to exotic or vagrant. Both class (native or non-native) and rarity (common, exotic, etc.) data come from contents within Peterson's Field Guide to Birds of Eastern and Central North America (Peterson, 2010).

The local biodiversity of GIRA can be described by reporting the species diversity and richness with respect to species and number of bird visits to each roof type (Table

4.4). Of the four hundred and fifty-one instances of birds observed landing on model roofs at GIRA, thirty-three (13.66%) individual sightings representing nine species were counted on the control roof type. *Sedum* roofs observed two hundred and thirty (50.99%) individual sightings which represented sixteen species and prairie roofs observed one hundred and eighty-eight (41.69%) individual sightings which represented ten species. Of the sixteen total observed species at GIRA, five species were observed at least fifty times, one species was observed more than twenty-five times but less than fifty, and seven species were observed fewer than five times during the study. The six most common species will be reported on in more detail because these species provided the largest amount of data for analysis.

The six most common species observed during the study include: *Zenaida macroura* (MODO), *Agelaius phoeniceus* (RWBL), *Mimus polyglottos* (NOMO), *Sturnus vulgaris* (EUST), *Sialia sialis* (EABL), and unknown sparrow species, Emberizidae (UNSP). Overall, each of the six most common species was observed at least once on the control test roof type at some point during the study. Roof use by these species was graphed so level of activity over time could be analyzed. This study does not attempt to quantify the factors which impact beta diversity nor does it attempt to discuss the results herein in those more sophisticated terms (Tuomisto & Ruokolainen, 2006). It is noteworthy to mention as the species roof use data by test roof type was graphed, apparent patterns did emerge. The following sections detail the trends for each of the 6 most common species. First is a descriptive discussion of each species' presence on each roof type, second is the associated raw data table (Table 4.5), and final part offers a series of figures which illustrates the observed roof usage by the six most common species.

On control roofs, EUST was observed the most often with nine total observations, followed by EABL with eight total observations. EUST were observed utilizing this roof type only during the approximate first half of the study, while EABL observations occurred periodically over the duration of the entire study period. UNSP observations also only occurred during the approximate first half of the study. Around the time that EUST vanished from the data, RWBL and MODO were sighted on the control roofs. Very late in the study, EABL, MODO, and NOMO were the only species which were observed utilizing the control roof types (Figure 4.1).

For the *Sedum* roof type, EABL was observed most often with forty-eight total sightings. EABL was seen most frequently during the approximate first half of the study but was still consistently observed throughout the entire study period. NOMO was observed the second most often with a total of forty-one sightings. While the species was present on the roof type from the beginning of the study, its detection increased as time progressed. MODO, observed a total of thirty-seven times, was observed just once on the first day of the study and then was witnessed in two apparent spikes of activity towards the middle and end of the study. UNSP, with twenty-three sightings, was only detected during the approximate first third of the study after which they were not observed on the *Sedum* roofs again. EUST, detected twenty-one times on this test roof type, was observed most frequently during the approximate first half of the study. RWBL, which was observed fifteen times, was also more frequently observed during the beginning of the study period (Figure 4.2).

Prairie test roofs were utilized most frequently by UNSP with forty-six observations, followed by EUST with forty-four observations, and EABL with thirt-eight observations. All three of these species dominated the first several weeks of the study in terms of total observations. RWBL, with nineteen observations, was consistently present from the start; however, the species experienced a small spike in increased detection during the middle of the study. With seventeen total detections, MODO was also observed over the duration of the entire study, but frequency of detection increased twice, which manifested in two small spikes in the graph. NOMO, observed just twelve times on the prairie roofs, was most often observed on this roof type during the middle of the study (Figure 4.3).

When the data from the presence of the common species on each of the roof types was overlaid, a single illustrative graph was generated (Table 4.5). This graph expresses the six most common species' usage of the three test roof types over six months at GIRA. Stacking the curves together paints a stronger picture in terms of observed activity during the study (Figure 4.4).

The most commonly observed species was EABL, with ninty-four total observations. EABL detection was weighted towards the first several weeks of the study, especially on both prairie and *Sedum* roof types. After a certain point in time, however, EABL were no longer detected on the prairie test roofs and were only observed on the control and *Sedum* types. EUST, with seventy-four total observations, was also weighted towards the beginning of the study. EUST were detected with relative consistency through the first half of the study, but they appeared to abandon the site with the exception of one observation date which occurred in mid-July. UNSP, also detected seventy-four times, was observed only through the end of April before seemingly vanishing from the site altogether. MODO observations, of which there were fifty-eight, manifested into two spikes from two clusters of high activity dates. NOMO, sighted fifty-four times, was seen fairly consistently throughout the study, increasing in frequency in the middle of the study with a flourish of observed activity in the final weeks of the study. The sixth most common species, RWBL, was observed thirty-five times overall. The stacked curves for RWBL also manifested into two apparent curves. The first captured RWBL presence on the decline in the beginning of the study and the second created a spike in activity around April and May when overall species detection increased.

Flyover birds represent one thousand four hundred and thirty-nine of the observed individuals counted (Table 4.6). The positive identification of twenty-one individual species was confirmed. As with observations on roofs, blackbirds and sparrows were generalized at the genus level. Flyover species represented fourteen families and had as many as two hundred and fifty-eight (17.92%) UNBI counted. On March 7th, 10th, and 19th large flocks of roughly 100, 300, and 40 individuals, respectively, were observed flying directly overhead.

Common flyover species included MODO, RWBL, NOMO, EUST, EABL, *Hirundo rustica* (BARS), *Sturnella magna* (EAME), and *Turdus migratorius* (AMRO). The native to non-native ratio was 23:4 and the observed rarity range was also common to exotic or vagrant. It is notable that on the 18th of June, an unidentified hummingbird (UNHU) (Trochilidae) was clearly seen visiting a prairie roof. As this sighting did not occur during an actual observation session, it could not be included in the official results of the study.

Photographic representation of the GIRA array can be found in Figures 4.5-4.27. The control roofs, 1-6, are only pictured once each. The living roofs, however, were photographed once a month from February-July to show the character of the vegetated roofs. This study does not attempt to measure or quantify the vegetative cover in each of the living test roofs. Instead, this photographic representation was offered as a supplemental component to help ground the study in context.

Table 4.2 Bird visits to individual test roofs between February 17-August 1, 2014 at GIRA

	roof type																										
	control						*Sedum*											prairie									
	roof treatment number																										
Date	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**
17-Feb				1			1					2	1	2	1	1	1		2	1		2	3				1
18-Feb												1											1				
19-Feb							1																1	1			
20-Feb	1			2			1						1	1				2					3	1			
21-Feb									2						2					2	1	1					
26-Feb					2		2								1												
27-Feb								1					1			1								1		1	
5-Mar							1			1		1											2	3	1		
6-Mar				1		1	2			1			3	1	1		1	2	1	2			2	3	3	3	3
7-Mar							1	3		1							2	3		1			1	1	1	1	1
9-Mar				1	1		1			1			2		2		1	3	1				3		1	1	1
10-Mar																	2						1				
11-Mar											1		3	4	5		7	3	5			4					3
12-Mar													3	1		1	1	1					1				
17-Mar							2						1					3	2	1	1		2	2		1	2
19-Mar													1					1					1				
20-Mar				2			1						4				1			2		2				1	2
24-Mar													2	1	1		1		1	2	1	3	3	1	2	1	2
2-Apr	1	1	1			1						1	1	1	1	1	3	1				1		1	1		1
7-Apr																								1			

Table 4.2 (continued)

16-Apr				1			5	2	1	1	1	2	2		1	1	3					1			1		
18-Apr													1										1				
19-Apr									1					1				1									
21-Apr					1																						
23-Apr																	1	1				2		2			
25-Apr		1	1				1						1		4		2						1				
30-Apr					1				1			1		1	1				1	2		1			1	1	1
3-May									1			4				2		2	1	1			1			2	2
8 -May				1	1	1	1					1				1					1	1					
12-May									1	2		3	1	1	2	2	3	1									
13-May							4											1						1			
19-May																		1		1							
20-May																							1				
21-May																							3	3			
22-May							2										1						2				
26-May						1		1						1								1					
28-May																											
4-Jun																											
5 Jun								1	1																		
11-Jun																											
13-Jun																											
18-Jun						1																					
19-Jun																											
20-Jun																											

Table 4.2 (continued)

23-Jun							1								1												
25-Jun							2			1			2														
27-Jun														2	1		1										
30-Jun									1						1	1	1										
1-Jul							1	2		1			1	1	1		1										
3-Jul															1												
14-Jul				2	1	1								1	4	2	2										
16-Jul				1						1			4		1			1	2		1						
17-Jul																											
21-Jul							3	1	1	1	3		1								1						
28-Jul											1					2											
30-Jul																											
1-Aug																											
Total	2	2	2	12	7	6	33	11	10	11	6	16	36	19	32	15	35	27	16	15	6	19	33	21	11	12	19
Soil-type total							54			33			87			50		83					96				
Slope-type total	6			25			87						137					179									
Grand total	33						224											179									

Note: "Total" refers to the number of bird landings for each roof treatment.

"Soil-type totals" refer to distinctions in soil media depth or composition. Treatments with 6 in of substrate were roofs 7-9, 13-15, and 18-27. Treatments with 4 in of substrate are roofs 10-12, 16, and 17. Roofs18-22 represent treatments with the control substrate mix and roofs 23-27 represent treatments with the 11% by weight native prairie soils addition.

"Slope-type total" refers to the breakdown of the treatments with respect to slope. Treatments numbered 1-3 refer to the 2% slope control roofs, 4-6 refer to the 33% slope control roofs; 7-12 refer to the 2% slope *Sedum* roofs, 13-17 refer to the 33% slope *Sedum* roofs, 18-27 refer to the prairie roofs which all have a 2% slope.

"Grand total" refers to the number of bird landings for each overall roof treatment type: control (orange), *Sedum* (blue), and prairie (purple). Refer to Figure 3.1 for illustration of GIRA array detail (page 34) for treatment distinctions.

Table 4.3 Species detected on the array at the GIRA site

Common Name	Family	Taxonomic Name	4-Letter Code	Class	Rarity	No. Obs.
indigo bunting	Cardinalidae	*Passerina cyanea*	INBU	Native	Common	2
northern cardinal	Cardinalidae	*Cardinalis cardinalis*	NOCA	Native	Common	1
mourning dove	Columbidae	*Zenaida macroura*	MODO	Native	Common	58
Eurasian collared-dove	Columbidae	*Streptopelia decaocto*	EUCD	Non-native	Exotic	2
white-winged dove	Columbidae	*Zenaida asiatica*	WWDO	Native	Vagrant	4
purple finch	Fringillidae	*Haemorhous purpureus*	PUFI	Native	Uncommon	12
house finch	Fringillidae	*Haemorhous mexicanus*	HOFI	Non-native	Common	4
barn swallow	Hirundinidae	*Hirundo rustica*	BARS	Native	Common	1
red-winged blackbird	Icteridae	*Agelaius phoeniceus*	RWBL	Native	Common	35
unknown blackbird	Icteridae	*(genus species)*	UNBL	Native	Common	6
eastern meadowlark	Icteridae	*Sturnella magna*	EAME	Native	Uncommon-Fairly Common	7
northern mockingbird	Mimidae	*Mimus polyglottos*	NOMO	Native	Common	54
unknown sparrow	Emberizidae	*(genus, species)*	UNSP	Native	Common	74
European starling	Sturnidae	*Sturnus vulgaris*	EUST	Non-native	Common	74
American robin	Turdidae	*Turdus migratorius*	AMRO	Native	Common	3
eastern bluebird	Turdidae	*Sialia sialis*	EABL	Native	Fairly common	94
unknown bird	Aves	*(genus, species)*	UNBI			20
					Total	**451**

Note: *No. Obs.* is shorthand for Number of Observations.

Table 4.4 Frequency of species detection on each roof type at GIRA

4-Letter Code	roof class			species total
	control	*Sedum*	prairie	
UNBI	2	14	4	**20**
EUST†	9	21	44	**74**
AMRO		3		**3**
RWBL†	1	15	19	**35**
MODO†	4	37	17	**58**
NOMO†	1	41	12	**54**
EABL†	8	48	38	**94**
UNSP†	5	23	46	**74**
UNBL		3	3	**6**
EAME	1	4	2	**7**
CARD		1		**1**
EUCD	2			**2**
WWDO		4		**4**
INBU		2		**2**
BARS		1		**1**
HOFI		4		**4**
PUFI		9	3	**12**
total visits per roof type	**33**	**230**	**188**	**451**
total number of species represented	9	16	10	

Note: "†" represents the six most common species observed at GIRA

Table 4.5 Overall observations of six most common species on all test roof types at GIRA

Control		***Sedum***		**Prairie**		Total number of observations of each species
Species 4-letter code	Total No. of Obs. on roof type	**Species 4-letter code**	Total No. of Obs. on roof type	**Species 4-letter code**	Total No. of Obs. on roof type	
EUST	9	EUST	21	EUST	44	**74**
RWBL	1	RWBL	15	RWBL	19	**35**
MODO	4	MODO	37	MODO	17	**58**
NOMO	1	NOMO	41	NOMO	12	**54**
UNSP	5	UNSP	23	UNSP	46	**74**
EABL	8	EABL	48	EABL	38	**94**

Note: "No. of Obs." is short for Number of Observations

Table 4.6 Flyover species detected at GIRA site

Common Name	Family	Taxonomic Name	4-Letter Code	Type	Rarity	No. Obs.
Cananda goose	Anatidae	*Branta canadensis*	CANG	Native	Common	11
cattle egret	Ardeidae	*Bulbucus Ibis*	CAEG	Native	Common	40
turkey vulture	Cathartidae	*Cathartes Aura*	TUVU	Native	Common	18
killdeer	Charadriidae	*Charadrius vociferous*	KILL	Native	Common	9
Eurasian collared-dove	Columbidae	*Streptopelia decaocto*	EUCD	Non-native	Locally common, exotic	10
white-winged dove	Columbidae	*Zenaida Asiatica*	WWDO	Native	Vagrant	1
mourning dove	Columbidae	*Zenaida Macroura*	MODO	Native	Common	90
house finch	Fringillidae	*Haemorhous mexicanus*	HOFI	Non-native	Common	1
purple finch	Fringillidae	*Haemorhous purpureus*	PUFI	Native	Uncommon	1
barn swallow	Hirundinidae	*Hirundo Rustica*	BARS	Native	Common	149
red-winged blackbird	Icteridae	*Agelaius phoeniceus*	RWBL	Native	Common	95
American crow	Icteridae	*Corvus brachyrhynchos*	AMCR	Native	Common	8
blue jay	Icteridae	*Cyanocitta Cristata*	BLJA	Native	Common	2
eastern meadowlark	Icteridae	*Sturnella Magna*	EAME	Native	Uncommon-fairly common	27
unknown blackbird	Icteridae	*Varies*	UNBL	Native	Common	2
loggerhead shrike	Laniidae	*Lanius ludovicianus*	LOSH	Native	Uncommon-rare	1
northern mockingbird	Mimidae	*Mimus polyglottos*	NOMO	Native	Common	75
unknown sparrow	Emberizidae	*Varies*	UNSP	Native	Common	8
European starling	Sturnidae	*Sturnus Vulgaris*	EUST	Non-native	Common	261
Eastern bluebird	Turdidae	*Sialia Sialis*	EABL	Native	Fairly common	35
American robin	Turdidae	*Turdus migratorius*	AMRO	Native	Common	36
eastern kingbird	Tyrannidae	*Tyrannus Tyrannus*	EAKI	Native	Common	1
unknown bird	Aves	*Varies*	UNBI			558
					Total	**1439**

Note: *No. Obs.* is shorthand for Number of Observations

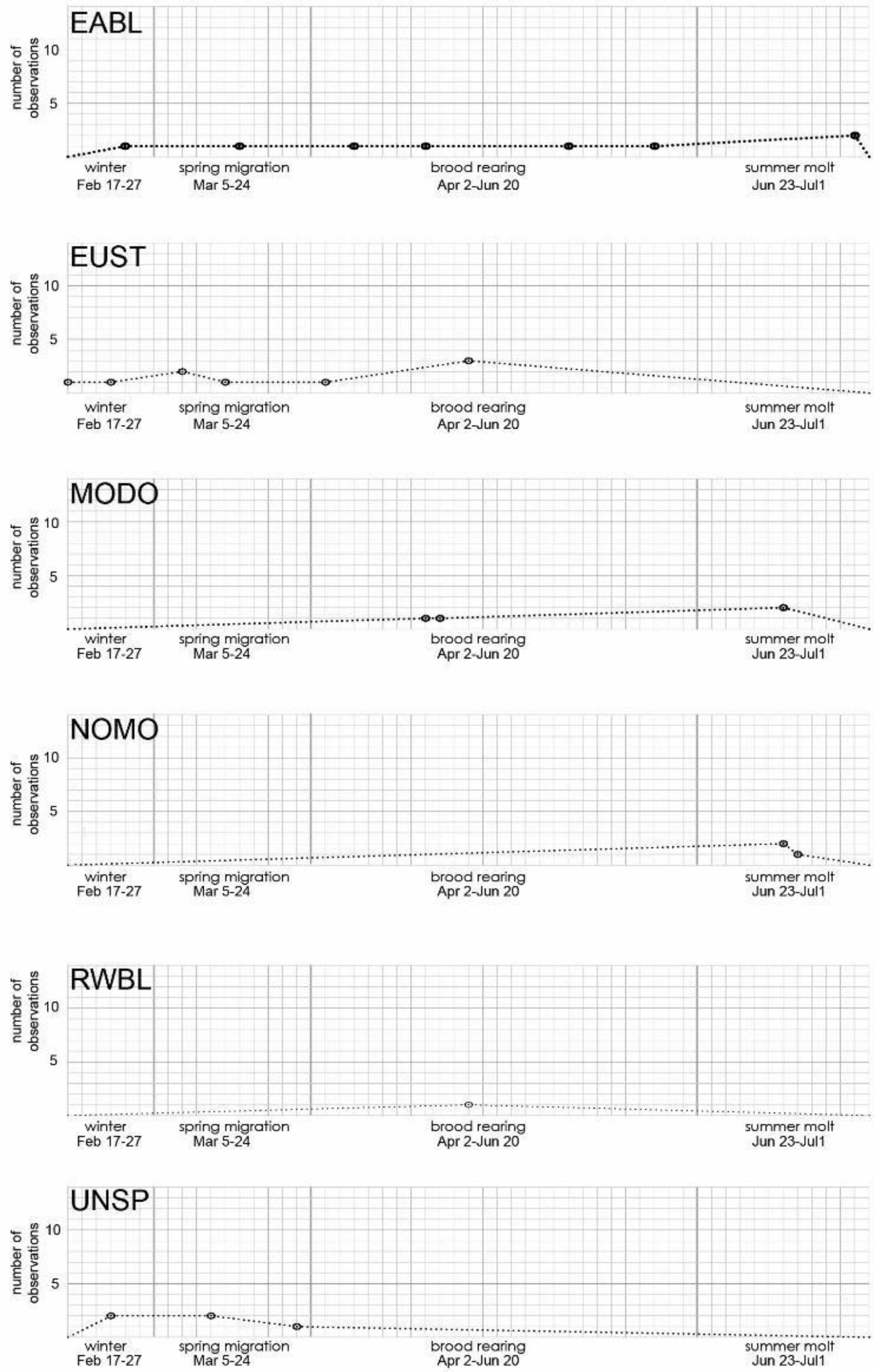

Figure 4.1 Graph of common species visits on control roofs at GIRA from February 17-August 1

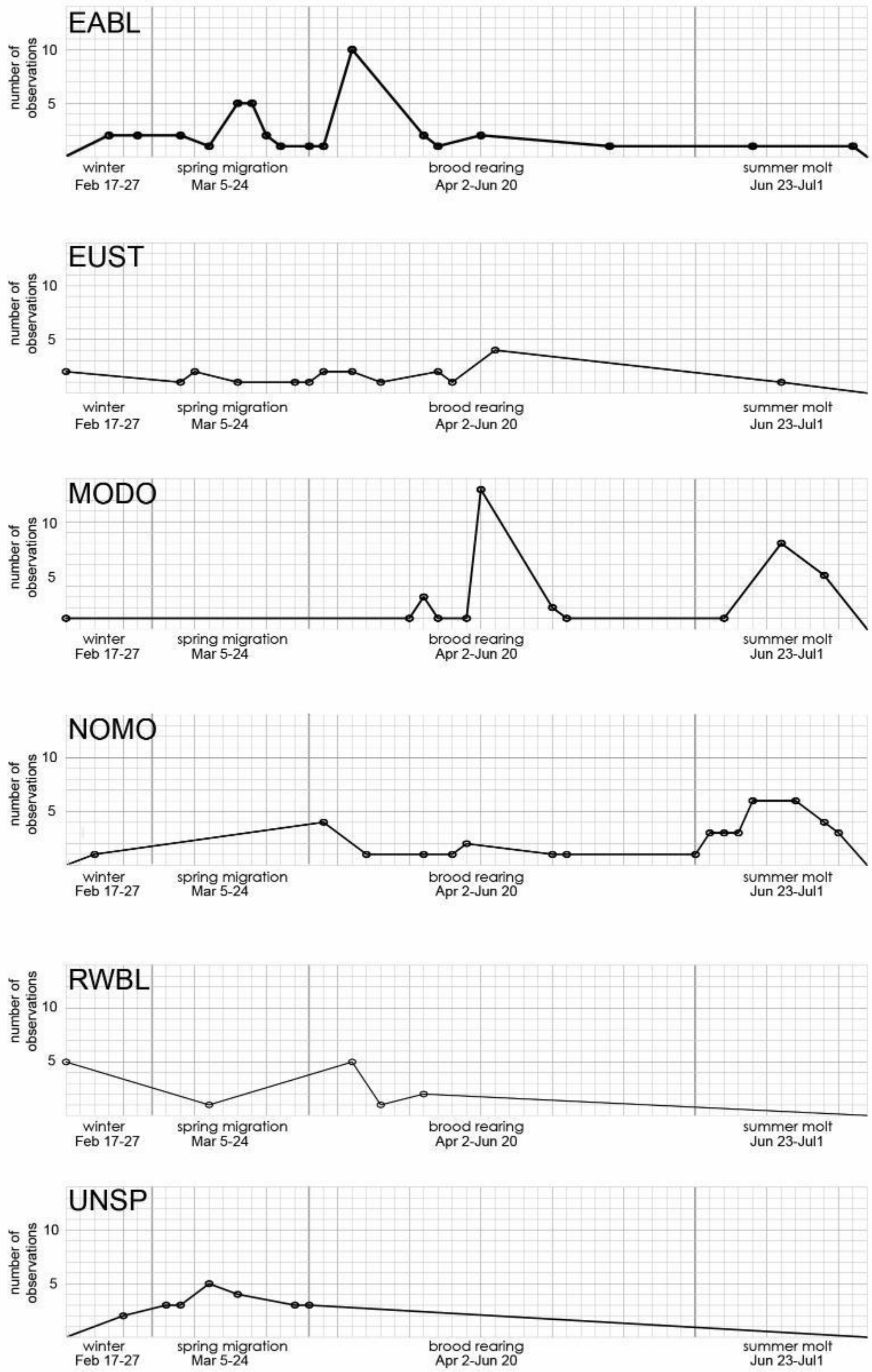

Figure 4.2 Graph of common species visits on *Sedum* roofs at GIRA from February 17-August 1

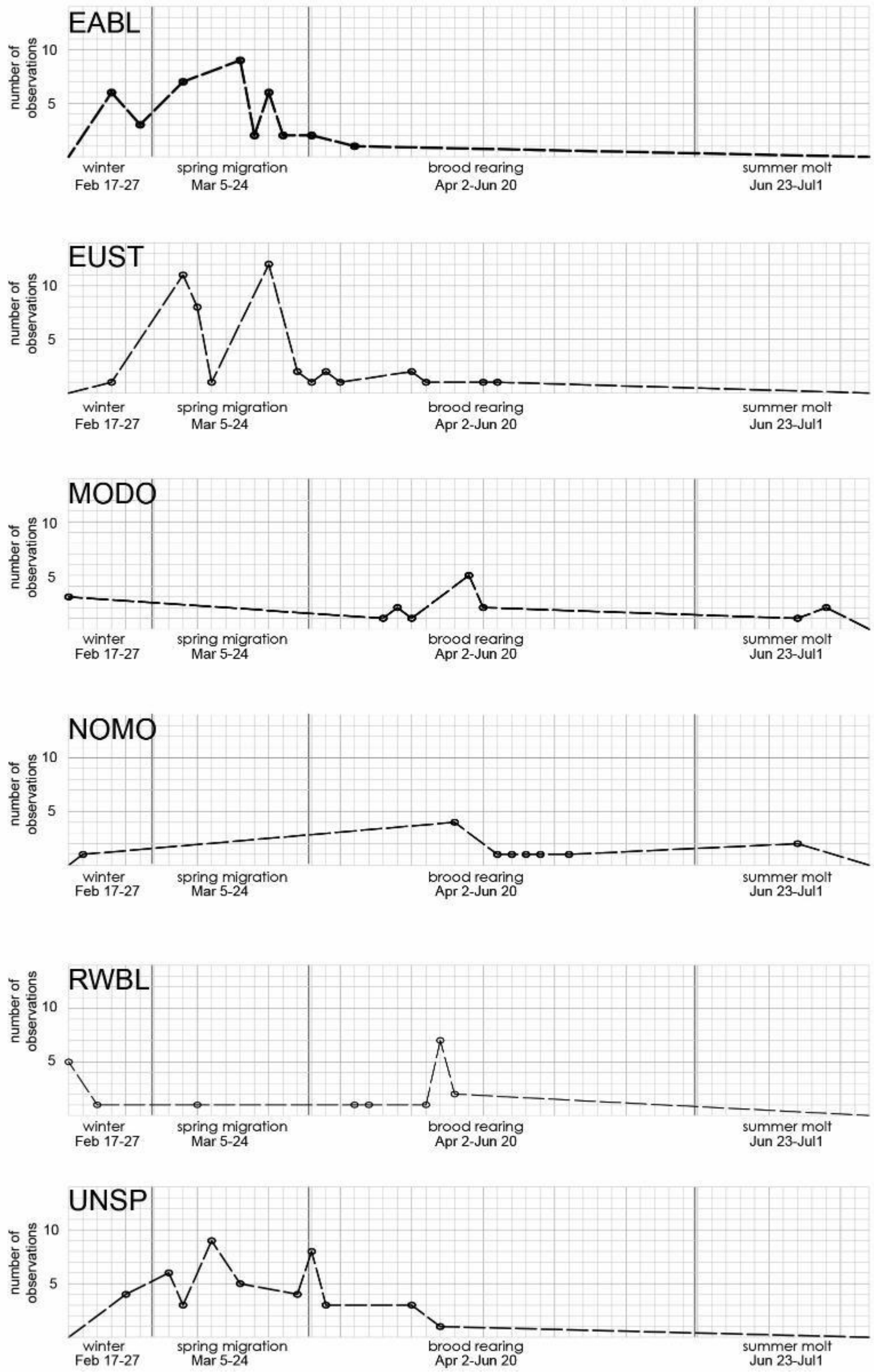

Figure 4.3 Graph of common species on prairie roofs at GIRA from February 17-August 1

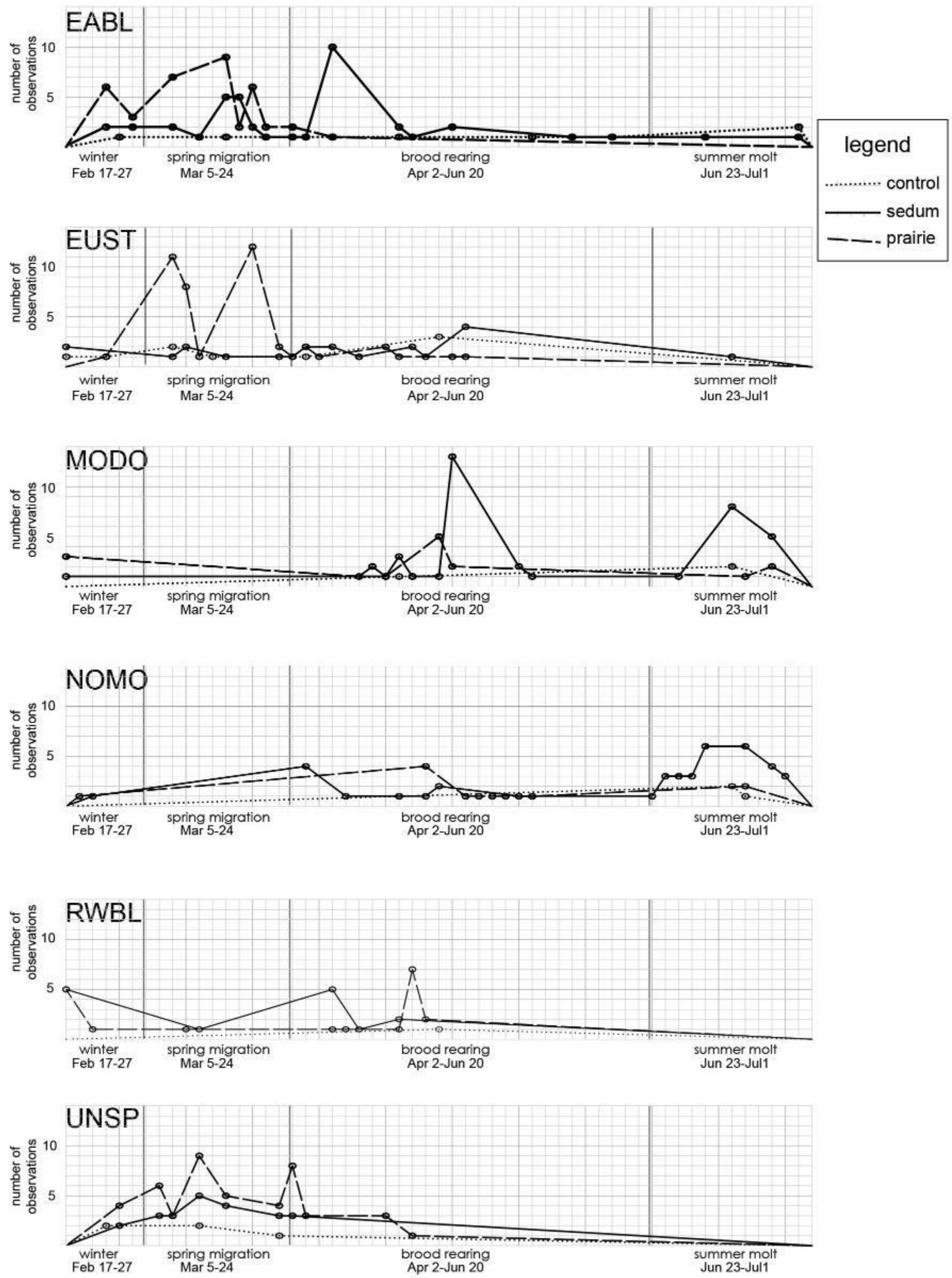

Figure 4.4 Graph of overall roof use by common species at GIRA from February 17-August 1

Figure 4.5 Control roofs 1-6 are all covered with traditional impervious building materials.

The waterproofing layer on roofs 1-3 (2% slope) is Sopralene FLAM180 and FLAM 180 GR (Arnold, 2011). Roofs 4-6 are covered with conventional asphalt shingles.

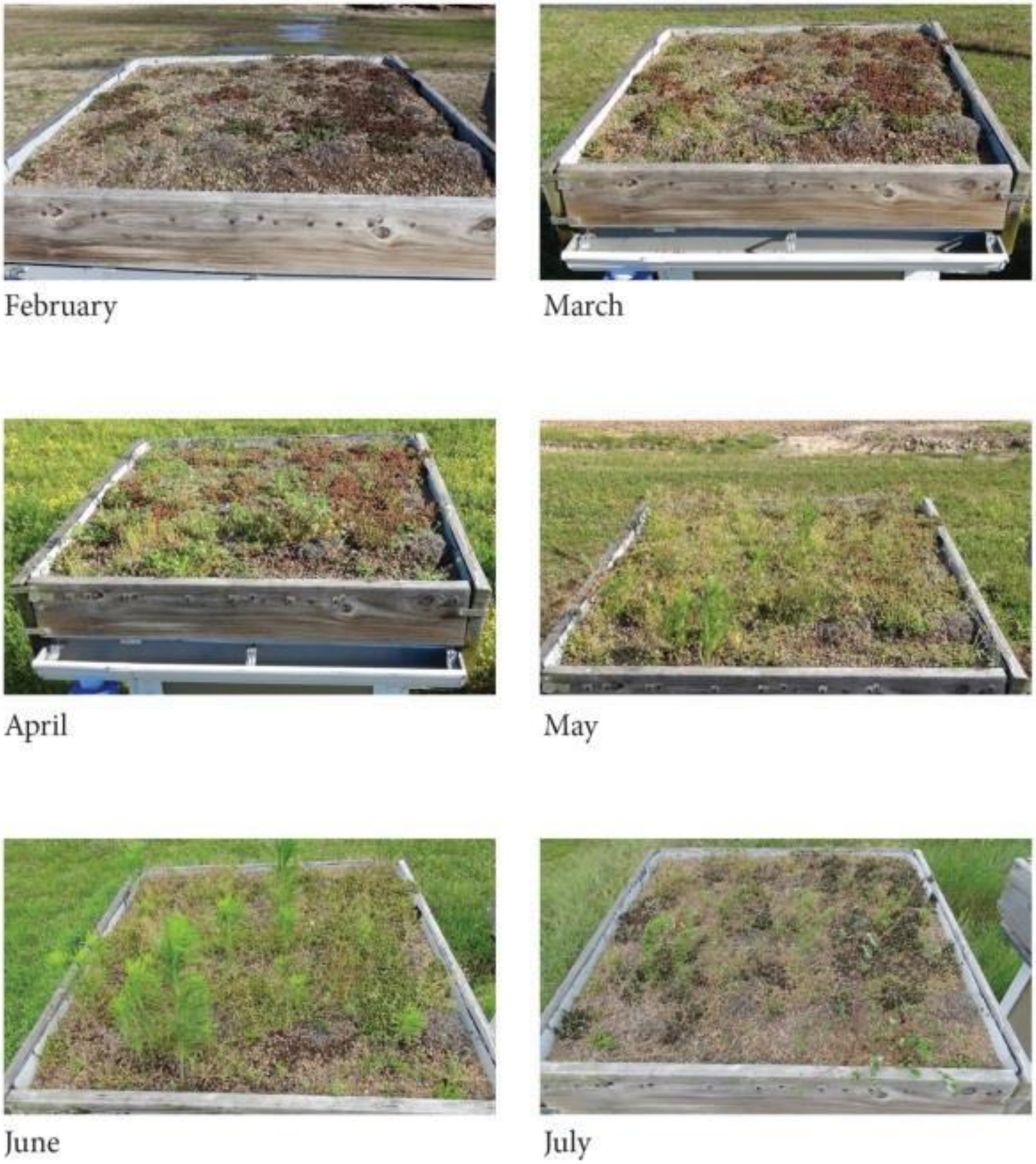

Figure 4.6 Monthly vegetative progression on *Sedum* roof 7

Note: slope: 2%, substrate depth: 15.26 cm (6 in), dominant plant community: *Sedum* spp.

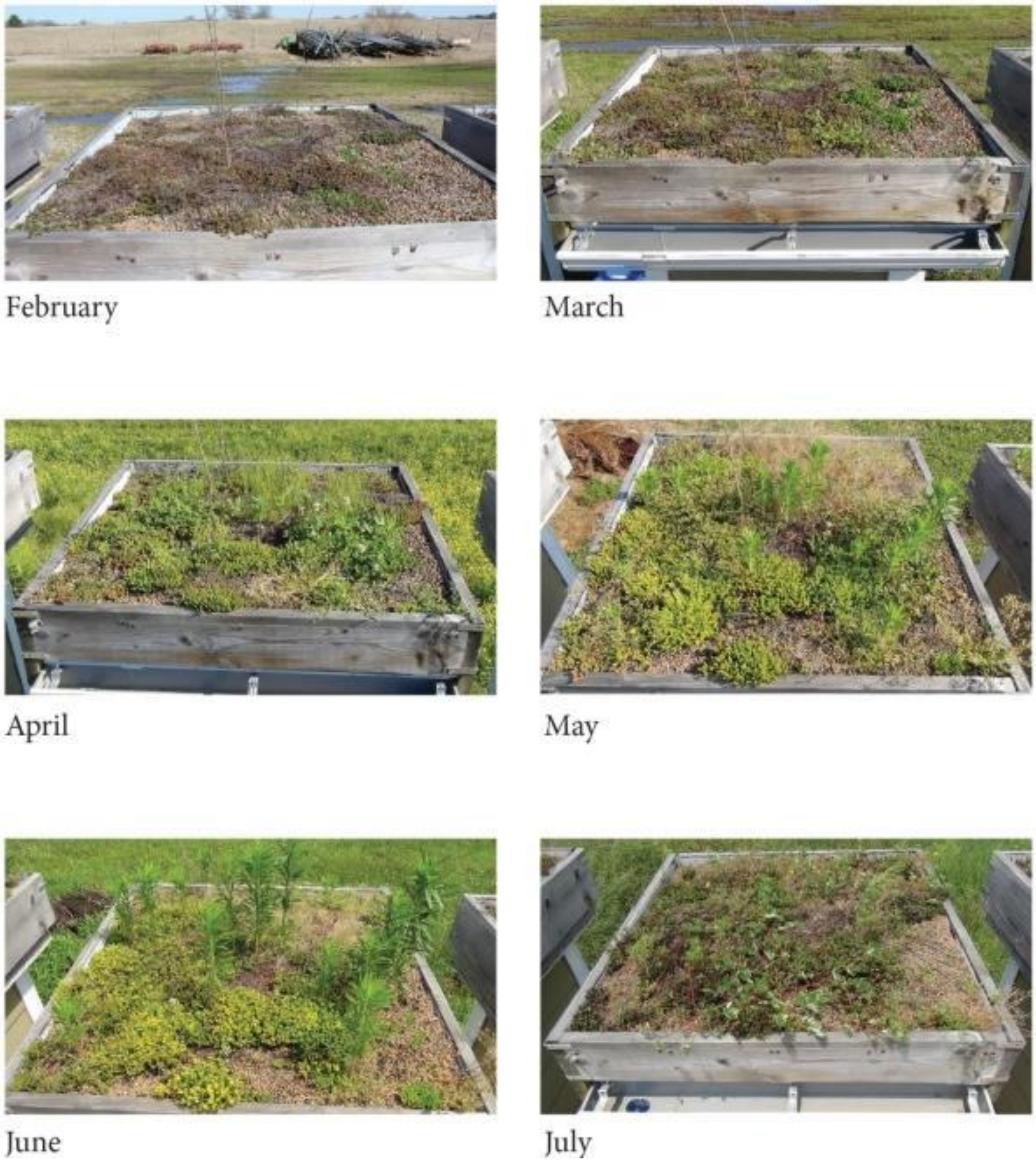

Figure 4.7 Monthly vegetative progression on *Sedum* roof 8

Note: slope: 2%, substrate depth: 15.26 cm (6 in), dominant plant community: *Sedum* spp.

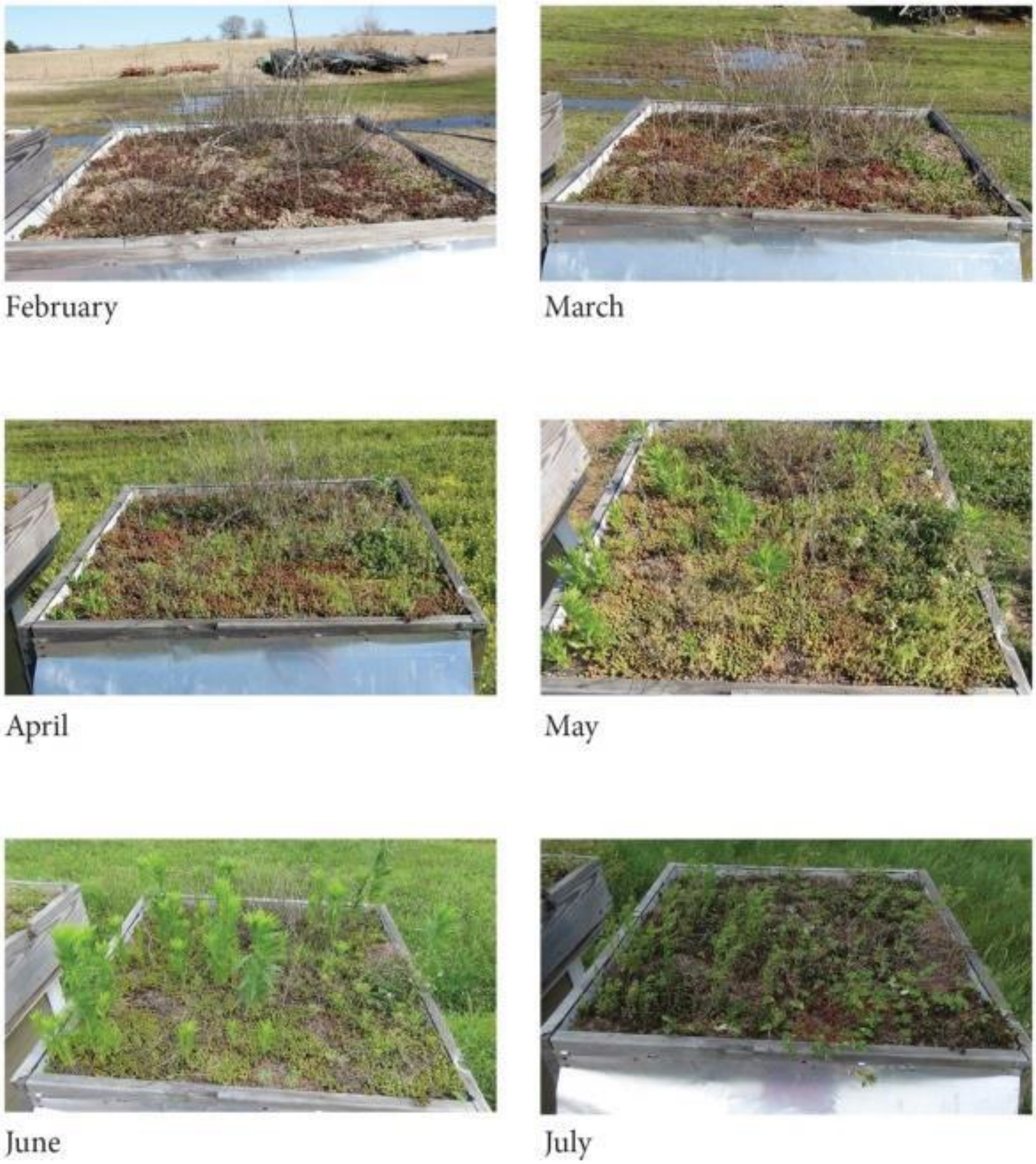

Figure 4.8 Monthly vegetative progression on *Sedum* roof 9

Note: slope: 2%, substrate depth: 15.26 cm (6 in), sominant plant community: *Sedum* spp.

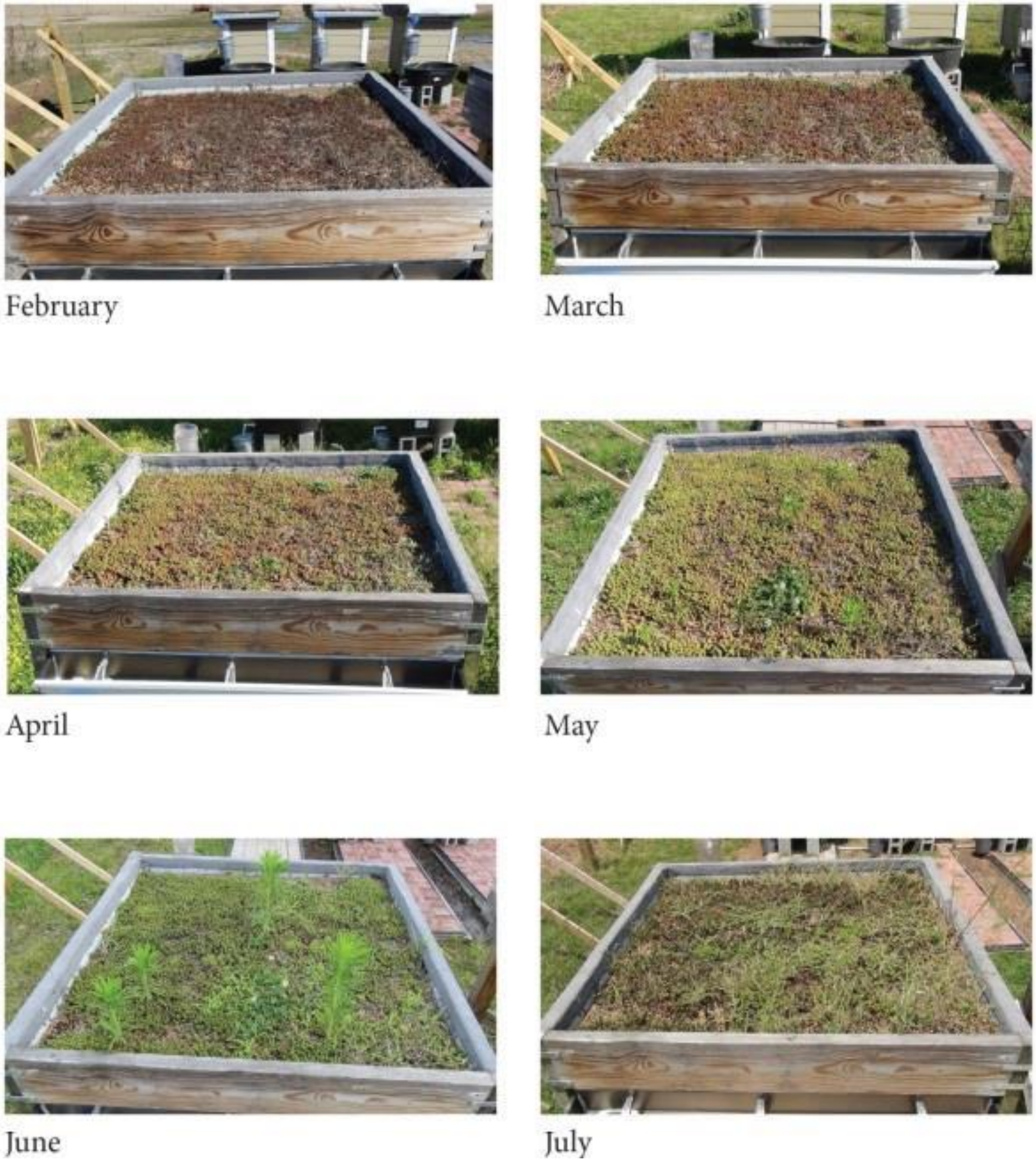

Figure 4.9 Monthly vegetative progression on *Sedum* roof 10

Note: slope: 2%, substrate depth: 10.16 cm (4 in), dominant plant community: *Sedum* spp.

Figure 4.10 Monthly vegetative progression on *Sedum* roof 11

Note: slope: 2%, substrate depth: 10.16 cm (4 in), dominant plant community: *Sedum* spp.

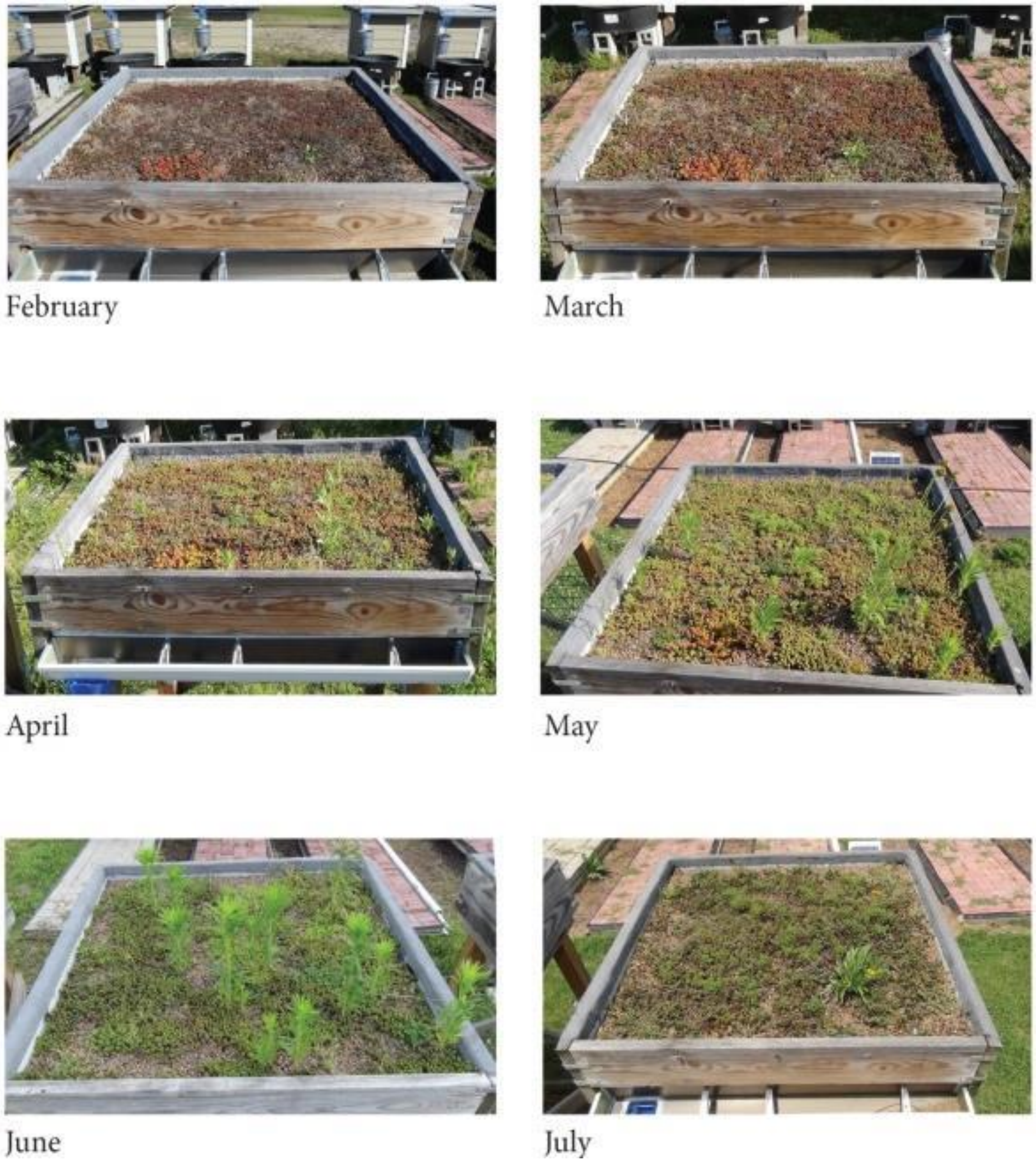

Figure 4.11 Monthly vegetative progression on *Sedum* roof 12

Note: slope: 2%, substrate depth: 10.16 cm (4 in), dominant plant community: *Sedum* spp.

Figure 4.12 Monthly vegetative progression on *Sedum* roof 13

Note: slope: 33%, substrate depth 15.26 cm (6 in), dominant plant community *Sedum* spp.

Figure 4.13 Monthly vegetative progression on *Sedum* roof 14

Note: slope: 33%, substrate depth 15.26 cm (6 in), dominant plant community: *Sedum* spp.

Figure 4.14 Monthly vegetative progression on *Sedum* roof 15

Note: slope: 33%, substrate depth 15.26 cm (6 in), dominant plant community: *Sedum* spp.

Figure 4.15 Monthly vegetative progression on *Sedum* roof 16

Note: slope: 33%, substrate depth: 10.16 cm (4 in), dominant plant community: *Sedum* spp.

Figure 4.16 Monthly vegetative progression on *Sedum* roof 17

Note: slope: 33%, substrate depth: 10.16 cm (4 in), dominant plant community: *Sedum* spp.

Figure 4.17 Monthly vegetative progression on prairie roof 18

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie

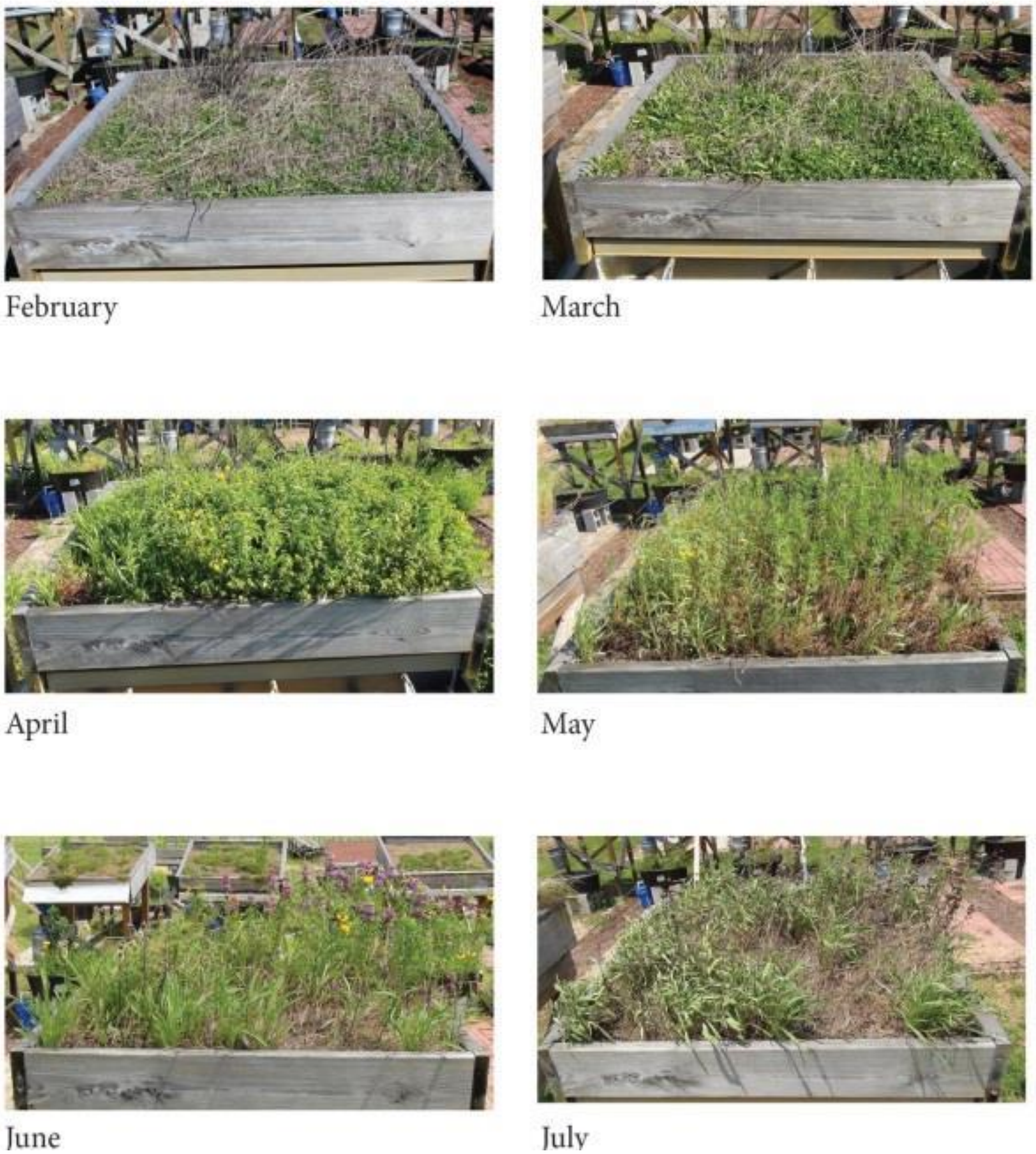

Figure 4.18 Monthly vegetative progression on prairie roof 19

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie

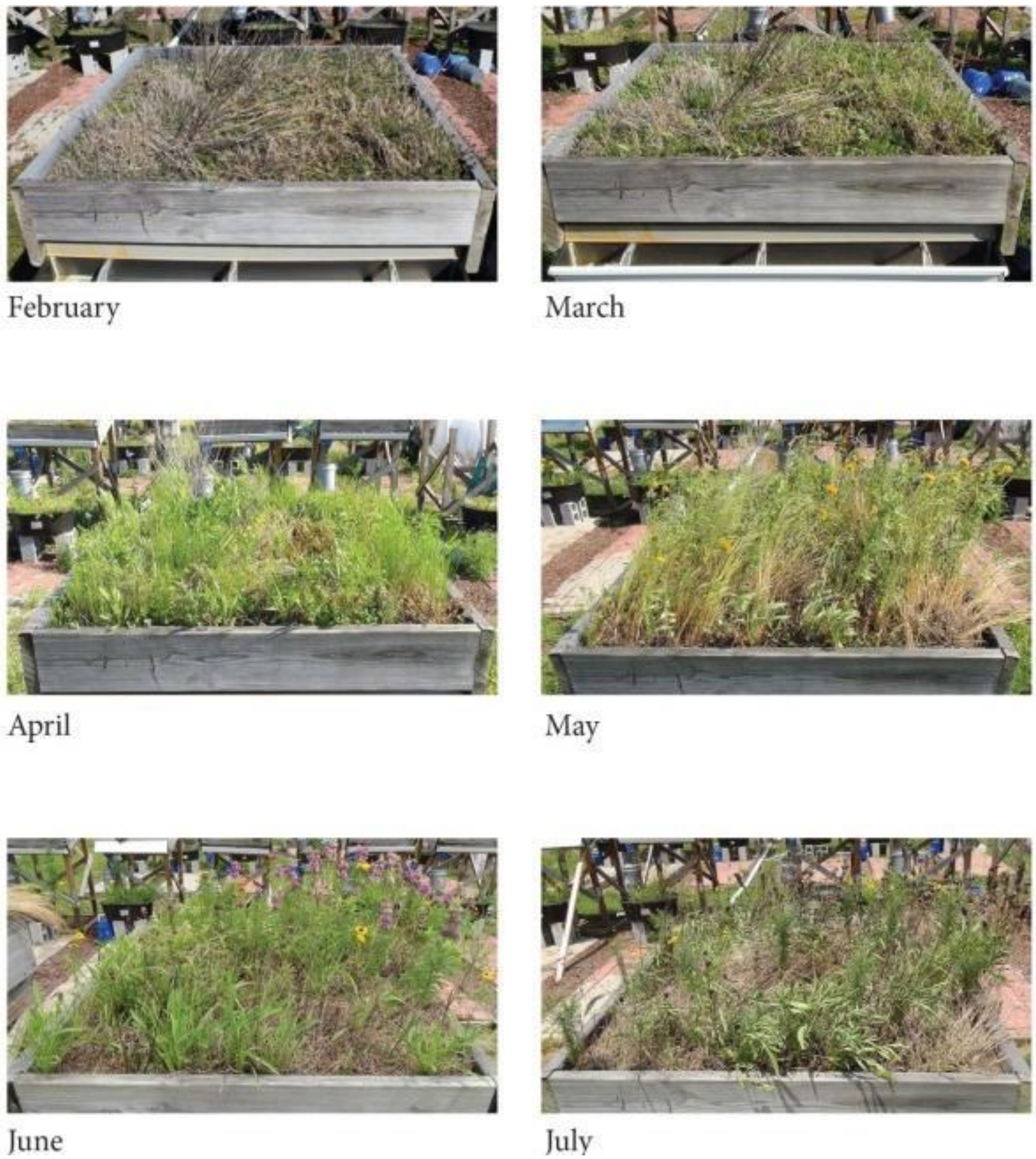

Figure 4.19 Monthly vegetative progression on prairie roof 20

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie

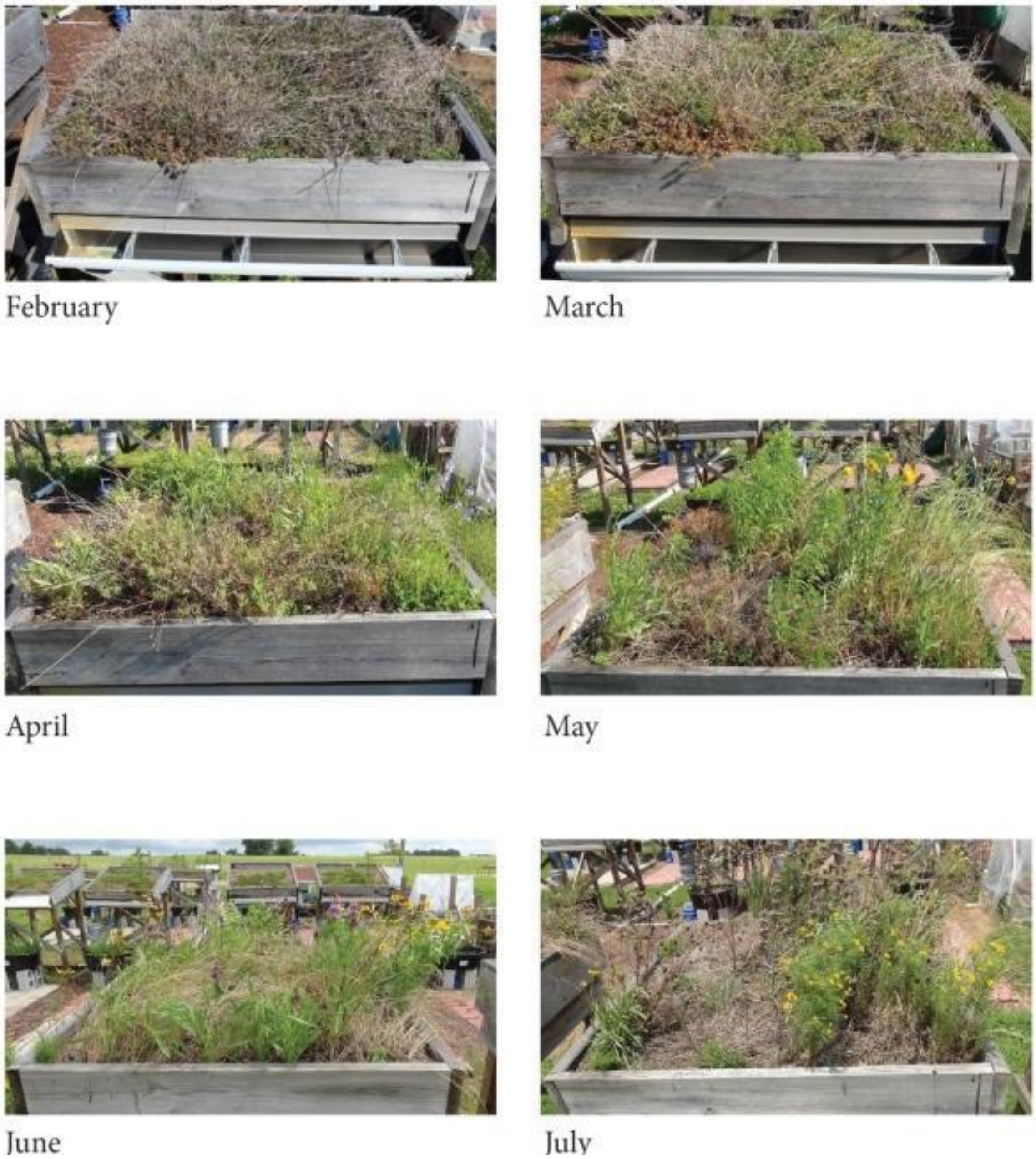

Figure 4.20 Monthly vegetative progression on prairie roof 21

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie

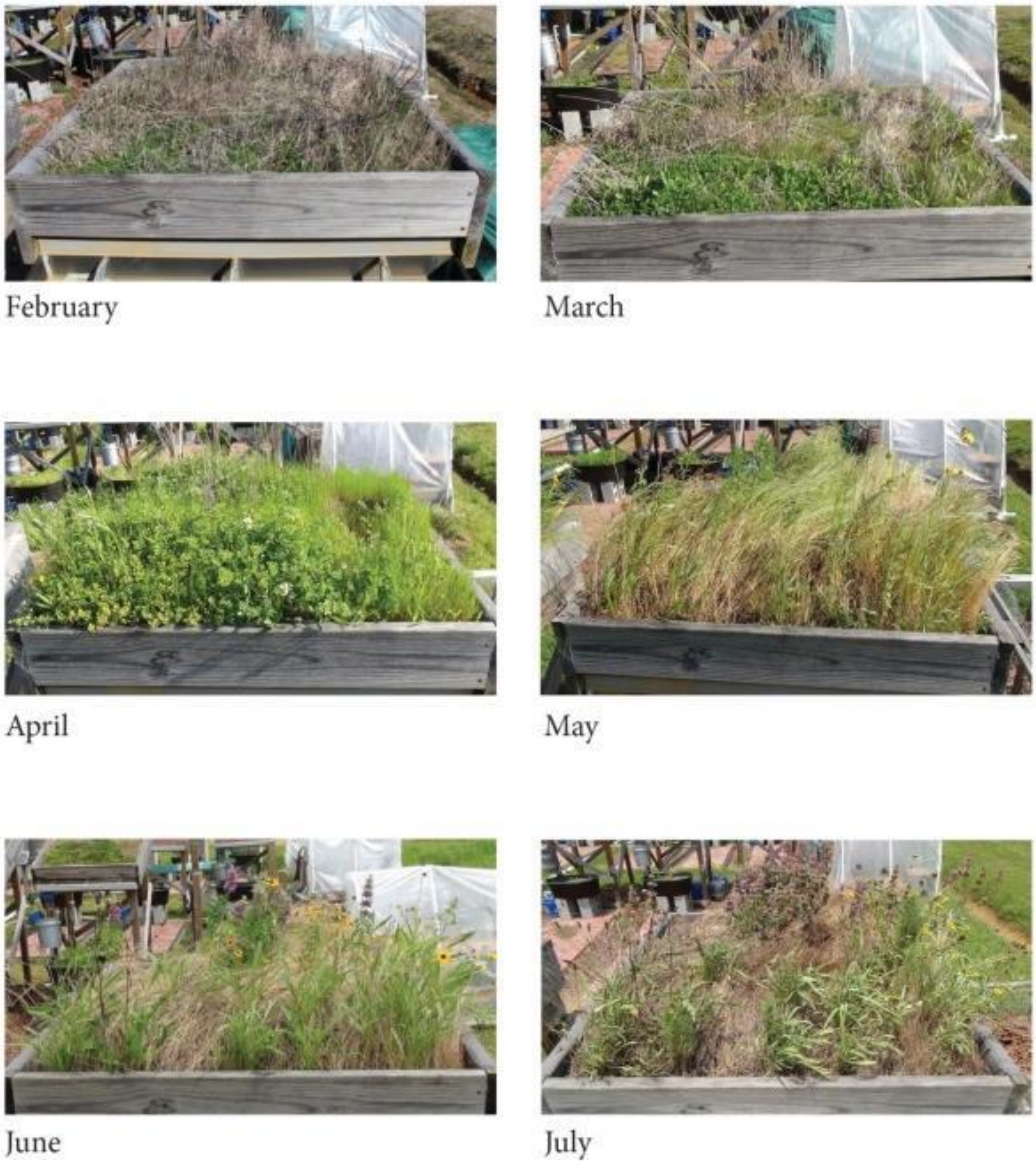

Figure 4.21 Monthly vegetative progression on prairie roof 22

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie

Figure 4.22 Monthly vegetative progression on prairie roof 23

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie, substrate mix addition: 11% by weight local prairie soils

Figure 4.23 Monthly vegetative progression on prairie roof 24

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie, substrate mix addition: 11% by weight local prairie soils

Figure 4.24 Monthly vegetative progression on prairie roof 25

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie, substrate mix addition: 11% by weight local prairie soils

Figure 4.25 Monthly vegetative progression on prairie roof 26

Notes: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie, substrate mix addition: 11% by weight local prairie soils

Figure 4.26 Monthly vegetative progression on prairie roof 27

Note: slope: 2%, substrate depth: 15.26 cm (4 in), dominant plant community: Blackland Prairie, substrate mix addition: 11% by weight local prairie soils

Site 2: Oktibbeha County Heritage Museum

A total of one hundred and twenty-four observations sessions were completed during thirty-one site visits between February 25th and July 29th, 2014. A total of six hundred and thirty-six birds were observed on the roof or flying directly above it. The twenty-nine birds observed physically on the roof consist of only four species. The bird observations represented four families and all visiting birds were positively identified. The species detected on the roof include the NOMO, EUST, *Haemorhous mexicanus* (HOFI), and AMRO (Table 4.7). The native to non-native ratio was 2:2 and all species observed are considered common (Peterson, 2010).

Table 4.7 Species detected on the OCHM roof

Common Name	**Family**	**Taxonomic Name**	**4-Letter Code**	**Type**	**Rarity**	**No. Obs.**
house finch	Fringillidae	*Haemorhous mexicanus*	HOFI	Non-native	Common	4
northern mockingbird	Mimidae	*Mimus polyglottos*	NOMO	Native	Common	23
European starling	Sturnidae	*Sturnus vulgaris*	EUST	Non-native	Common	1
American robin	Turdidae	*Turdus migratorius*	AMRO	Native	Common	1
					Total	**29**

Note: *No. Obs.* is shorthand for Number of Observations.

Flyover birds represent 607 of the observed individuals counted. The positive identification of nineteen individual species was confirmed. As with observations at GIRA, blackbirds and sparrows were generalized at the family level. Flyover species represent fourteen families and had as many as one hundred and two (16.8%) unknown individuals counted (UNBI). Common flyover species include MODO, BARS, *Cyanocitta cristata* (BLJA), NOMO, *Melanerpes erythrocephalus* (RHWP), EUST, and the AMRO. The native to non-native ratio was 4:17 with rarity ranging from common to exotic (Table 4.8).

Table 4.8 Flyover species detected at the OCHM site

Common name	**Family**	**Scientific Name**	**4-Letter Code**	**Type**	**Rarity**	**No. Obs.**
Mississippi kite	Accipitridae	*Ictinia mississippiensis*	MIKI	Native	Fairly common	1
chimney swift	Apodidae	*Chaetura pelagica*	CHSW	Native	Fairly common	6
cattle egret	Ardeidae	*Bulbucus ibis*	CAEG	Native	Uncommon-common	16
northern cardinal	Cardinalidae	*Cardinalis cardinalis*	NOCA	Native	Common	9
mourning dove	Columbidae	*Zenaida macroura*	MODO	Native	Common	27
Eurasian collared-dove	Columbidae	*Streptopelia decaocto*	EUCD	Non-native	Locally common, exotic	7
house finch	Fringillidae	*Haemorhous mexicanus*	HOFI	Non-native	Common	8
purple finch	Fringillidae	*Haemorhous purpureus*	PUFI	Native	Uncommon	2
barn swallow	Hirundinidae	*Hirundo rustica*	BARS	Native	Common	28
blue jay	Icteridae	*Cyanocitta cristata*	BLJA	Native	Common	39
unknown blackbird	Icteridae	*varies*	UNBL	Native	Common	208
northern mockingbird	Mimidae	*Mimus polyglottos*	NOMO	Native	Common	55
brown thrasher	Mimidae	*Toxostoma rufum*	BRTH	Native	Uncommon-fairly common	1
Carolina chickadee	Paridae	*Poecile carolinmmonensis*	CACH	Native	Common	1
house sparrow	Passeridae	*Passer domesticus*	HOSP	Non-native	Common	1
unknown sparrow	Emberizidae	*varies*	UNSP	Native	Common	7
red-headed woodpecker	Picidae	*Melanerpes erythrocephalus*	RHWO	Native	Uncommon	20
northern flicker "yellow shafted"	Picidae	*Colaptes auratus*	NOFL	Native	Common	2
red-bellied woodpecker	Picidae	*Melanerpes carolinus*	RBWO	Native	Common	2
European starling	Sturnidae	*Sturnus vulgaris*	EUST	Non-native	Common	27
American robin	Turdidae	*Turdus migratorius*	AMRO	Native	Common	36
unknown bird	Aves	*varies*	UNBI			102
					Total	605

Note: *No. Obs.* is shorthand for Number of Observations.

Photographic representation of the site can be found in Figures 4.27-4.38. Again, this study does not attempt to measure or quantify the vegetative cover in the OCHM roof. Instead, this photographic representation was offered as a supplemental component to help ground the study in context. Figure 4.27 shows the extensive roof just after the plugs were planted and the path was established. Figure 4.28 shows the condition of the OCHM roof two months after planting where the small plants were still small, but surviving. In the first year, the plants had a very attractive bloom (Figure 4.29). Figures 4.30-4.38 captured the progression of the vegetation in the roof from February to May and in July. And although this was not a plant study, it was hard not to notice how well *Sedum kamtschaticum* appeared to perform over the duration of the photographic period during the roof's second year of growth. The conspicuous, bright green, mounding *Sedum* can be observed in every image. In Figures 4.31 and 4.33, the two locations where the tripod was set up can be seen. And following the photographic documentation, a comparison of both the OCHM and GIRA site data, can be found in Table 4.9 at the end of the section.

Figure 4.27 View of freshly planted plugs, December 2012

Note: The fresh plugs on the green roof were spaced several inches apart with a narrow path which created a ring in the center of the planting area. Image courtesy of Cory Gallo

Figure 4.28 Detail of assorted plantings, February 2013

Note: Plugs were spaced so they would be allowed to mix and mingle. Since the original planting date, *Sedum* sprouts have been transplanted from the path back into bald spots in the planting area. Image courtesy of Cory Gallo.

Figure 4.29 Detail of the original plant assembly during its first year, May 2013

Note: When this image was captured, plantings were in their first growth year and the rooftop had not yet been stressed by extreme heat or drought conditions. Image courtesy of Bill Poe.

Figure 4.30 View facing northeast on OCHM green roof, February 2014

Note: The harsh winter caused many plants to die back from the previous year.

Figure 4.31 View facing east on OCHM green roof, February 2014

Note: The original placement for the video camera was in the southeastern corner of the roof. Note the tripod in the upper right hand corner of the image.

Figure 4.32 View facing northeast on OCHM green roof, March 2014

Note: In March, the vegetation began to improve and expand. Especially the *Sedum kamtschaticum* (vibrant green), which appeared to return with vigor and the species' expansion on the rooftop was hard to miss.

Figure 4.33 View facing north on OCHM green roof, March 2014

Note: The tripod position which granted the best view can be seen in the northeast corner of the roof in the image above. Notice the vertical shape in the right corner of the roof.

Figure 4.34 View facing northeast on OCHM green roof, April 2014

Note: By April, the vegetation had improved, increasing in size and appearing greener in color. Some lavender-colored flowers can be seen blooming in the right side of the image above.

Figure 4.35 View facing north on OCHM green roof, April 2014

Note: The advance of spring has brought the entire neighborhood to life. Crape myrtles drop their progeny into the roof, so saplings must be managed for diligently or else their roots may penetrate drainage or waterproofing layers below the substrate.

Figure 4.36 View facing southeast on OCHM green roof, April 2014

Note: Often the pavilion is used for public events so the roof top may often be utilized by humans. Note the extension cord in the right hand side of the image.

Figure 4.37 View facing north on OCHM green roof, May 2014

Note: Last year's growth was allowed to remain on the roof well into the spring and summer. Blooms emerged and stems branched out from dry, old twigs.

Figure 4.38 View facing northeast on OCHM green roof, July 2014

Note: The vegetation has suffered some from the local drought, but in general seemed to stand up well to the seasonal stress.

Table 4.9 Side by side comparison of GIRA and OCHM species data

Common Name	Family	Taxonomic Name	4-Letter Code	type	rarity	O.C.H.M. FO	O.C.H.M. OR	O.C.H.M. total	G.I.R.A. FO	G.I.R.A. OR	G.I.R.A. total	grand total
unknown bird	Aves	*Varies*	UNBI			102		**102**	558	17	**575**	**877**
European starling	Sturnidae	*Sturnus vulgaris*	EUST	non-native	common	27	1	**28**	261	73	**334**	**362**
northern mockingbird	Mimidae	*Mimus polyglottos*	NOMO	native	common	55	23	**78**	75	60	**135**	**213**
barn swallow	Hirundinidae	*Hirundo rustica*	BARS	native	common	28		**28**	149	1	**150**	**178**
mourning dove	Columbidae	*Zenaida macroura*	MODO	native	common	27		**27**	90	57	**147**	**174**
red-winged blackbird	Icteridae	*Agelaius phoeniceus*	RWBL	native	common				95	34	**129**	**129**
eastern bluebird	Turdidae	*Sialia sialis*	EABL	native	fairly common				35	87	**122**	**122**
unknown sparrow	Emberizidae	*varies*	UNSP	native	common	7		**7**	8	63	**75**	**82**
American robin	Turdidae	*Turdus migratorius*	AMRO	native	common	36	1	**37**	36	3	**39**	**76**
cattle egret	Ardeidae	*Bubulcus ibis*	CAEG	native	uncommon-common	16		**16**	40	1	**41**	**57**
blue jay	Icteridae	*Cyanocitta cristata*	BLJA	native	common	39		**39**	2		**2**	**41**
eastern meadowlark	Icteridae	*Sturnella magna*	EAME	native	uncommon-fairly common				27	5	**32**	**32**
unknown blackbird	Icteridae	*varies*	UNBL	native	common	208		**208**	2	11	**13**	**21**
red-headed woodpecker	Picidae	*Melanerpes erythrocephalus*	RHWO	native	uncommon	20		**20**				**20**
turkey vulture	Cathartidae	*Cathartes aura*	TUVU	native	common				18		**18**	**18**
house finch	Fringillidae	*Haemorhous mexicanus*	HOFI	non-native	common	8	4	**12**	1	4	**5**	**17**
Eurasian collared-dove	Columbidae	*Streptopelia decaocto*	EUCD	non-native	locally common, exotic	7		**7**	10	1	**11**	**18**
purple finch	Fringillidae	*Haemorhous purpureus*	PUFI	native	uncommon	2		**2**	1	12	**13**	**15**

Table 4.9 (continued)

Canada goose	Anatidae	*Branta canadensis*	CANG	native	common				11		**11**	**11**
kildeer	Charadriidae	*Charadrius vociferus*	KILL	native	common				9		**9**	**9**
northern cardinal	Cardinalidae	*Cardinalis cardinalis*	NOCA	native	common	9		**9**				**9**
American crow	Icteridae	*Corvus brachyrhynchos*	AMCR	native	common				8		**8**	**8**
chimney swift	Apodidae	*Chaetura pelagica*	CHSW	native	fairly common	6		**6**				**6**
white-winged dove	Columbidae	*Zenaida asiatica*	WWDO	native	vagrant				1	4	**5**	**5**
indigo bunting	Cardinalidae	*Passerina cyanea*	INBU	native	common					2	**2**	**2**
northern flicker "yellow shafted"	Picidae	*Colaptes auratus*	NOFL	native	common	2		**2**				**2**
red-bellied woodpecker	Picidae	*Melanerpes carolinus*	RBWO	native	common	2		**2**				**2**
brown thrasher	Mimidae	*Toxostoma rufum*	BRTH	native	uncommon-fairly common	1		**1**				**1**
Carolina chickadee	Paridae	*Poecile carolinensis*	CACH	native	common	1		**1**				**1**
eastern kingbird	Tyrannidae	*Tyrannus tyrannus*	EAKI	native	common				1		**1**	**1**
house sparrow	Passeridae	*Passer domesticus*	HOSP	non-native	common	1		**1**				**1**
loggerhead shrike	Laniidae	*Lanius ludovicianus*	LOSH	native	uncommon-rare				1		**1**	**1**
Mississippi kite	Accipitridae	*Ictinia mississippiensis*	MIKI	native	fairly common	1		**1**				**1**
						605	29	**634**	1439	435	**1878**	**2512**
						FO	**OR**	**total**	**FO**	**OR**	**total**	**Grand Total**
						O.C.H.M.			**G.I.R.A.**			

Note: "FO" refers to observed flyovers, "OR" refers to observations of birds on roofs.

Statistical Analysis

Prior to analysis, seasonal breaks were defined by identifying natural breaks in the raw data. These breaks were often caused by weather prohibiting observation, which created a literal break in the data; but some breaks were defined by locating a low point in the numbers. Because of natural variation, the seasons were not intended to be "accurate" per se, but more or less descriptive of what was observed happening at GIRA. The seasons were defined as winter (February 17-24), spring migration (March 5-24), brood rearing (April 2- June 20), and summer molt (June 23-August 1). The names for each season were selected based on which avian life cycle season could be roughly associated with the defined time periods in the data. Defining the data in this way was done to make the data both descriptive and manageable.

This study originally sought to determine whether there was a statistical difference between green roof vegetative cover class with respect to mean number of birds landing on the roofs at GIRA. To address this question, an analysis of variance (ANOVA) test of the mean data for each roof type was conducted. The ANOVA indicated there was a difference in the mean between the three roof classes, so it was decided to conduct a linear contrasts test. The linear contrasts compared all three roof type's means against each other and simultaneously compared the *Sedum* vs prairie, control vs *Sedum*, and control vs prairie roof types, which produced comparable mean square and P-values. Using these values, the source of variance was located. In the linear contrasts test, one null hypothesis was accepted and three were not, so a multiple comparisons test was conducted. The steps used to perfrom the ANOVA, linear contrasts, and multiple comparisons analyses in SAS are detailed in the following sections.

Analysis of Variance

Mean bird visits for each roof class were modeled in an analysis of variance (ANOVA). The code used in SAS was Proc GLM because this case was unbalanced as the number of roof treatments varied with six of the control type, ten of the prairie type, and eleven of the *Sedum* type. The null hypothesis tested by this model states the mean number of bird visits for the three roof types was the same. The binomial data input into SAS paired roof class and mean number of birds observed on the vegetative roof types (Table 4.10).

Table 4.10 Mean data input

Roof Number	Roof Class	Mean Number of Birds
1	C	2
2	C	2
3	C	2
4	C	12
5	C	7
6	C	6
7	S	33
8	S	11
9	S	10
10	S	11
11	S	6
12	S	16
13	S	36
14	S	19
15	S	32
16	S	15
17	S	35
18	P	27
19	P	16
20	P	15
21	P	6
22	P	19
23	P	33
24	P	21
25	P	11
26	P	12
27	P	19

Note: The binomial input into SAS was: roof class, mean number of birds. Roof number refers to the arbitrary roof number assigned to each test roof for this study. Roof class refers to cover class: "C" for control, "S" for *Sedum*, and "P" for prairie. The mean number of birds value refers to the mean value computed for each individual test roof.

The Treatment Summary Table Output from SAS (Table 4.11) was used to produce the ANOVA table (Table 4.12). The model testing the one-way ANOVA for mean bird visits by roof class assumed the mean for each roof class was the same. The analysis of variance rejected the hypothesis, which meant there was a significant difference between roof types with respect to mean number of birds that landed. Comparing the P-value against the 0.05 significance level informs the result, where 0.0083 < 0.05, thereby confirming the decision to reject the null hypothesis. Because of this finding, further analysis was conducted to determine the source of this variance.

Table 4.11 Treatment summary

Roof Class	Number of Roofs in Each Class	Sum of Total Bird Visits	Mean	Corrected SS	Standard Deviation
Control	6	31	5.1666667	80.833333	4.0220779
Prairie	10	179	17.9	558.9	7.8803553
Sedum	11	224	20.363636	1292.55	11.369017

Note: Analysis variable for treatment summary table was mean number of roof visits.

Table 4.12 One-way ANOVA for mean bird visits by roof class

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	949.573064	474.78653	5.9	0.0083
Error	24	1932.27879	80.511616		
Corrected Total	26	2881.85185			

The one-way ANOVA run on the data was a Type III SS and corresponding F-test Generating a P-value of .0083, the F-test rejected the null hypothesis which stated there would be no differences in mean number of birds visiting each roof class. The test concludes that at least two of the roof types are different from the other types with respect to mean number of birds landing on the roofs (MSU Statistical Counseling Center).

Linear Contrasts

Because a difference was detected, the linear contrasts test was employed. Linear contrasts help locate source of variance by comparison of means. The linear contrasts was composed of 4 models which test a series of hypotheses to determine whether there was a significant difference between each of the roof classes observed in the study. Model 1 tested whether there was a significant difference between the control roofs and the *Sedum* and prairie roofs (C vs S & P) on average. The null hypothesis used for the first model states there is no difference between the three roof classifications. Models 2, 3, and 4 tested for a significant difference between two of the three roof classes as follows: model 2: *Sedum* vs prairie (S vs P), model 3: control vs *Sedum* (C vs S), and model 4: control vs prairie (C vs P); the corresponding null hypotheses state there was no significant difference between each association (Table 4.13).

Table 4.13 Linear contrasts of roof class

Model	Contrast	Mean Square	P-Value	Pr > F	Accept/Reject Hypothesis	Significant Difference
1	**C vs S & P**	909.65937	**P < 0.0083**	0.0026	Reject	Yes
2	**S vs P**	31.792641		0.5357	Accept	No
3	**C vs S**	608.01667		0.0112	Reject	Yes
4	**C vs P**	896.62121		0.0028	Reject	Yes

Note: In the Contrast column, “C” refers to control, “S” refers to *Sedum*, and “P” refers to prairie roof classes, respectively.

For each of the models, significance levels were generated and each hypothesis was either accepted or rejected. Model 1 tested the sum of the control roof mean added twice against the sum of the prairie and *Sedum* means summed together. Model 1 rejected the null hypothesis, which indicated there was a significant difference somewhere within the contrast between the three roof classes. The null hypotheses for models 3 & 4 were also rejected, which indicated a significant difference between control and *Sedum* and control and prairie roof type contrasts. The null hypothesis of model 2 was accepted, which indicates there was no significant difference between *Sedum* and prairie types with respect to mean number of birds landing. The linear contrasts suggest the control roof type is the source of the variance because it was most unlike either of the vegetated roof types. This means that in terms of mean number of birds landing on the green roofs, the control roofs were significantly different than the *Sedum* and prairie roofs, which in turn were statistically similar to each other.

Multiple Comparisons

The multiple comparisons allowed the least square means (Table 4.14) to be compared through a series of simple T-tests (Table 4.15). Comparing the least square means through multiple comparisons is one step beyond the linear contrasts and provided an understanding of the performance of the green roofs at GIRA. The *Sedum* and prairie roof type means were not significantly different from each other, but they were significantly different than the control roof type mean. This implies that neither the *Sedum* nor prairie roof type was better than the other, because their means were not statistically different. Conversely, the means of the vegetated roofs each were significantly higher than the control roof mean, which implied that vegetated roofs were significantly better than the control roofs in terms of mean number of bird visits. The test statistics for the least squares mean of each combination of treatments was used to reject the null hypothesis for the comparison of control and prairie and control and *Sedum* roof types (Table 4.16). This supported the conclusion that there was a difference between the vegetative and control roofs with respect to mean number of birds landing on them, but not a significant difference between the vegetated roof types themselves.

Table 4.14 Least squares means for each roof type

Significant Difference	Roof	Least Squares Mean	Least Squares Mean Number
No	S	20.36364	3
No	P	17.9	2
Yes	C	5.166667	1

Note: "S" refers to *Sedum*, "P" refers to prairie, and "C" refers to control roof types. "Least Squares Mean Number" refers to the number ascribed each roof type for representation in the T-test.

Table 4.15 Least squares means

Roof	Least Squares Mean	Standard Error	Observed Significance Pr > |t|	Least Squares Mean Number
C	5.1666667	3.663141	0.1712	1
P	17.9	2.837457	<0.0001	2
S	20.363636	2.705409	<0.0001	3

Note: The α for this test was 0.05.

Table 4.16 Comparison of least squares means

	C	P	S
C	x	-2.74807	-3.33715
		0.0112	0.0028
P	2.478074	x	-0.6284
	0.0112		0.5357
S	3.337146	0.628397	x
	0.0028	0.0537	

Note: Pr> |t|. The α for this test was 0.05.

Descriptive Data Overview and Analysis

This section describes the GIRA site first, followed by the OCHM site. For the GIRA site, each season is described in terms of which birds landed, what behaviors they exhibited, and what flyover species were observed during each of the seasons. For the OCHM site, so few observations were obtained that the data will be presented in one general discussion which follows the same basic format as the GIRA site discussion. This information provides clues as to which species are responding to green roofs in this region as well as how they are utilizing them. Designers and planners can use this information to understand how already-existing roofs may be impacting avifauna and how avian response to green roofs appears to vary between species and over time.

Introduction

For the following sections, bird data discussed involves either a bird on a green roof or a bird flying over a green roof. The following section clarifies how individual birds observed visiting the roofs were counted and classified.

For site 1, GIRA, if a bird landed on *Sedum* roofs 10, 11, and 12, in rapid succession without leaving the immediate GIRA area, it was counted as 1 bird visit. If a bird landed on *Sedum* roof 10, flew away from the GIRA area, and then flew back minutes later and landed on *Sedum* roof 11, it was counted as two individual birds visiting even though it may have actually been the same individual. For OCHM, counted individual birds followed the same method. If a bird was observed flying onto the pavilion green roof, it was counted as one bird. If a visiting bird was seen flying away and disappeared from the immediate context and then returned several minutes later, it was counted as two separate individual birds visiting when in fact it could have been the same individual.

In reference to bird behaviors, the data is discussed in terms of individual behaviors observed by the birds visiting the roofs. In a particular situation, one bird would be counted multiple times if it was observed exhibiting or expressing more than one behavior within an observation session. For instance, if a bird was observed resting over the duration of two, 10-minute observation periods on one roof, it was counted as two instances of resting behavior observed. In a similar case, if a single bird was observed resting, foraging, and singing/calling within one observation session, three separate behaviors were recorded. In addition, certain behaviors were subject to a few conditional requirements. For a behavior to be counted into the resting/perching category, a bird either landed and rested in a fixed place on the roof for any noticeable length of time or became still for any length of time after no certain other behavior was observed. For instance, if a bird came to land and stayed still for an entire observation session; it was then counted as one instance of resting/perching behavior. Also, if a bird came to land to groom and then took flight again; this behavior was recorded as simply grooming. In turn, if a bird landed to forage and then immediately took flight without becoming still for any discernable amount of time, it was considered simply foraging behavior because there was no implied rest. And in the last scenario, if a bird landed to forage and then became still for several minutes, this was recorded as two behaviors: foraging and resting/perching.

With regard to birds flying over the roofs, data discussed is in terms of individual birds observed flying over the roofs. If a bird was observed flying over the array and then immediately flew over again without leaving the local airspace or line of sight within the same observation session, it was counted as one bird flying over. If a bird was observed flying over and then disappeared from the immediate context and ultimately returned to fly over again within the same observation session, it was counted as two flyovers. If a bird, or flock of birds, regardless of size, did not fly directly over the array or flew at an altitude of anything greater than approximately 150 ft, then it was not counted as a flyover. Birds flying at altitudes above this threshold became distorted and difficult to perceive if they were flying directly over the roof or just in the general area.

More than just a count or recording of birds physically on roofs and their associated behaviors, the dataset, when considered holistically, becomes a narrative where the roof use and behaviors of species in response to seasonal progression can be discussed in general. The descriptive analysis is a narrative and involves species lists which can be thought of like a shifting cast of characters using the roofs in different ways at different points in time. For the purpose of the analysis, seasonal definitions are the same as for the statistical analysis: winter (February 17-27), spring migration (March 5-24), brood rearing (April 2- June 20), and summer molt (June 23-August 1)

Site 1: Green Infrastructure Research Area

The following report discusses the GIRA data in terms of the overall observation period from February to August. First, the unbalanced nature of the observation data is discussed. Then the overall data is discussed, followed by each of the isolated four seasons. Each of these sections presents the results by first identifying which birds are using the roofs, then describing their respective behaviors, and finally discussing the observed flyover species.

Overall Observation Period: February 17-August 1

As previously mentioned, three hundred and eighty-five individual birds were counted using the roofs over the course of the twenty-four week study. Data for the following analysis can be obtained in Table 4.17. Breaking the study into the four seasonal subsets reveals fifty-three (13.76%) individual birds using the roof during winter, one hundred and fifty-nine (41.29%) during spring migration, one hundred and nineteen (30.90%) during brood rearing, and fifty-four (14.02%) during the summer molt (Figure 4.39).

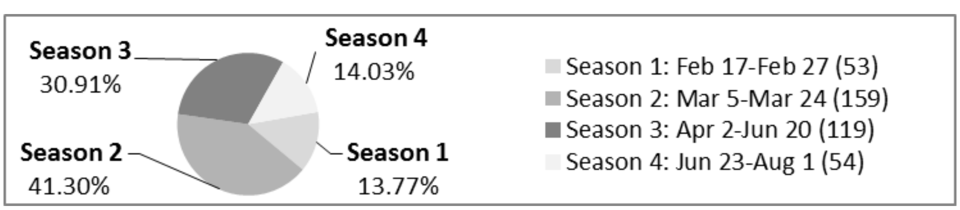

Figure 4.39 Observed proportion of bird visits at GIRA with respect to season

The observations over the four different seasons revealed that the species observed utilizing the test roofs at GIRA varied over time. In the first season, seven species were identified visiting the roofs: AMRO, EABL, EUST, NODO, NOMO, RWBL, and UNSP. In season 2, eight species were observed: AMRO, EABL, EAME, EUST, UNBL, UNSP, RWBL, and PUFI. In season 3, eleven species were identified: EABL, EUST, EUCD, MODO, NOMO, UNSP, UNBL, RWBL, WWDO, NOCA, and BARS. And finally, in season 4, seven species were identified: EABL, EUST, EAME, MODO, NOMO, HOFI, and INBU. Throughout the four seasons, EABL, EUST, MODO, NOMO, RWBL, and UNSP were the dominant species observed utilizing the roofs.

At first glance it appears that most of the activity occurred in the spring migration and brood rearing seasons, but this is deceptive. Both the actual number of observation days and the total number of days included in each seasonal period differed. Because unbalanced data is more difficult to compare, an adjusted total was generated for each of the 4 seasons. The mean number of observations per day for each season was calculated for each season by dividing the sum of the daily observations by the number of actual observation days in each period (Table 4.18). Comparison of the observed means revealed the spring migration season was twice as active in terms of the mean number of birds visiting as the winter or brood rearing seasons and the proportion is slightly higher for the summer molt season as well.

Overall, sixteen species were recorded using the roofs, with the six most common species being EABL, UNSP., EUST, NOMO, MODO, and RWBL, in order of abundance. EABL observations totaled seventy-five (19.48%) and RWBL were observed thirty-one (8.05%) times. Figure 4.40 shows the proportions of individual birds observed by species as a percentage of the total number of visits between February 17 and August 1, 2014

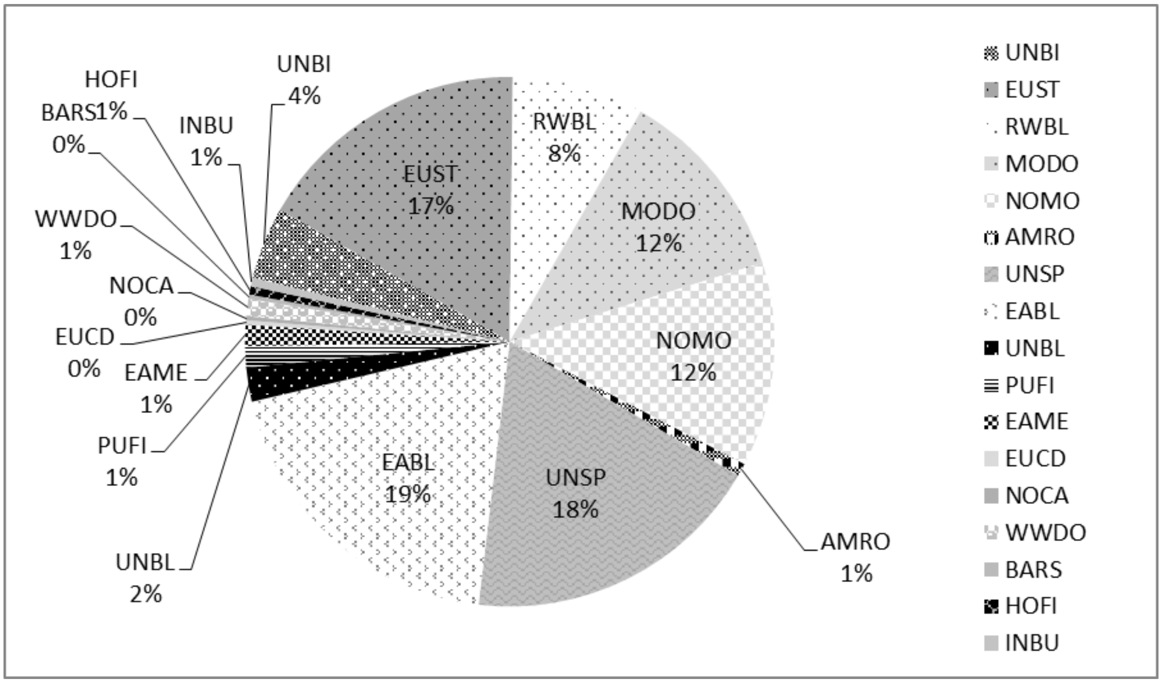

Figure 4.40 Proportion of individual birds observed as a percentage of the total number of visits: February 17-August 1, 2014

The three hundred and eighty-five individuals counted using the roofs were observed expressing five hundred and ninety-three separate behaviors while in contact with the green roof array. Behavior data for GIRA can be found in Table 4.19. Overall, the most common behavior observed was resting and/or perching, as it was observed in every species and counted three hundred and eighty-three (64.85%) times. With one hundred and seventeen (19.73%) observations, foraging behavior was the second most observed behavior (Figure 4.41) and was observed in all species except AMRO, BARS, *Streptopelia decaocto* (EUCD), *Zenaida asiatica* (WWDO), *Passerina cyanea* (INBU), and *Cardinalis cardinalis* (NOCA). Singing and calling yielded sixty-nine (11.63%) observations, making it the third most observed behavior. Overall, seventeen instances of grooming were observed in EABL, NOMO, MODO, EUST, EAME, UNSP, and UNBL. Defending/aggressing behaviors was only witnessed in EUST and NOMO on the roofs, but RWBL was observed in this behavior type in flight as it ran EUST from the array. Display behaviors were counted three times for the RWBL as an energetic show consisting of multiple individuals during the April 2-June 20 observation period.

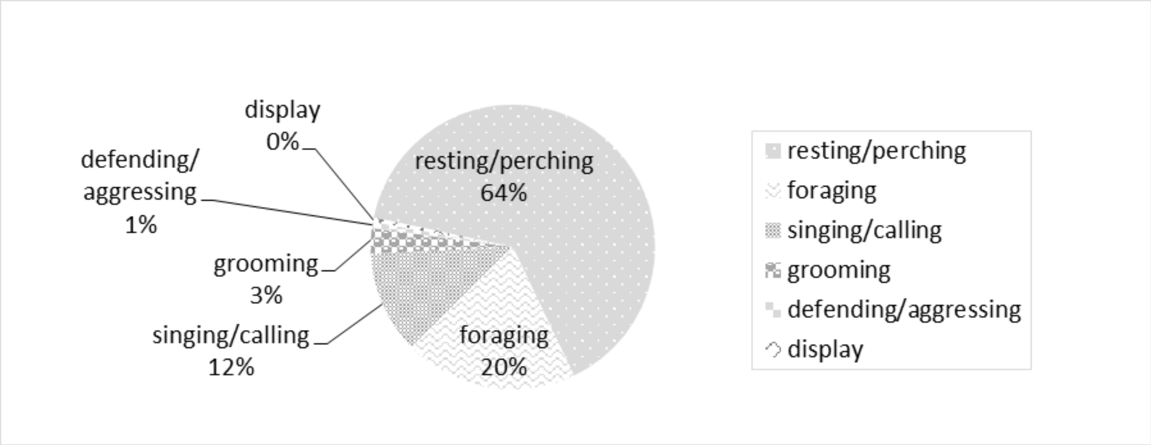

Figure 4.41 Overall proportion of observed behaviors during February 17- August 1 at GIRA

Over the course of the six month study, one thousand four hundred and thirty-nine birds were observed flying over the GIRA array (Table 4.19). Of these, two hundred and fifty eight (17.92%) were UNBI. When observations are compared by time period, the winter season had one hundred and forty-two flyovers which represented 9.86% of the total birds observed. The spring migration season had six hundred and fifty-four flyovers, or 45.44% of the total birds observed and the brood rearing season had three hundred and ninety-nine flyover observations, or 27.72%. The summer molt season had two hundred and fourty-four observations, which represented the final 16.95% of the total birds observed over the twenty-four weeks. Like the observation data for birds on roofs, the flyover data is difficult to compare because of variation in both the number of days observing per season and the total number of days contained in each season's time period. For each season the daily mean number of birds observed was calculated (Table 4.20) using data from Table 4.19 so that seasonal activity could be understood with greater clarity. With a mean value of 59.45 daily bird observations, the data indicated that spring migration season was, in fact, the most active time period for flyovers at GIRA.

The most common species observed flying over the site included EUST, BARS, RWBL, MODO, and NOMO with sightings ranging from two hundred and sixty-one for EUST to seventy-five for NOMO. Other commonly-observed species included AMRO, EABL, EAME, *Bulbucus ibis* (CAEG), and *Cathartes aura* (TUVU) with sightings ranging from forty for CAEG to eighteen for TUVU. See Figure 4.42 for the proportion of flyover birds by species which flew over the GIRA site over the course of the study. Table 4.20 contains data for the total number of observed flyovers per day separated by season.

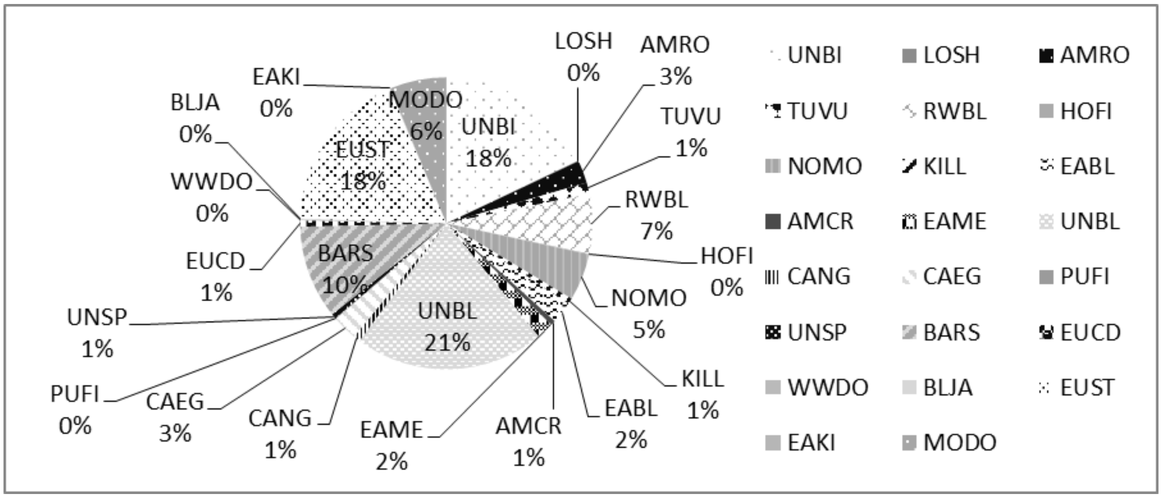

Figure 4.42 Proportion of flyover birds during February 17 to August 1 at GIRA

Observation Period: February 17-27

During the winter period, fifty-three bird observations were made, where only six (11.32%) UNBI. The forty-seven remaining observations were from EUST, RWBL, MODO, NOMO, AMRO, EABL, and UNSP. RWBL and EABL were the most common species observed, with twelve and thirteen observations, respectively (Figure 4.43).

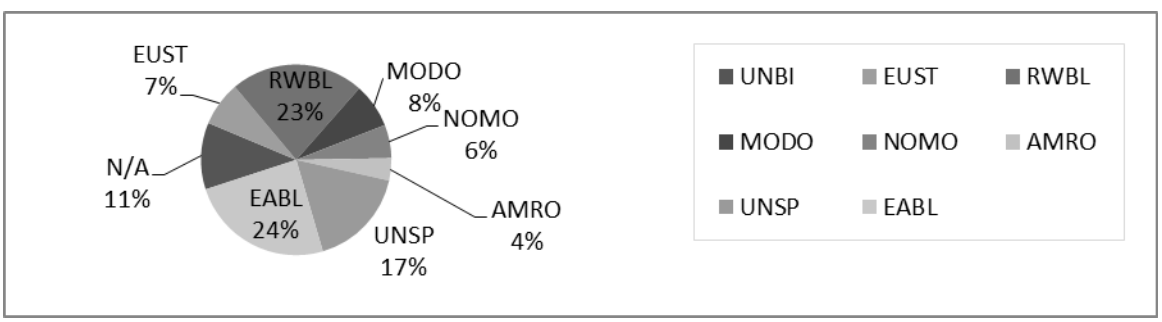

Figure 4.43 Proportion of birds observed during February 17-27 at GIRA

The fifty-three individual birds counted in this time period were observed expressing seventy-eight different behaviors. Resting/perching was counted fifty-one (65.38%) times and is present in all of the species recorded during this time period. The eighteen instances of singing/calling observations were witnessed in: AMRO, RWBL, NOMO, and UNSP. RWBL was the only species observed foraging in the green roofs: six occurred in the *Sedum* type, and three in the prairie type (Figure 4.44).

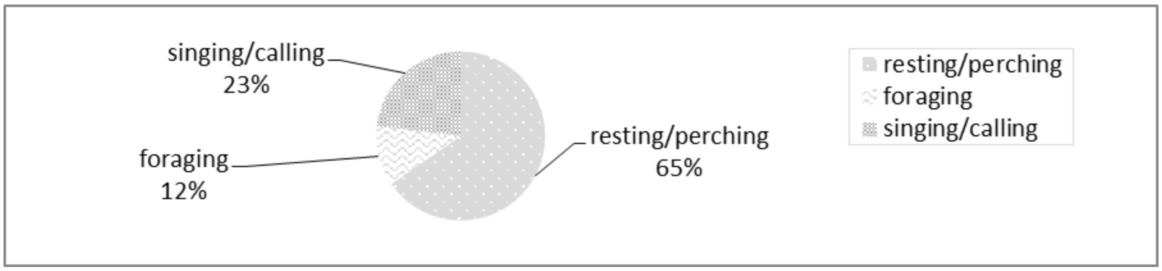

Figure 4.44 Proportion of observed behaviors during February 17-27 at GIRA

As mentioned above, the winter season experienced one hundred and forty-two of the one thousand four hundred and thirty-nine total flyover observations. The common species flying over the GIRA array during this time period is EUST with seventy-two (50.70%) total sightings. UNBI were observed thirty-six (25.35%) times (Figure 4.45).

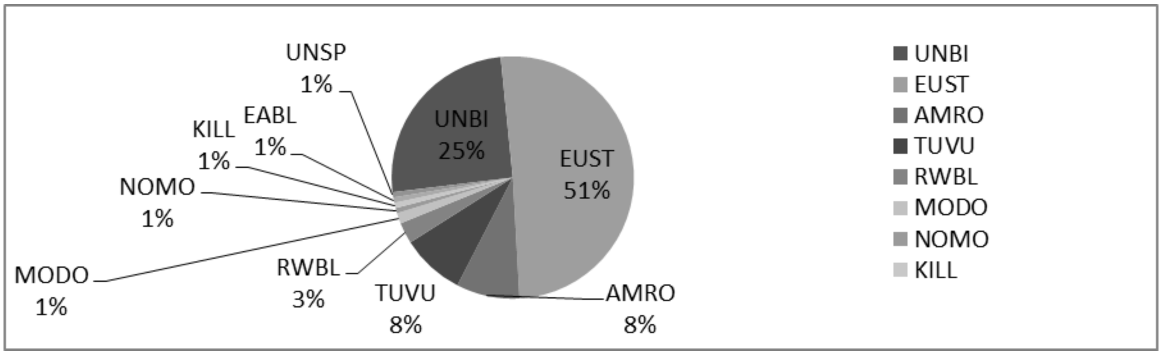

Figure 4.45 Proportion of flyover birds observed during February 17-27 at GIRA

As with observations of birds utilizing roofs at GIRA, the number of species observed flying over the test roofs during each time frame varied from season to season. During the first season, nine species were identified: AMRO, EABL, EUST, KILL, MODO, NOMO, UNSP, TUVU, and RWBL. During season 2, this number increased by two: AMRO, AMCR, EABL, EUST, EAME, CANG, UNSP, UNBL, TUVU, RWBL, and NOMO were the bird species observed. During season 3, nineteen species were identified flying over the roofs and included AMCR, AMRO, BLJA, BARS, CAEG, CANG, EABL, EAKI, EUST, EAME, EUCD, KILL, MODO, NOMO, PUFI, RWBL, TUVU, UNSP, and WWDO. During season 4, thirteen species were identified. These included HOFI, KILL, LOSH, MODO, NOMO, RWBL, TUVU, BARS, BLJA, CAEG, EABL, EAME, and EUST.

Table 4.17 Proportion of visits at GIRA by each species and by season as a percentage of the total number of visits

		Season	1	2	3	4		
Common Name	**Taxonomic Name**	**4 Letter-Code**	**Feb 17-Feb 27**	**Mar 5 - Mar 24**	**Apr 2-Jun 20**	**Jun 23-Aug 1**	**Total # of Birds**	**% of Grand Total**
unknown bird	*varies*	UNBI	6	8	3		17	4.41%
European starling	*Sturnus vulgaris*	EUST	4	37	23	1	65	16.88%
red-winged blackbird	*Agelaius phoeniceus*	RWBL	12	2	17		31	8.05%
mourning dove	*Zenaida macroura*	MODO	4		26	16	46	11.94%
northern mockingbird	*Mimus polyglottos*	NOMO	3		17	28	48	12.46%
American robin	*Turdus migratorius*	AMRO	2	1			3	0.77%
unknown sparrow	*varies*	UNSP	9	56	6		71	18.44%
eastern bluebird	*Sialia sialis*	EABL	13	41	18	3	75	19.48%
unknown blackbird	*varies*	UNBL		6	2		8	2.07%
purple finch	*Haemorhous purpureus*	PUFI		5			5	1.29%
eastern meadowlark	*Sturnella magna*	EAME		3		2	5	1.29%
Eurasian collared-dove	*Streptopelia decaocto*	EUCD			1		1	0.25%
northern cardinal	*Cardinalis cardinalis*	NOCA			1		1	0.25%
white-winged dove	*Zenaida asiatica*	WWDO			4		4	1.03%
barn swallow	*Hirundo rustica*	BARS			1		1	0.25%
house finch	*Haemorhous mexicanus*	HOFI				2	2	0.51%
indigo bunting	*Passerina cyanea*	INBU				2	2	0.51%
		Seasonal Total	53	159	119	54	**385**	
		% of Seasonal Total	13.76%	41.29%	30.90%	14.02%		

Note: This species analysis is after Burgess (2004).

Table 4.18 Calculated daily mean of the number of birds observed on test roofs during each season at GIRA

season	date	# days spent observing	total # of days in season	observed total # visits	observed mean (# obs./day)
winter	Feb 17-Feb 27	7	11	54	**7.71**
spring migration	Mar 5-Mar 24	11	20	176	**16**
brood rearing	Apr 2-Jun 20	26	60	142	**7.1**
summer molt	Jun 23-Aug 1	12	40	62	**6.2**

Note: Data for this table from Table 4.2. "Observed mean" refers to the mean calculated from dividing the total number of visits observed in each season by the number of observation days in each season

Table 4.19 Species and observed behaviors at GIRA

Common Name		*Taxonomic Name*		(Family)	**4- Letter Code**
Unknown bird		*varies*		Aves	**UNBI**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	6	8	4		**18**
foraging		1	1		**2**
singing/calling					
grooming					
defending/aggressing					
TOTAL	**6**	**9**	**5**	**0**	**20**
northern cardinal		*Cardinalis cardinalis*		(Cardinalidae)	**NOCA**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching			1		**1**
foraging					
singing/calling					
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**1**	**0**	**1**

Table 4.19 continued

Common Name		*Taxonomic Name*		(Family)	**4- Letter Code**
European starling		*Sturnus vulgaris*		(Sturnidae)	**EUST**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	5	29	17	1	**52**
foraging		23	7	1	**31**
singing/calling		2	2		**4**
grooming		1	1		**2**
defending/aggressing		1			**1**
TOTAL	**5**	**56**	**27**	**2**	**90**
American robin		*Turdus migratorius*		(Turdidae)	**AMRO**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	2	1			**3**
foraging					
singing/calling	2				**2**
grooming					
defending/aggressing					
TOTAL	**4**	**1**	**0**	**0**	**5**
red-winged blackbird		*Agelaius phoeniceus*		(Icteridae)	**RWBL**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	9	2	21		**32**
foraging	9		3		**12**
singing/calling	4		15		**19**
grooming			2		**2**
defending/aggressing					
display			3		**3**
TOTAL	**22**	**2**	**44**	**0**	**68**
mourning doves		*Zenaida macroura*		(Columbidae)	**MODO**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	4		28	18	**50**
foraging			4	7	**11**
singing/calling			1		**1**
grooming				1	**1**
defending/aggressing					
TOTAL	**4**	**0**	**33**	**26**	**63**

Table 4.19 continued

Common Name		*Taxonomic Name*		(Family)	4- Letter Code
northern mockingbird		*Mimus polyglottos*		(Mimidae)	**NOMO**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	3	1	18	26	**48**
foraging			5		**5**
singing/calling	2	1	7	5	**15**
grooming			1	2	**3**
defending/aggressing				3	**3**
TOTAL	**5**	**2**	**31**	**36**	**74**
Eastern bluebird		*Sialia sialis*		(Turdidae)	**EABL**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	14	40	21	3	**78**
foraging			6	1	**7**
singing/calling	2	4	3		**9**
grooming		4			**4**
defending/aggressing					
TOTAL	**16**	**48**	**30**	**4**	**98**
unknown sparrow				(Emberizidae)	**UNSP**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching	8	52	9		**69**
foraging		35	3		**38**
singing/calling	8	3	2		**13**
grooming		2			**2**
defending/aggressing					
TOTAL	**16**	**92**	**14**	**0**	**122**
eastern meadowlark		*Sturnella magna*		(Icteridae)	**EAME**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching		6		2	**8**
foraging				1	**1**
singing/calling		2			**2**
grooming		1			**1**
defending/aggressing					
TOTAL	**0**	**9**	**0**	**3**	**12**

Table 4.19 continued

Common Name		*Taxonomic Name*		(Family)	4- Letter Code
unknown blackbird				(Icteridae)	**UNBL**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching		6	1		**7**
foraging		3			**3**
singing/calling			1		**1**
grooming		2			**2**
defending/aggressing					
TOTAL	**0**	**11**	**2**	**0**	**13**
purple finch		*Haemorhous purpureus*		(Fringillidae)	**PUFI**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching		6			**6**
foraging		5			**5**
singing/calling		2			**2**
grooming					**0**
defending/aggressing					**0**
TOTAL	**0**	**13**	**0**	**0**	**13**
Eurasian collared-dove		*Streptopelia decaocto*		(Columbidae)	**EUCD**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching			2		**2**
foraging					
singing/calling					
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**2**	**0**	**2**
barn swallow		*Hirundo rustica*		(Hirundinidae)	**BARS**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching			1		**1**
foraging					
singing/calling					
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**0**	**0**	**1**

Table 4.19 continued

Common Name		Taxonomic Name		(Family)	4- Letter Code
White-winged dove		*Zenaida asiatica*		(Columbidae)	**WWDO**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching			4		**4**
foraging					
singing/calling					
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**0**	**0**	**4**
indigo bunting		*Passerina cyanea*		(Cardinalidae)	**INBU**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching				2	**2**
foraging					
singing/calling					
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**0**	**2**	**2**
house finch		*Haemorhous mexicanus*		(Fringillidae)	**HOFI**
behavior	**Feb 17-27**	**Mar 5-24**	**Apr 2-Jun 20**	**Jun 23 Aug 1**	**TOTAL**
resting/perching				2	**2**
foraging				2	**2**
singing/calling				1	**1**
grooming					
defending/aggressing					
TOTAL	**0**	**0**	**0**	**5**	**5**

Table 4.20 Flyovers observed at GIRA

		Season	1	2	3	4		
Common Name	**Taxonomic Name**	**4-Letter Code**	**Feb 17 - Feb 27**	**Mar 5 - Mar 24**	**Apr 2 - Jun 20**	**Jun 23 - Aug 1**	**Total # of Birds**	**% of Grand Total**
American crow	*Corvus brachyrhynchos*	AMCR		3	5		8	0.55%
American robin	*Turdus migratorius*	AMRO	12	23	1		36	2.50%
barn swallow	*Hirundo rustica*	BARS			92	57	149	10.35%
blue jay	*Cyanocitta cristata*	BLJA			1	1	2	0.13%
cattle egret	*Bulbulcus ibis*	CAEG			20	20	40	2.77%
Canada goose	*Branta canadensis*	CANG		8	3		11	0.76%
eastern bluebird	*Sialia sialis*	EABL	1	11	15	8	35	2.43%
eastern kingbird	*Tyrannus tyrannus*	EAKI			1		1	0.06%
eastern meadowlark	*Sturnella magna*	EAME		10	10	7	27	1.87%
Eurasian collared-dove	*Streptopelia decaocto*	EUCD			10		10	6.94%
European starling	*Sturnus vulgaris*	EUST	72	50	105	34	261	18.13%
house finch	*Haemorhous mexicanus*	HOFI				1	1	0.06%
kildeer	*Charadrius vociferus*	KILL	1		4	4	9	0.62%
loggerhead shrike	*Lanius ludovicianus*	LOSH				1	1	0.06%
mourning dove	*Zenaida macroura*	MODO	2		34	54	90	6.25%
Northern mockingbird	*Mimus polyglottos*	NOMO	1	3	35	36	75	5.21%
purple finch	*Haemorhous purpureus*	PUFI			1		1	0.06%

Table 4.20 continued

red-winged blackbird	*Agelaius phoeniceus*	RWBL	4	33	40	18	95	6.60%
turkey vulture	*Cathartes aura*	TUVU	12	4	1	1	18	1.20%
unknown bird	*varies*	UNBI	36	201	19	2	258	17.92%
unknown blackbird	*varies*	UNBL		302			302	20.98%
unknown sparrow	*varies*	UNSP	1	6	1		8	0.55%
white-winged dove	*Zenaida asiatica*	WWDO			1		1	0.06%
		seasonal total	142	654	399	244	**1439**	
		% of seasonal total	9.86%	45.44%	27.72%	16.95%		

Table 4.21 Calculated daily mean of the number of birds observed flying over test roofs during each season at GIRA

season	time period	# days spent observing	total # of days in season	observed total # flyovers	observed mean (# flyovers /# days in season)
winter	Feb 17-Feb 27	7	11	142	**20.29**
spring migration	Mar 5-Mar 24	11	20	654	**59.45**
brood rearing	Apr 2-Jun 20	26	60	399	**15.35**
summer molt	Jun 23-Aug 1	12	40	244	**20.33**

Note: Data for this table from Table 4.19. "Observed mean" refers to the mean calculated from dividing the total number of visits observed in each season by the number of observation days in each season.

Description of how avifauna utilized GIRA

The following sections address each roof class with respect to how birds were observed generally using them. This descriptive analysis is included to support the analysis of variance. The control roofs are discussed first, followed by a *Sedum* type discussion, and finishing with a prairie roof type discussion. The following narrative seeks to provide a broad picture of what was happening on the roofs. Photographs and anecdotal accounts are included to help reinforce the story.

Control roofs

Avifauna were observed utilizing the control roofs during the study. On multiple occasions, EABL and NOMO were observed perching on various roofs and then using them as a vantage point from which to hunt in the vegetation below. Other species also utilized these roofs occasionally to perch. In winter, birds observed on the control roofs at dawn seemed to be strongly correlated with choosing perches located in patches of sun light. In the spring, *(Streptopelia decaocto)* EUCD was observed walking across the flat roofs (Figure 4.46).

Figure 4.46 April 2, 2014: EUCD walks across control roof.

Sedum roofs

EABL activity increased in the spring migration and brood rearing seasons where they were often observed using the edge of roofs as either a perch and/or as a vantage point from which to hunt (Figure 4.47). Sometimes, EABL would perch for long periods of time on the edges of test roofs between these hunts. EABL were so frequently observed in the area that many individuals of both sexes were often observed simultaneously.

EUST were observed throughout the entire study. During the winter and spring migration seasons, there was a lot of forage and perching activity. EUST frequented the roofs for forage, but were also observed leaving their nest simply to rest in a green roof. At least four young were observed being fed by EUST in this nearby nest. After the juveniles began to fly, they were observed together in the array (Figure 4.48). Outside of the official count, the juveniles were observed utilizing the roofs for several days during the spring before they dispersed and were not observed again. EUST were observed going in and out of the shielded gutters which remain attached to some of the green roofs (Figure 4.49). Nests have been observed in these locations and in others at the array, but no nests have been observed on the green roof itself.

MODO began using the *Sedum* roofs more during the spring migration season, where there is a notable spike in number of roof visits by individuals to perch or rest. Often mourning doves would arrive in pairs or small groups and would spend time walking around the roofs (Figure 4.50).

NOMO utilized the *Sedum* roofs most in the brood rearing season and had a late spike during the summer molt as well. It seemed as if there were a few resident NOMO nearby who claimed at least part of the array in their territory, as they spent a lot of time perching or running about on the tall *Sedum* roofs: 13-17 (Figure 4.51).

Figure 4.47 April 25, 2014: Female EABL perches on *Sedum* roof 17

Figure 4.48 May 15, 2014: 4 juvenile EUST visit roof 7 for forage and chatter

Note: There was a 5th juvenile with this group but I did not have the good fortune of capturing all 5 of them in one photograph.

Figure 4.49 April 19, 2014: EUST investigates stormwater infrastructure on a *Sedum* roof

Note: Before the onset of this study, a nest was reportedly removed from a similar location at the GIRA array. In addition, one was discovered in August 2014 in the downspout portion of a different roof.

On February 17, RWBL was observed foraging from the roofs several times, but was not observed foraging in the roofs again until well into brood rearing. RWBL had a burst of activity during the brood rearing season where it was often observed perching or singing and calling from the roofs. Several RWBL used the roofs for a very boisterous mating display in April. A RWBL and EUST were observed together on *Sedum* roof 7 (Figure 4.52).

All activity for UNSP is entirely in the winter and spring migration seasons where they were primarily observed foraging. March 24 was the last day UNSP were observed using this roof type.

Typical species behavior on all roof types consisted of brief perching visits sometimes accompanied by foraging activity. For instance, a NOCA was observed visiting the site and remained long enough to be photographed (Figure 4.53). Some visits were so brief it was hard to tell if some birds even let their feet touch the ground.

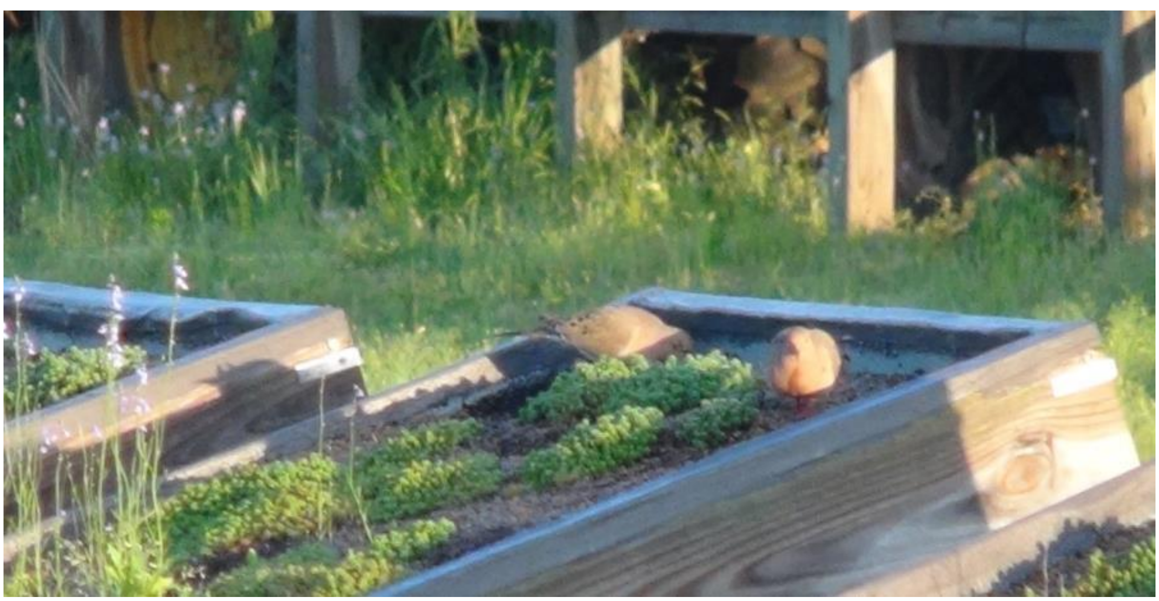

Figure 4.50 April 25, 2014: 2 MODO forage together in a *Sedum* roof

Figure 4.51 April 2, 2014: NOMO perches with grass.

Figure 4.52 April 16, 2014: RWBL and EUST enjoy a perch together on roof 7

Figure 4.53 April 16, 2014: Male NOCA perches on a *Sedum* roof

Prairie roofs

EABL had a stronger presence during winter and spring migration where it was primarily using the edges of the prairie roofs as a vantage from which to hunt. Often, EABL was observed simply resting on the edge for long periods of time (Figure 4.54).

Figure 4.54 March 24, 2014: EABL perched on prairie roof 23

During the spring migration season, EUST seemed to favor the prairie roof type. Numerous trips to and from nests were witnessed as multiple EUST foraged for nesting materials from within the prairie roofs. Mostly grasses and long, twiggy plant materials were extracted, but smaller bits were observed being retrieved as well. EUST nearby were observed on multiple occasions dropping old nesting material from the entrance of the nest in the building exhaust tube before flying to the roofs to gather more.

MODO observed a spike in activity through the spring migration and brood rearing seasons where they would spend long periods of time resting in the roofs. Often, MODO were observed nestled in the taller prairie grasses to rest, but there was no other apparent activity or vocalization detected.

NOMO visited the roofs just once during the winter period. Part way through the brood rearing season, NOMO activity increased dramatically and individuals were observed more frequently coming to the roofs to perch and sing, perch and hunt, and spend time at rest.

RWBL were often observed calling and puffing up slightly as they perched on the prairie roofs. Both sexes of RWBL were observed using the prairie roofs for foraging activities (Figure 4.55). They were also used by males frequently as a vantage point from which to sing/call (Figure 4.56). In addition, they were also the stage of a boisterous mating display witnessed in April.

UNSP were observed using the prairie roofs most during the first part of the study. The presence of UNSP was only officially counted from winter to partially through the brood rearing season, however during off-times, UNSP were observed perching on the prairie roofs or foraging from them through the first part of spring (Figure 4.57).

Figure 4.55 April 2, 2014: Female RWBL forages from prairie roof 27

Figure 4.56 April 25, 2014: Male RWBL calls from atop a mound of prairie roof vegetation

Figure 4.57 April 30, 2014: UNSP perched on a prairie roof

Observation Period: March 5- March 24

The March 5- 24 time period observed one hundred and fifty-nine birds with only eight (5.03%) UNBI. The remaining one hundred and fifty-three successfully-identified birds included EUST, RWBL, AMRO, EABL, *Haemorhous purpureus* (PUFI), *Sturnella* *magna* (EAME), UNBL and UNSP. The common species observed during this time period were UNSP, EABL, and EUST (Figure 4.58).

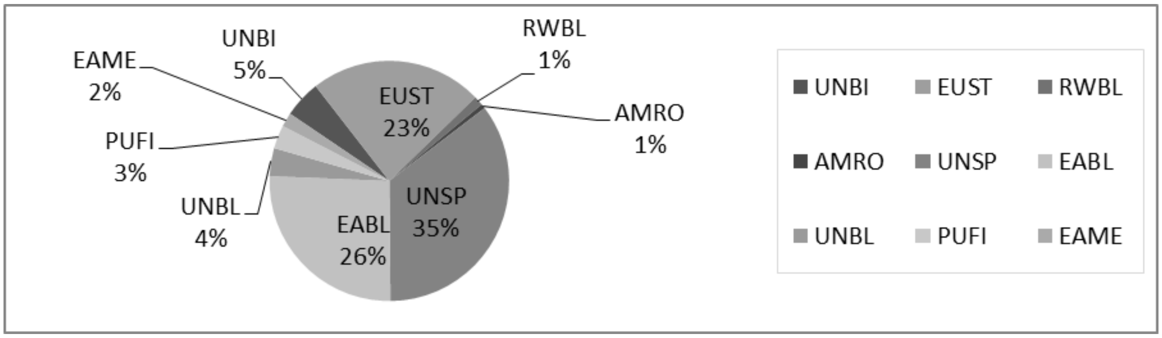

Figure 4.58 Proportion of birds observed during March 5-24 at GIRA

The one hundred and fifty-nine birds observed using the roofs were seen expressing two hundred and forty-three separate instances of behavior. Resting/perching, the most commonly observed behavior was witnessed one hundred and fifty-one (62.13%) times for species recorded during this time period. The most common species included UNSP, EABL, and EUST. EAME, an uncommon to fairly common grassland species, was observed resting/perching on the roofs a total of six times during this period. This is notable because there was significant debate amongst committee members as to whether EAME might notice and use the roofs at all. For all birds, instances of foraging were counted sixty-seven times (27.57%) and were primarily observed in EUST, which was observed twenty-three times, and UNSP, which was observed thirty-five times. The fourteen singing/calling instances were observed in EABL, EAME, EUST, NOMO, PUFI, and UNSP. The act of grooming was witnessed ten times total in EABL, EAME, EUST, UNBL, and UNSP. EUST was the only species observed engaged in defensive/aggressive behavior during this time period (Figure 4.59).

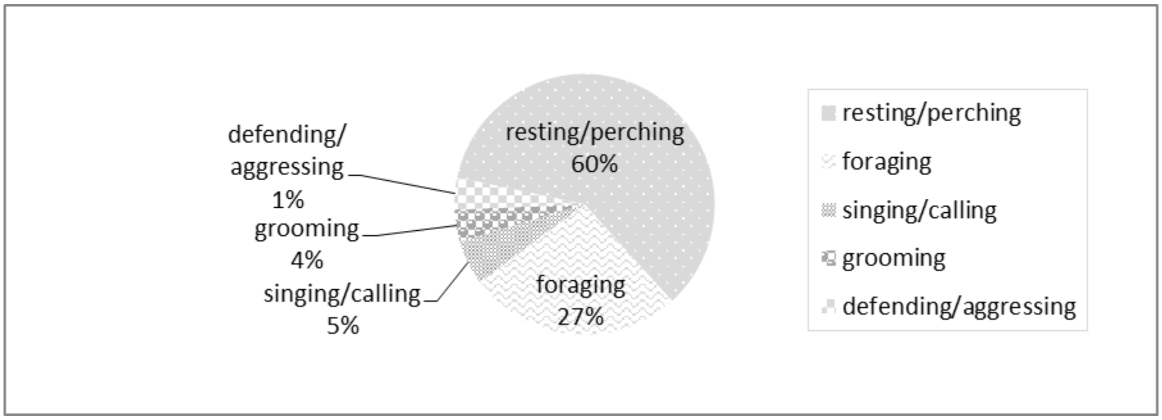

Figure 4.59 Proportion of observed behaviors during March 5-24 at GIRA

For the spring migration season, flyovers were observed six hundred and fifty-four times with two hundred and one (30.73%) UNBI. On March 10, a flock of approximately three hundred UNBL flew low over the GIRA array and landed on the patch of grass adjacent to the site where the collective foraged for several minutes before flying over the array again and off into the distance. Outside of this single occurrence where a massive flock of birds flew within range of the array, the most common flyover species were EUST, RWBL, and AMRO (Figure 4.60).

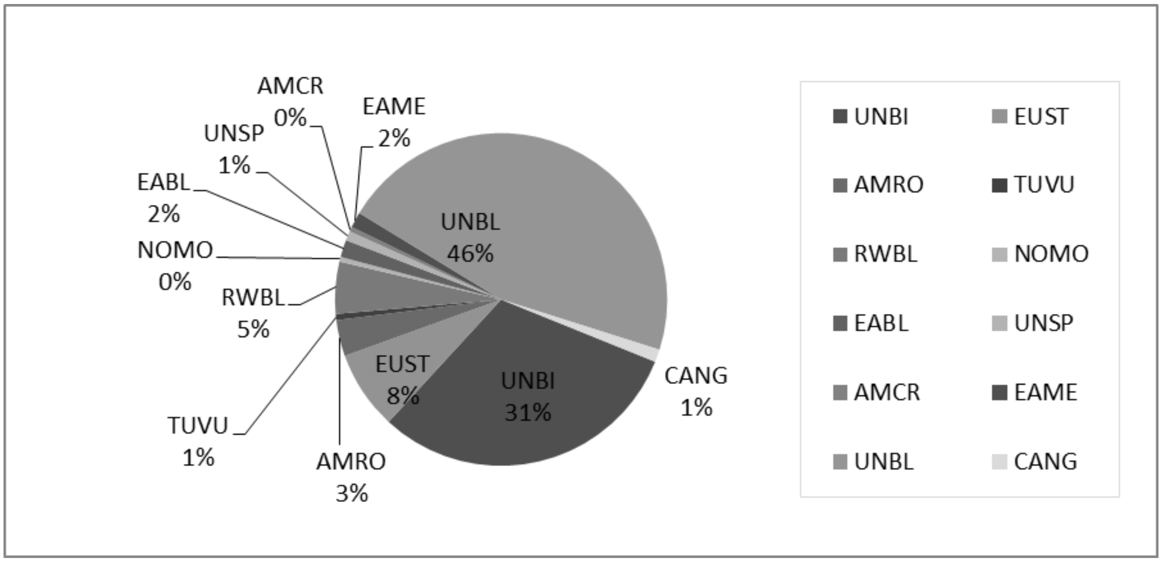

Figure 4.60 Proportion of flyover birds during March 5-24 at GIRA

Observation Period: April 2- June 20

Individual birds were observed one hundred and nineteen times during the brood rearing season with only three (2.52%) UNBI (Figure 4.61). The species represented during this time period are EUST, RWBL, MODO, NOMO, EABL, NOCA, WWDO, BARS, UNSP, and UNBL with MODO and EUST as the most commonly observed species with twenty-six and twenty-three sightings, respectively.

There were one hundred niney-three total behaviors recorded for the one hundred nineteen individual birds counted on the array during this time period (Figure 4.62). As with the previous seasons, resting/perching behaviors dominated the count with one hundred twenty-six total observations, 65.28% of total observed behaviors. Foraging behaviors were observed twenty-nine times and singing/calling was witnessed thirty-one times in EUST, RWBL, MODO, NOMO, EABL, and UNSP. While the foraging behavior appeared to be generally the same amongst species observed, the same was not true for singing/calling. RWBL dominated this behavior type during this time period with fifteen of the thirty-one total observations. On April 16, RWBL was observed engaged in acrobatic flight and displays of plumage. At least five individual RWBL were sighted participating in this activity, although not all visited the array.

There were three hundred and ninety-nine flyovers recorded during the brood rearing season, where nineteen (4.76%) UNBI were counted (Figure 4.63). The most common species observed were EUST and BARS. Other commonly-observed flyovers were RWBL, MODO, NOMO, and *Branta Canadensis* (CANG).

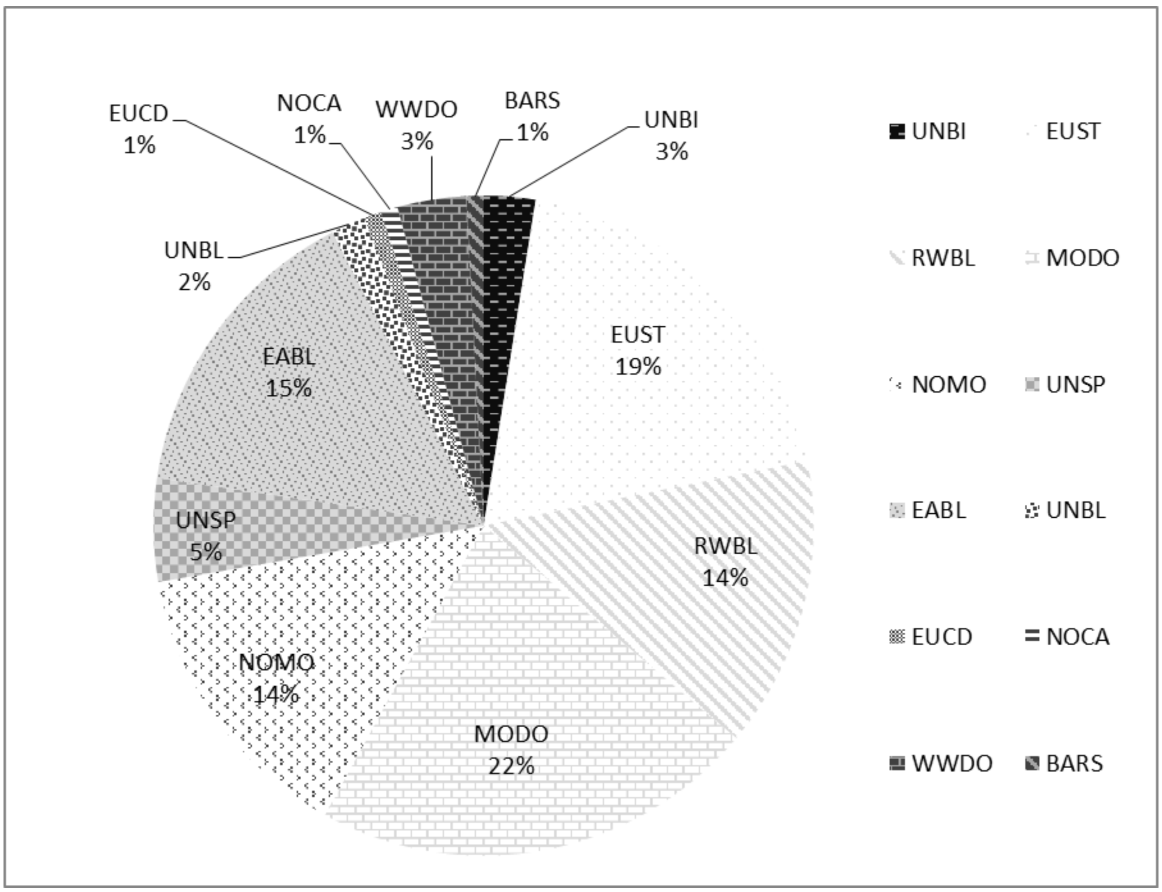

Figure 4.61 Proportion of birds by species observed during April 2- June 20 at GIRA

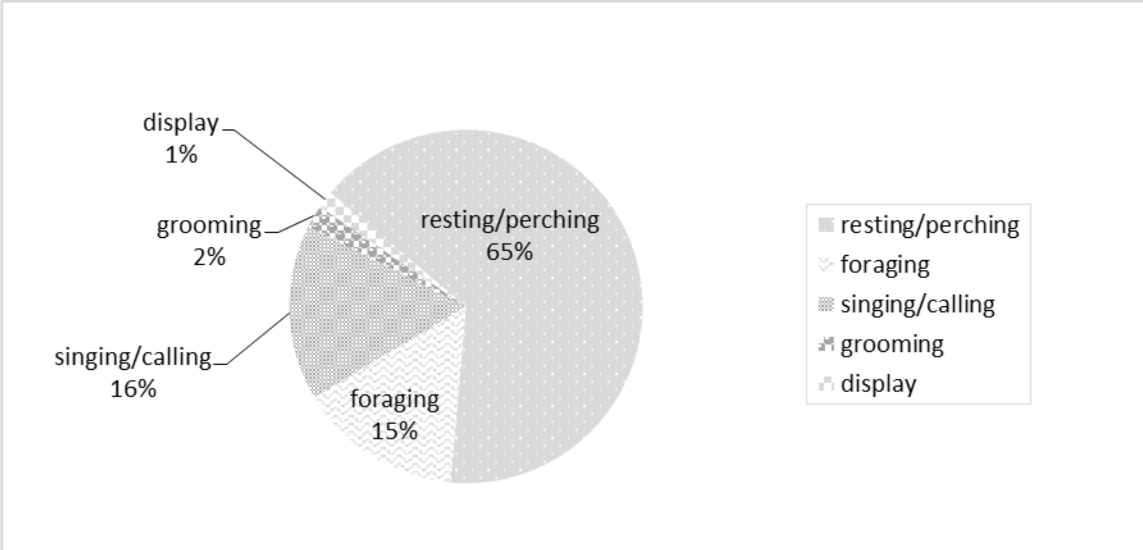

Figure 4.62 Proportion of observed behaviors during April 2- June 20 at GIRA

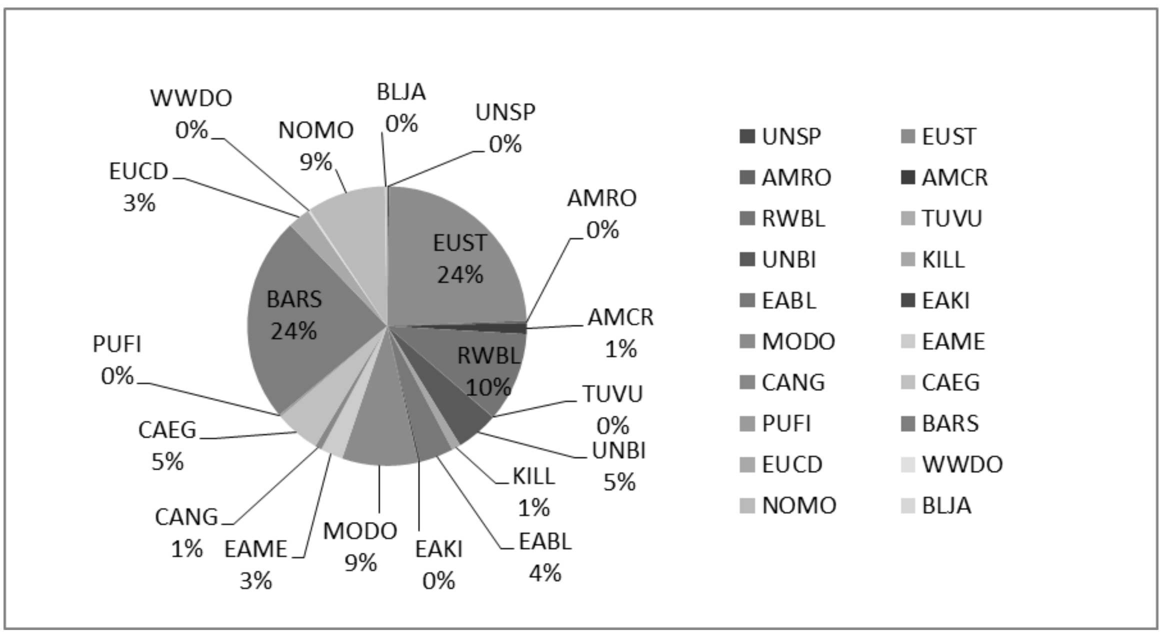

Figure 4.63 Proportion of flyover birds during April 2-June 20 at GIRA

Observation Period: June 23- August 1

In the final observation period, summer molt, fifty-four individual birds were spotted with 100% positive species identifications. Species observed include EUST, MODO, NOMO, EABL, EAME, *Haemorhous mexicanus* (HOFI), and INBU with NOMO as the most common species observed with twenty-eight individual sightings. The proportion of species observed is shown in Figure 4.64.

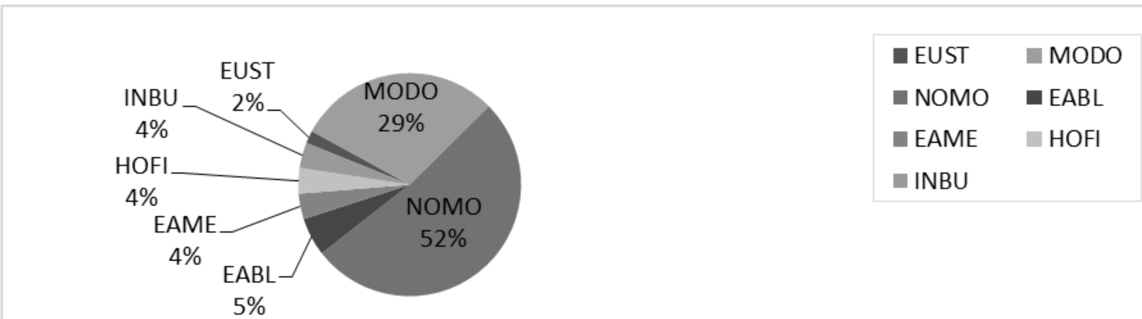

Figure 4.64 Proportion of species observed during June 23-August 1

Seventy-eight behaviors were recorded for the fifty-four individuals observed during the brood rearing season. Every individual which engaged with the array was counted in the resting/perching behavior category. EUST, MODO, EABL, EAME, and HOFI were observed foraging in the vegetated roofs; although MODO was observed more often taking advantage of forage opportunities than any other species. Singing/calling was recorded six times: five belonging to NOMO and one to HOFI. Grooming behaviors were observed in MODO and NOMO. Defending/Aggressing behaviors were witnessed three times in NOMO during this time period as well (Figure 4.65).

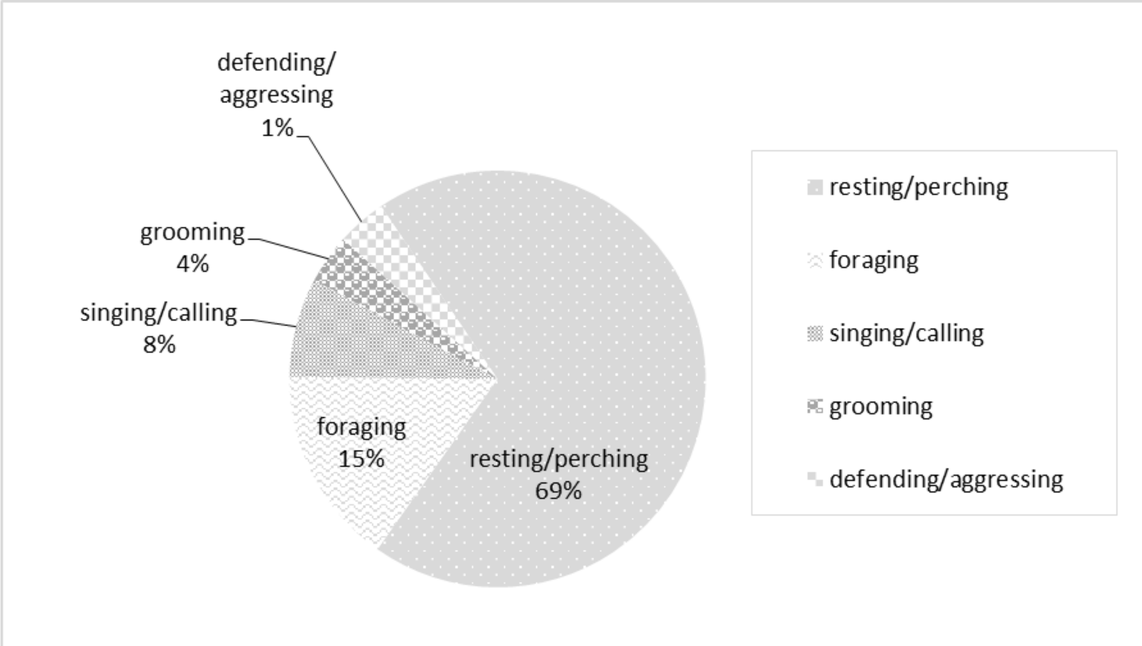

Figure 4.65 Proportion of behaviors observed during June 23- August 1 at GIRA

The June 23-August 1 time period yielded two hundred and fourty-four total flyover observations. Of these, only two (0.81%) were UNBI. The most common species flying over during this time were MODO and BARS and other commonly observed species include RWBL, NOMO, and CAEG (Figure 4.66).

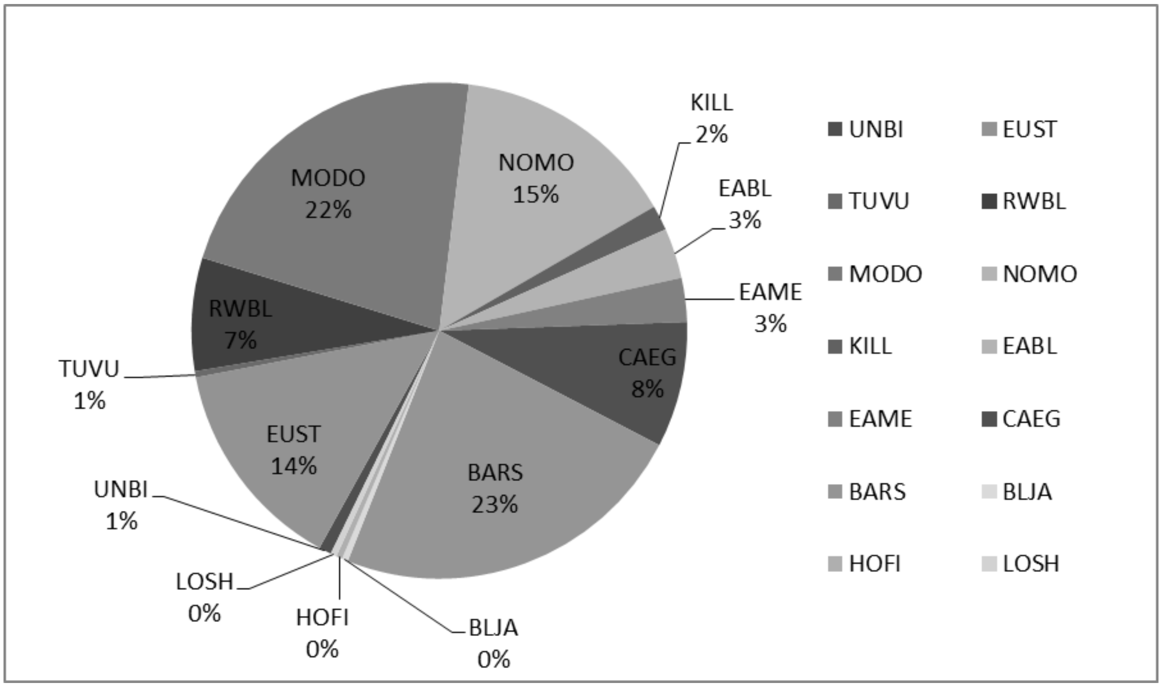

Figure 4.66 Proportion of flyover birds during April 2-June 20 at GIRA

Site 2: Oktibbeha County Heritage Museum

The following report will discuss the OCHM data in terms of the overall observation period from February to August. The results for this site are reported in a similar manner to those previously described for GIRA. First, the unbalanced nature of the observation data is discussed. Next is a section which identifies the birds that were using the roofs, followed by a discussion of their observed behavior, and finally a discussion of the observed flyovers with respect to season. Bird usage of the roof will be discussed in general terms with respect to the entire study period. For flyover observations, each of the 4 seasons will be isolated and described.

Overall Observation Period: February 25- July 29

Altogether, twenty-nine individual birds were observed on the OCHM extensive *Sedum* green roof over the course of the study (Table 4.22). The winter season, was only one observation date, February 25, and no birds were observed on the roof that day. The spring migration season (March 1-21) observed one NOMO using the roof. The bulk of the observations of birds visiting the roofs, twenty-six of the twenty-nine (89.65%) total, occurred during the brood rearing season (April 8-June 17) where twenty of the observations belonged to NOMO, four to HOFI, and one to AMRO. The summer molt (July 2-29) saw two NOMO visiting the site on one day but no other observations during any other day during that time period (Figure 4.67). These seasonal percentages are somewhat misleading and difficult to compare. The mean number of birds visiting the OCHM roof during each season was only calculated for the spring migration, brood rearing, and summer molt seasons because the winter period consisted of only one observation date and therefore a mean could not be generated for comparison (Table 4.23). Due to the imbalance in the seasonal periods, the mean number of daily observations allows for a clearer comparison of observed activity levels. In terms of birds observed on the OCHM roof, the generated mean of 1.52 birds observed per day supported the observed data which stated the brood rearing season was the season with the highest general activity levels.

Table 4.22 Proportion of visits on the OCHM green roof as a percentage of the total number of species and total seasonal visits

Common Name	Taxonomic Name	4-Letter Code	Observation Period: 25-Feb	Mar 1 - Mar 21	Apr 8 - Jun 17	Jul 2 - Jul 29	Total # of Birds	% of Grand Total
northern mockingbird	*Mimus polyglottos*	NOMO		1	20	2	23	79.31%
American robin	*Turdus migratorius*	AMRO			1		1	3.44%
European starling	*Sturnus vulgaris*	EUST			1		1	3.44%
house finch	*Haemorhous mexicanus*	HOFI			4		4	13.79%
	Seasonal Total		0	1	26	2	29	
	% of Seasonal Total		0%	3.44%	89.65%	6.89%		

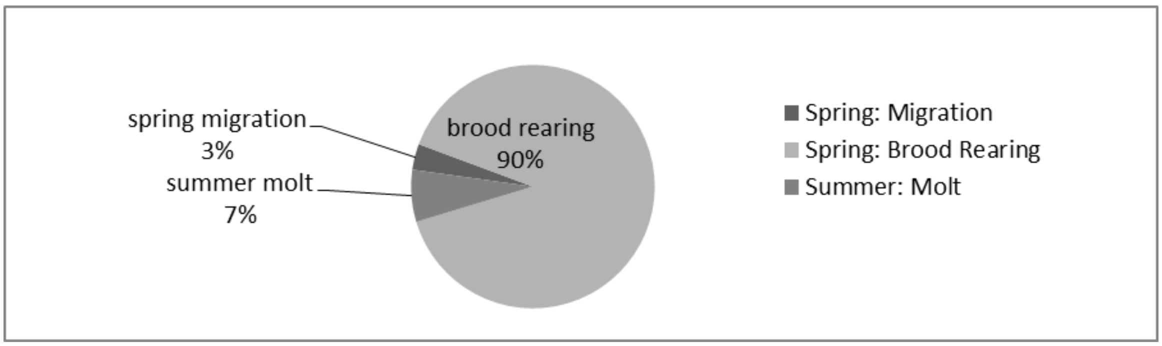

Figure 4.67 Overall seasonal proportion of birds observed on OCHM roof

Table 4.23 Calculated daily mean of the number of birds observed on the green roof during each season at OCHM

season	time period	# days spent observing	total # of days in season	observed total # flyovers	observed mean (# flyovers /day)
spring migration	Mar 1- Mar 21	7	21	1	**0.143**
brood rearing	Apr 8 -Jun 17	17	70	26	**1.52**
summer molt	Jul 2- Jul 29	5	28	2	**0.2**

Note: The winter season was excluded because there was not enough observation data to generate a mean.

The most common behavior observed at the OCHM green roof over all seasons was resting/perching. This behavior was counted twenty-eight total times over the study period, where every bird that landed on the roof remained at least for some period of time before leaving except for one NOMO who only briefly foraged during their particular visit. Foraging behaviors were expressed five times during the April 8-June 17 time period and only one time during the July 1-29 time period. All observations of forage were unique to NOMO. NOMO was also the only species observed singing/calling from the OCHM green roof and this behavior was witnessed only during the April 8- June 17 time period (Table 4.24). NOMO often would perch on the camera and once flew directly towards the lens before taking a rest on the Handycam (Figures 4.68-69).

Figure 4.68 June 12, 2014: NOMO approaches camera to perch

Figure 4.69 June 12, 2014: NOMO the moment before it landed on the camera

A total of six hundred and seven flyovers were observed at this site over the course of the twenty-four week study with one hundred and two (49.75%) observations counted as UNBI (Table 4.25). The most common flyover species were NOMO, AMRO, EUST, MODO, *Streptopelia decaocto* (EUCD), BARS, and *Melanerpes erythrocephalus* (RHWO). UNBL was also considered a common flyover species; however, one massive low-flying flock on the winter observation date was responsible for its appearance on the list.

The winter observation date (February 25) accounts for 37.23% of the flyover observations with two hundred and twenty-six sightings (Figure 4.71). The large flock of UNBL which flew in low over the roof accounted for 88.49% of observed flyover individuals on that date. Spring migration (March 1-21) observed just twenty-three individuals at 3.78%. By season, the most flyovers were observed during the April 8-June 17 brood rearing time period where two hundred and seventy-one birds made up the 44.64% of the total. The summer molt (July 2- July 29) observed eighty-seven, or 14.33% of flyovers.

Aside from the large flock of UNBL observed on the winter date AMRO, NOMO, and UNSP were the only species clearly observed on that day. During the spring migration period there were only twenty-three flyover birds observed total. Of these, thirteen (56.52%) were UNBI. NOMO was responsible for seven of the ten positive ID's, where AMRO, *Toxostoma rufum* (BRTH), and MODO were each observed once during this time period (Figure 4.72). Of the two hundred and seventy-one flyover observations made during the April 8 - June 17 time period, sixty-five (23.98%) individuals were UNBI. Beyond this, the most common species observed include BLJA, NOMO, and BARS each being counted thirty-eight, thirty-one, and twenty-six times, respectively (Figure 4.73). Eighty-seven flyovers were counted in the summer molt period where ten (11.49%) of these were UNBI. Common species observed flying over the OCHM green roof include AMRO, CAEG, and MODO (Figure 4.74). The process for generating the mean number of flyover birds observed each day was repeated using the OCHM data to create a clearer seasonal comparison (Table 4.26). The means generated suggested both the brood rearing and summer molt seasons were the busiest on average for flyover birds at OCHM with mean values of 77.4 and 62, respectively. The spring migration season observed approximately 21.58 birds a day which was at least 60% fewer birds per day than the other comparable seasons.

The species observed flying over OCHM during each of the four seasons helps to show which species were present during each time period. During season 1, only four species were observed flying over and were identified as: AMRO, NOMO, UNBL, and UNSP. Season 2, like season 1, only saw four species: AMRO, NOMO, MODO, and BRTH. During season 3, sixteen species were identified and included: AMRO, BARS, BLJA, EUCD, EUST, HOFI, HOSP, MODO, NOCA, NOFL, NOMO, PUFI, RBWO, RHWO, UNBL, and UNSP. Season 4 observed ten species: AMRO, BARS, BLJA, CACH, CAEG, CHSW, RHWO, NOMO, MODO, and MIKI.

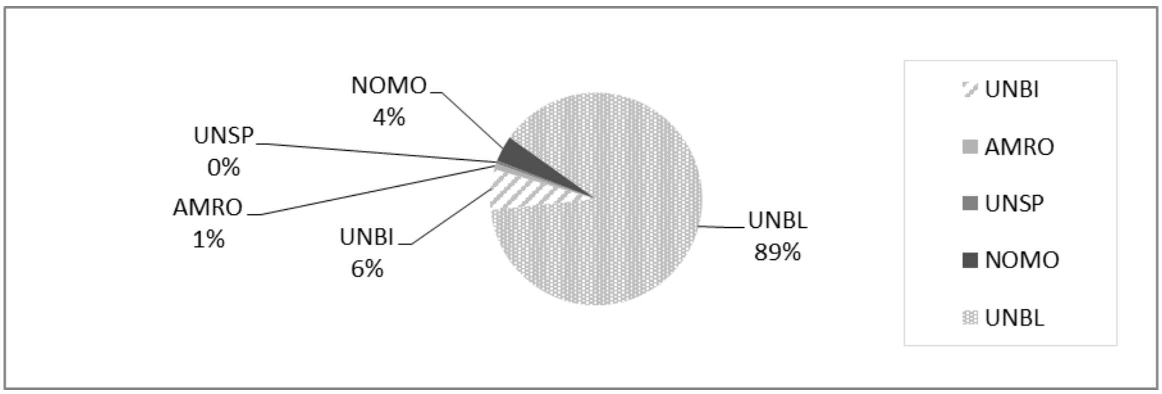

Figure 4.70 Proportion of flyover birds February 25 at OCHM

Table 4.24 Observed species and behaviors at OCHM

Common Name	*Taxonomic Name*		(Family)	**4-Letter Code**
European starling	*Sturnus vulgaris*		(Sturnidae)	**EUST**
behavior	**Mar 1-21**	**Apr 8-Jun 17**	**Jul 1-29**	**TOTAL**
resting/perching		1		**1**
foraging				
singing/calling				
grooming				
defending/aggressing				
TOTAL		**1**		**1**
American robin	*Turdus migratorius*		(Turdidae)	**AMRO**
behavior	**Mar 1-21**	**Apr 8-Jun 17**	**Jul 1-29**	**TOTAL**
resting/perching		1		**1**
foraging				
singing/calling				
grooming				
defending/aggressing				
TOTAL		**1**		**1**
northern mockingbird	*Mimus polyglottos*		(Mimidae)	**NOMO**
behavior	**Mar 1-21**	**Apr 8-Jun 17**	**Jul 1-29**	**TOTAL**
resting/perching	1	19	2	**22**
foraging		5	1	**6**
singing/calling		2		**2**
grooming				
defending/aggressing				
TOTAL	**1**	**26**	**3**	**30**
house finch	*Haemorhous mexicanus*		(Fringillidae)	**HOFI**
behavior	**Mar 1-21**	**Apr 8-Jun 17**	**Jul 1-29**	**TOTAL**
resting/perching		4		**4**
foraging				
singing/calling				
grooming				
defending/aggressing				
TOTAL		**4**		**4**

Table 4.25 Proportion of OCHM flyovers as a percentage of the total number of species and total seasonal visits

		Season	1	2	3	4		
Common Name	**Taxonomic Name**	**4-Letter Code**	**25-Feb**	**Mar 1- Mar 21**	**Apr 8- Jun 17**	**Jul 2- Jul 29**	**Total # of Birds**	**% of Grand Total**
American robin	*Turdus migratorius*	AMRO	2	1	16	17	36	5.88%
barn swallow	*Hirundo rustica*	BARS			26	2	28	4.57%
Blue jay	*Cyanocitta cristata*	BLJA			38	1	39	6.37%
Carolina chickadee	*Poecile carolinensis*	CACH				1	1	0.16%
cattle egret	*Bubulcus ibis*	CAEG				16	16	2.61%
chimney swift	*Chaetura pelagica*	CHSW				6	6	0.98%
Eurasian collared-dove	*Streptopelia decaocto*	EUCD			7		7	1.14%
European starling	*Sturnus vulgaris*	EUST			27		27	4.41%
house finch	*Haemorhous mexicanus*	HOFI			8		8	1.30%
house sparrow	*Passer domesticus*	HOSP			1		1	0.16%
Mississippi kite	*Ictinia mississippiensis*	MIKI				1	1	0.16%
mourning dove	*Zenaida macroura*	MODO		1	11	15	27	4.41%
Northern cardinal	*Cardinalis cardinalis*	NOCA			9		9	1.47%
northern flicker "yellow shafted"	*Colaptes auratus*	NOFL			2		2	0.32%
northern mockingbird	*Mimus polyglottos*	NOMO	9	7	31	8	55	8.98%
purple finch	*Haemorhous purpureus*	PUFI			2		2	0.32%
red-bellied woodpecker	*Melanerpes carolinus*	RBWO			2		2	0.32%
red-headed woodpecker	*Melanerpes erythrocephalus*	RHWO			10	10	20	3.26%

Table 4.25 continued

unknown bird	varies	UNBI	14	13	65	10	102	16.66%
unknown blackbird	(Icteridae)	UNBL	200		8		208	33.98%
unknown sparrow	(Emberizidae)	UNSP	1		6	7	14	2.28%
brown thrasher	*Toxostoma rufum*	BRTH		1			1	0.16%
	Seasonal Total		226	23	269	94	**612**	
	% of Seasonal Total		36.93%	3.75%	43.95%	15.35%		

Table 4.26 Calculated daily mean of the number of birds observed flying over the green roof during each season at OCHM

season	date	# days spent observing	total # of days in season	observed total # flyovers	observed mean (# flyovers /day)	expected total (obs. mean x # days in season)	adjusted total (obs. mean x 20)
spring migration	Mar 1-Mar 21	7	21	23	**1.09**	22.89	**21.58**
brood rearing	Apr 8-Jun 17	17	70	271	**3.87**	270.9	**77.4**
summer molt	Jul 2- Jul 29	5	28	87	**3.1**	86.8	**62**

Note: Data from Table 4.25.

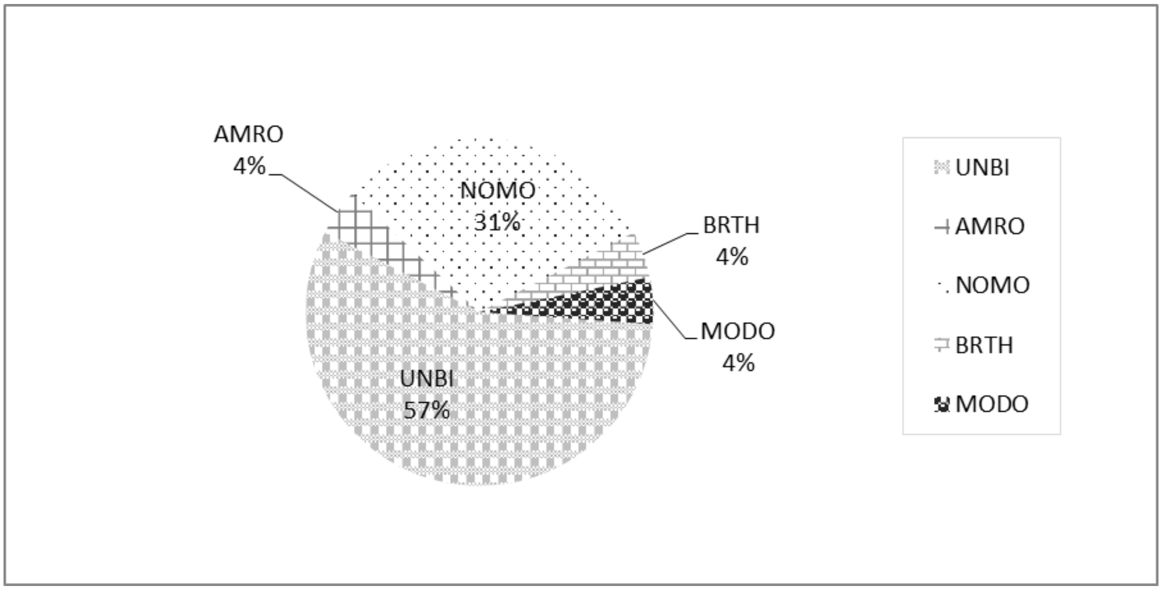

Figure 4.71 Proportion of flyover birds March 1-21 at OCHM

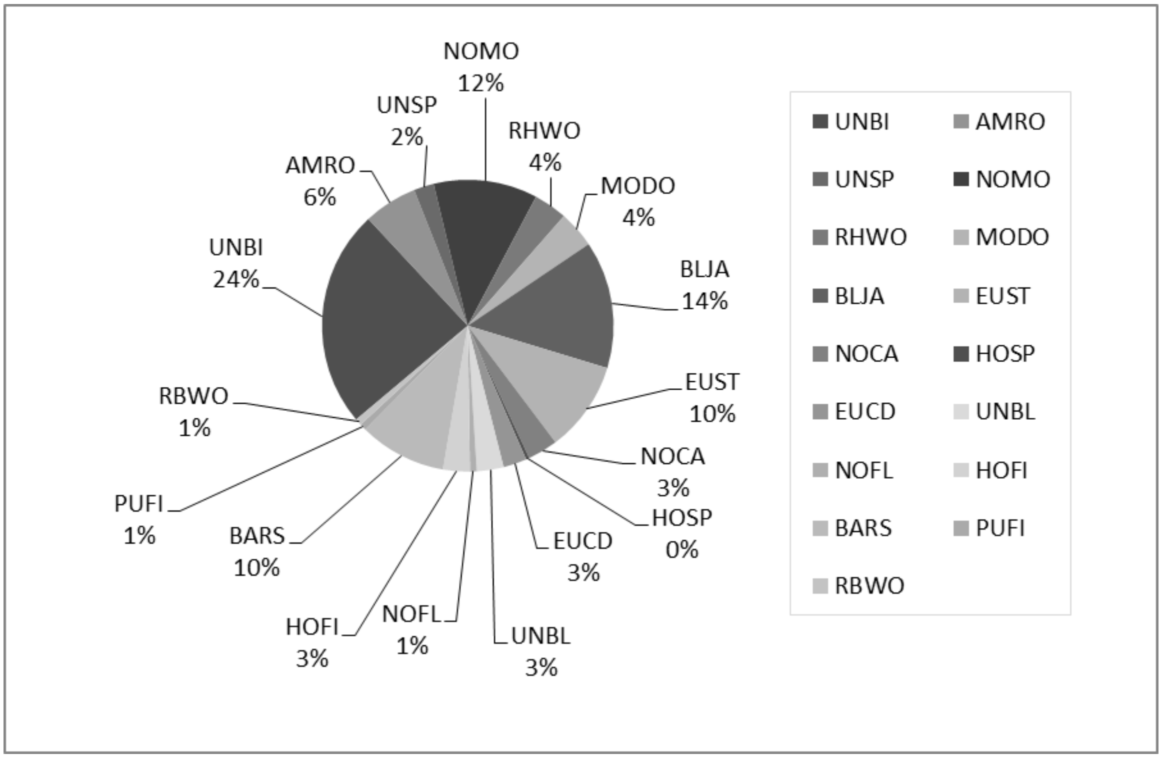

Figure 4.72 Proportion of flyover birds April 8-June 17 at OCHM

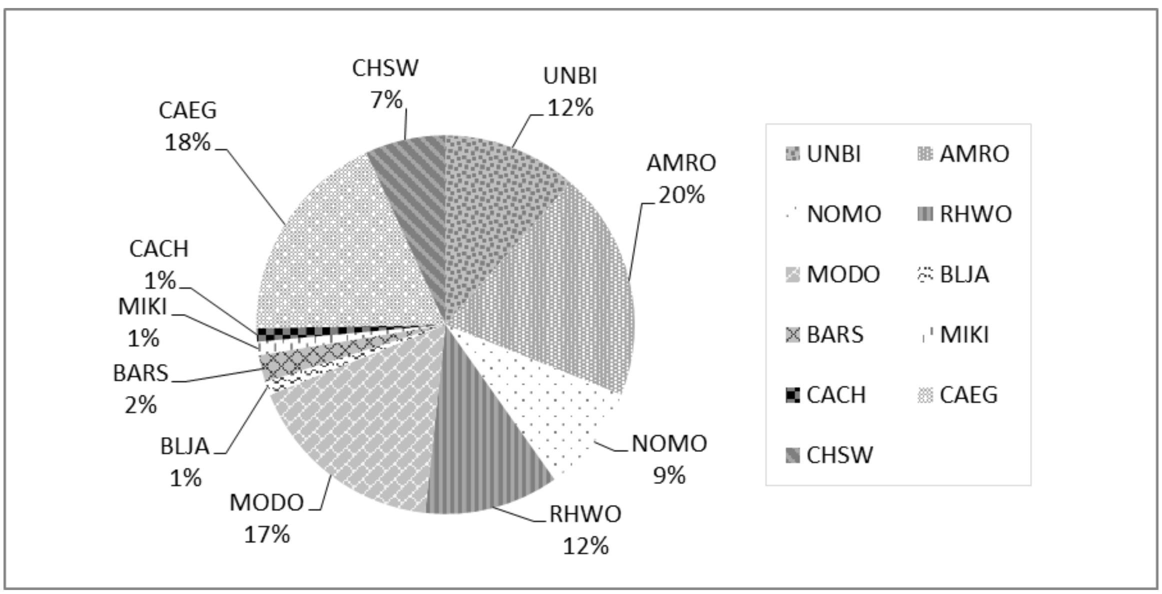

Figure 4.73 Proportion of flyover birds July 1-29 at OCHM

CHAPTER V

DISCUSSION AND CONCLUSIONS

Introduction

The final chapter of this thesis synthesizes the results and offers a discussion of and conclusions about the research. First, a review of the study purpose and methodology is offered. Next, a discussion follows, which considers observations made at both sites and offers detailed insight into the most common species identified in this study. The study's limitations are then reviewed. Then the conclusions are presented. And to conclude the thesis, recommendations regarding the advancement of the discipline of landscape architecture with reference to biodiversity management are offered.

Study Purpose and Methodology

It has already been established by multiple researchers across the globe that green roofs offer space for wildlife and play an important role in the local ecosystems where they exist (Baumann, 2006; Brenneisen, 2006; Eakin et al., 2013; Eakin, 2012; Gedge & Kadas, 2005). The purpose of this study was to measure avian response to green roof infrastructure in order to better understand what species are taking advantage of them and understand how they are utilizing the roofs. In doing this, a baseline would be established which helps define what role a green roof may have in enhancing biodiversity in the humid-subtropical climate. Systematic observations were conducted over twenty-four weeks at two sites of varying urban context where avian turnout and behaviors were recorded. Specifically, this thesis seeks to understand if there was a difference in *Sedum,* Prairie green, and traditional roof types with respect to avian response. Focusing on the ability to make a distinction between roof types at the GIRA site, the mean number of birds landing on the differing roof types was statistically analyzed to determine whether there was a difference in roof treatment with respect to vegetative class.

Discussion

The following discussion is divided into four sections. First, green roofs in the context of the greater landscape matrix will be addressed. Next, the discussion will approach how human activity influences avian diversity. The third section compares local and landscape diversity between OCHM and GIRA sites. And the final section discusses the six most common species observed at GIRA and what clues these species might provide for how green roofs are being utilized in the humid subtropical climate region.

Green Roofs in the Landscape Matrix

Each site contributes and relates to its respective context (Opdam & Wiens, 2002) because no system exists in a vacuum. And because the green roofs are living, they contribute to the existing patches of habitat in the greater landscape matrix (Baumann & Kasten, 2010). And the green roofs, like all anthropogenic constructions, are physical elements in the larger landscape matrix that impact wildlife habitat because their creation changed site conditions (Meyer & Turner, 1992). In the rural agricultural context of SF, the green roofs at GIRA fragment the landscape (Fahrig, 2003) because they further break up the existing landscape into smaller patches of habitat. At OCHM, the green roof and associated structure can also be considered habitat fragmentation (Fahrig, 2003) because the development of the green roof restored a living habitat niche to a location where a slab of lifeless impervious asphalt paving previously covered the ground. In Fahrig's (2003) study of the effect of fragmentation on biodiversity, he describes habitat fragmentation as a landscape process that simultaneously reduces overall available habitat while increasing the total number of habitat patches. Habitat fragmentation occurs through the breaking part of a habitat area into smaller habitat areas. This process is what increases the number of habitat patches. As fragmentation continues, the size of habitat patches become smaller and the space between patches increases (Fahrig, 2003).

In addition, the findings suggest that biotic response to habitat fragmentation does not parallel the process of fragmentation of habitat. Biodiversity takes a hit when habitat fragmentation includes habitat loss. Because of this, urban areas are often characterized by "reduced species richness, population abundance and distribution, and genetic diversity" (Fahrig, 2003) where anthropogenic manipulation brings the degree or percent of disturbance close to 100% and habitat loss is abundant.

The physical footprint of the BMP installments at GIRA replaced an area that was previously maintained as lawn with a combination of structures and additions on the ground. The model green roof array supports approximately 192 ft^2 of *Sedum* plantings and approximately 160 ft^2 of Blackland prairie plantings. Control roofs are associated with habitat loss because impervious surfaces are generally not considered habitat. The physical structures, however, are associated with an arguably small amount of habitat because insects in the order of Hymenoptera have been observed attempting to establish homes under all three kinds of model roof structures.

Fahrig's (2003) research also suggests habitat fragmentation is not necessarily a negative process. The positive effects of fragmentation include contributions to species which require multiple habitat types in their daily life cycles. If no habitat loss has occurred, increases in fragmentation means shorter distances between patches. This process simultaneously creates more edges, which can increase biodiversity (Fahrig, 2003).

The results of the analysis of variance (ANOVA) indicated a significant difference in mean number of birds visiting vegetated roofs vs mean number of birds visiting the control roof type at GIRA. The ANOVA detected the difference, and the linear contrasts were used to pinpoint the variance. The only null hypothesis accepted in the linear contrasts proposed that the *Sedum* and prairie roof types were the same ($P = 0.5357$) (Table 4.12). The apparent statistical similarity between vegetated roof types with respect to mean number of birds visiting supports the findings of Fahrig's 2003 study where habitat fragmentation has less of an effect on biodiversity than does habitat loss.

Human Activity Influences Avian Diversity

There is a lot of speculation about the limiting factors of bird diversity including the effects of climate and weather phenomena, disease and parasite irruptions, food availability, and predation (Lack, 1954). On the landscape scale, other factors influencing populations relates to quality and quantity of available vegetation and habitat (Clergeau et al., 1998) and distance between viable habitat patches (Melles, 2005). As conditions in nature are always changing, it can be difficult to identify the specific limiting factors (Holmes et al., 1986). Lack (1954) identified five major areas where humans impact bird populations: shooting/hunting/extermination, protection through conservation, collisions between maintenance/harvest and nesting/breeding seasons, supplemental feeding, and through the alteration of natural habitat. For better or worse, human activity impacts the environment, affecting species diversity, richness, and distribution (Alberti et al., 2003; Bibby, 2002) through settlement and the conversion of land (Meyer & Turner, 1992). Clergeau et al., (1998) suggest the dynamics of urban bird communities depend more on local site features than regional ones and are impacted more by the presence of high quality habitat versus low quality habitat. Regardless of the specific factor that may restrict avian diversity and distribution, birds will be present in the urban context as long as humans are providing for at least some, if not all, of their needs (Lancaster & Rees, 1979).

The major assumption of this study that certain birds (i.e. common species) were seen because they were already present in the landscape or nesting nearby because some, if not all, of their habitat requirements were being met. Reale and Blair (2005) cited several limiting factors for avian populations, but suggested the availability of nesting sites along the urban-rural gradient is the most important factor in determining avian distribution. In their study, sites with lower human populations in rural contexts were associated with greater species abundance and diversity than more urbanized sites with lower quantities of vegetation and a higher overall human population density. In addition, Reale and Blair (2005) noted available vegetation and open space for forage was also an important component of population dynamics. During the twenty-four week study, avian activity was observed at both GIRA and OCHM and because of time spent around the research sites, avian habitat and nests were observed in vicinity. Both GIRA and OCHM sites had additional nesting and foraging resources nearby.

All across SF, including the GIRA site, nest boxes are provided periodically along fencerows adjacent one to the roadside. INBU and EABL have been observed using these. In addition, at least one colony of EUST was identified as living in buildings adjacent to the study site. A group of BARS inhabit the high-tunnel barn to the immediate northwest of the study site. At least one breeding pair each of RWBL and NOMO were identified as local nesters and were observed flying between the green roof and nest sites on multiple occasions. It is assumed there were EAME nests nearby as they were observed frequently around SF and at GIRA, specifically. In addition, the rural nature of the SF context meant the entire surrounding areas could have provided both diverse forage and suitable habitat niches (i.e. pastures, streams, aquaculture, gardens, trees, and herbaceous research plots).

At OCHM, different habitat niches around the site have also been identified. Early in the spring, a pair of NOMO selected the *Acer rubrum* to the immediate south of the green roof for their nest. At least one pair of RHWO made their home in a *Carya illinoinensis* tree approximately 28 m away to the northwest of the roof. To the east of the roof approximately 34 m away, a *Liquidambar styraciflua* was home to at least one nest of BLJA and was observed to be a relatively popular feature for avifauna in the local context. The estimated 550,000 ft^2 cemetery neighboring the OCHM site was often observed in forage and local resources available at the cemetery included general turf grass and several *Juniperus virginiana,* and trees of the genera *Pinus* and *Quercus*. Residents in the area have also been known to provide feeders and supplemental water resources. In addition, the sky above a relatively recently razed lot (approximately 50,000 ft^2 of brownfield) to the southeast of the roof was often observed in forage by BARS. As the context around both sites is almost completely disturbed and periodically maintained, all available habitat and resources in these areas exist because of land-/homeowner choice (McKinney, 2002).

Although the context of both sites can be described at varying levels of disturbance with varying degrees of regular or semi-regular maintenance and traffic, they do provide enough resources to both attract and support a local avian population. A 2011 birdscape study in Baltimore, MD suggested avifauna have a delayed response to changes in the landscape with respect to urban development and sites may need up to two or three years before they are discovered and colonized (Nilon et al., 2011). A correlation between green roof age and biodiversity has been noted in other research regarding urban ecosystems (Baumann & Kasten, 2010; Dunnett et al., 2008).

Other research has cited phenomena related to urbanization's effect on avian populations. In a 2005 study examining the relationship between landscape dynamics and avian diversity revealed that access to high quality natural areas are critical for determining avian population densities, richness, and distributions (Melles, 2005). Because urban ecosystems are highly modified for human use and generally not planned with biodiversity or conservation in mind, the available habitat in urban areas are considered only coincidental (Melles, 2005). The gradient concept for avian diversity suggested by Clergeau, et al., (1998) state that on a gradient moving from urban to rural, the environment changes from one that is characterized by less vegetation and more structure to an environment where structures become less prevalent and vegetation increases. Along this urban to rural gradient the environment varies and the spatial structure of the settlement pattern is what influences natural annual cycles (Clergeau et al., 1998). In addition, Clergeau et al. (1998) suggest it is the local site features, not the greater landscape features which have a greater impact on species diversity. Sadler et al. (2010) suggest the "loss of urban green space may be leading to the loss of functional diversity in urban areas." This is a commonly recognized problem because of the apparent diversity gradient which occurs over differing levels of urbanization and disturbance (Clergeau et al., 1998; Reale & Blair, 2005).

Local versus Landscape Biodiversity

Comparison of species observed at each site afforded a glimpse into the biodiversity dynamics experienced at both sites in Starkville, MS. Birds that landed on the roofs at either GIRA or OCHM provided information regarding local species diversity. And flyover observations provided information regarding species diversity on the landscape scale.

Species observed vary in terms of scale across both sites. At GIRA, one thousand eight hundred and seventy-eight total birds were observed. Of these, four hundred and thirty-five observations were of birds representing sixteen species which landed on the model roofs and one thousand four hundred and thirty-nine were flyover observations that represented twenty-two total species. Overall, twenty-four individual species were recorded at GIRA. At OCHM, six hundred and thirty-four total birds were observed. Of these, twenty-nine were birds that were observed landing on the green roof and six hundred and five were birds observed as flyovers. Four species were observed utilizing the OCHM green roof and twenty-one species were observed flying over the OCHM site.

In terms of activity, GIRA saw more avian visitors both on the test roofs (29:435) as well as in the air (605:1439).

On the local scale, all of the species observed utilizing the OCHM green roof were observed on the green roofs at GIRA (NOMO, AMRO, EUST, & HOFI). In terms of diversity, GIRA appears to be the more diverse site with 8 additional species observed utilizing the roofs in the more rural context. At the landscape scale, twelve flyover species were found to be present flying over both sites. There were eight species observed flying over GIRA that were not observed flying over OCHM (WWDO, AMCR, RWBL, EABL, EAME, TUVU, CANG, & KILL) and eight species were observed flying over OCHM that were not observed flying over GIRA (HOSP, RHWO, NOCA, CHSW, NOFL, RBWO, BRTH, & CACH). Data regarding species observed in this study begins to define the regional response of avifauna to urban development in and around Starkville, MS. Data presented in this thesis contributes to the discussion about which species are present in regional landscape mosaics and utilizing existing green roof habitats (Brenneisen, 2006).

What has been generated through observation is a suite of species of varying degrees of rarity and density that were present in the landscape during the twenty-four week study (Table 5.1). The number of species observed changed from season to season, but overall, the number of species observed increased. Combining the overall species observation data for both sites into a single graphic allows for at-a-glance consideration of local and landscape species data while simultaneously being able to tell which species are responding to green roofs and which species were the most active roof users during each time period. During season 1, ten species were observed. Five species were unique to GIRA, four were observed at both sites, and only one species was unique to OCHM. During this time, UNSP, RWBL, EABL, and EUST were the most commonly observed species with the highest observed usage of the GIRA test roofs.

In season 2, fourteen species were observed with the most active of the common species shifted and RWBL dropped from the list of species with high activity on test roofs. During this time period, there was only one species observed solely at OCHM , three species common to both GIRA and OCHM, and ten species that were only observed at GIRA.

In season 3, twenty-six species were observed. Ten of these were common to both research sites, five species were unique to OCHM, and nine were observed only at OCHM during this time period. The most common species with activity spikes during this time period were EABL, NOMO, MODO, and RWBL. Season 4, with nineteen total species observed, had only NOMO and MODO representing common species with high levels of activity.

In review, regardless of local or landscape scale, the general suite of birds flying over the research sites and landing on the roofs was similar. The OCHM roof, a relatively-new installment in the landscape, observed just four species in the more urban context. GIRA, the more rural site, observed sixteen individual visiting species. In general, it appears both the GIRA and OCHM sites experience the same basic suite of species with exceptions being those species with habitat restrictions (i.e. EAME's preference for grasslands explains their presence at GIRA; RHWO's preference for cavity nesting in trees explains their presence at OCHM). This is consistent with Eakin

(2012) where birds using the green roofs have been those who nest nearby or have home ranges which encompass the green roof location.

Table 5.1 Overall species presence at both GIRA and OCHM

Season			
1	**2**	**3**	**4**
AMRO	*AMRO*	*AMRO*	AMRO
	AMCR	AMCR	
		BARS	BARS
		BLJA	BLJA
	BRTH		
			CACH
			CHSW
		CAEG	CAEG
	CANG	CANG	
		EAKI	
EABL	***EABL***	***EABL***	*EABL*
EUST	***EUST***	*EUST*	*EUST*
	EAME	EAME	*EAME*
		EUCD	
		HOFI	*HOFI*
		HOSP	
			INBU
KILL		KILL	KILL
			LOSH
			MIKI
MODO	MODO	***MODO***	***MODO***
NOMO	*NOMO*	***NOMO***	***NOMO***
		NOCA	
		NOFL	
	PUFI	PUFI	
RWBL	*RWBL*	***RWBL***	RWBL
		RBWO	
		RHWO	RHWO
UNBL	UNBL	*UNBL*	
UNSP	**UNSP**	*UNSP*	
TUVU	TUVU	TUVU	TUVU
		WWDO	
Legend			
Site	GIRA	OCHM	BOTH

Note: "**BOLD**"4-letter codes refers to activity spikes witnessed in the 6 most common species observed at GIRA (Figure 4.4, page 63) "*UNDERLINED ITALICS*" 4-letter codes refers to species that were observed landing on green roofs at GIRA and OCHM.

Common Species Provide Clues about Habitat Requirements

The six most common species observed were EABL, EUST, NOMO, MODO, RWBL, and UNSP. Each of these species is commonly found in this region and is tolerable of low levels of human disturbance. The final portion of the discussion focuses on the most common species observed because they are more likely to give clues about what needs the niche habitat green roofs were fulfilling. For the purpose of this discussion, the habitat requirements of the *Spizella pusilla* (FISP) will be utilized to represent UNSP because this species' presence in the SF context is a reasonable assumption. Based on information obtained from The Cornell Lab of Ornithology's *All About Birds* bird guide (n.d.), the habitat requirements of EABL, EUST, NOMO, MODO, RWBL, and FISP (Table 5.2) indicate each of these species are capable of utilizing a variety of habitat types (minimum of four each) and food sources (minimum of two each) in order to satisfy their needs. MODO, NOMO, RWBL, and FISP are cup nesters. FISP and MODO are known to nest on the ground as well as in trees, while RWBL prefers to nest in dense grass-like vegetation, NOMO prefers to nest in trees. EABL will nest in cavities in trees or will utilize nest boxes of human construction. EUST, who are also cavity nesters, are well-known for their association with human development (Maurer et al., 2001). Each of these habitat types was seemingly available at or around SF. At OCHM, where NOMO was most common, a confirmed NOMO nest was located in a tree within a few meters of the roof.

McKinney (2002) categorizes avifauna into three general groups: urban exploiters, urban adapters, and urban avoiders. Urban exploiters, species like EUST, are those whose existence is contingent on habitat and resources provided by human activities. Urban adapters, species like MODO, are those that will take advantage of both natural and anthropogenic resources. And urban avoiders, species like EAME, are those that have a specific preference for natural resources. Five of the six most common species observed in this study may be categorized as urban adapters, while EUST was the only urban exploiter commonly observed. Urban-adapted avifauna express a variety of traits, but McKinney (2002) explains many are members of generalist feeding guilds, including: omnivores, ground foragers, seed eaters, and aerial sweepers. The green roofs at GIRA and OCHM appear to have primarily attracted and supported urban adapters and urban exploiters over the duration of the entire study period.

Table 5.2 Habitat requirements of six most common species observed

Species	Habitat	Food	Behavior	Nests	Young
MODO	open woodland, wood lots, grasslands, agricultural fields, backyards, roadsides	99% seeds, occasionally berries or snails	ground foraging, open country bird	creates a flimsy nest of pine needles or twigs in/on trees, ground, gutters, eaves, abandoned equipment	2 eggs; 1-6 broods
NOMO	towns, suburbs, backyards, parks, forest edges, open land	omnivore; primarily insects, fruit	territorial, very vocal	cup nest created in trees	2-6 eggs; 2-3 broods
RWBL	marshes, along watercourses, meadows, fields	insects, seeds	territorial, very vocal	cup nest created in dense grass-like vegetation	2-4 eggs; 1-2 broods
EUST	towns, suburbs, backyards, parks, forest edges, open land	omnivore; insects, fruit, grains, seeds, nectar, livestock feed, garbage	territorial, very vocal	cavity nests; primarily associated with human development	3-6 eggs; 1-2 broods
EABL	pine savanna, open woods, pastures, agriculture fields, suburban parks, backyards, golf courses	insects, fruit	utilizes perches to hunt prey	cavity nests; trees or nest boxes	2-7 eggs; 1-3 broods
FISP	scrub, abandoned agricultural fields, openings in wooded areas, fencerows, pastures	seeds, insects	will forage in groups, shy around human habitation	cup nest created on the ground or low tree branches up to 10' high	1-5 eggs; 1-5 broods

Note: Data from Cornell Lab of Ornithology "All About Birds" online bird guide

Limitations

For the purpose of this study there were a few assumptions made. The first assumes that because each of the green roof sites exists in nature, it was reasonable to assume a bird might land on any of them. It was also assumed because of the size and context of the green and control roof array at the GIRA site, it might "act" like a single roof spatially, but that bird activity could still be counted with respect to roof type because in essence, birds still had a choice as to which specific roof type to land on.

The researcher's field glasses were upgraded after the first several weeks of observations. Originally, observations were made with MultiTech Survivor 8x22 Ruby field glasses. In April, waterproof Bushnell FOV305FT 10x42 field glasses were acquired and used continuously for observation until completion of the study.

In the first weeks of the study, attempts were made to make up missed site visits during the week due to inclement weather or other reasons on the following Saturday or Sunday. Attempts to keep up with missed site visits failed. The researcher did not anticipate so many conflicting variables which made performing the study difficult over the twenty-four week time period. The fluctuating observation schedule provided a challenging morning adjustment for the researcher. Unforeseen school and work obligations also occasionally dislodged observation appointments. In terms of inclement weather, the threshold of tolerable weather differed between OCHM and the GIRA. Precipitation forced the cancellation of observations from the OCHM because exposure of the video camera to moisture was imminent.

A perfect position for observation could never be achieved where line of sight was not obstructed in some capacity during each observation session at OCHM. And capturing the maximum area of the OCHM rooftop on camera was a challenge. The primary conflict was that the camera lens could only capture so much of the roof at one time. At OCHM, the Handycam was placed on the northeast corner of the green roof with the lens facing southwest after it was determined this would provide the best view of the roof (Figure 5.1). Because of the growing vegetation, the tripod position and height had to be manipulated several times at different points in the study in order to maintain visibility on the roof. As a consequence, there was slight variation in video captured from observation to observation. In addition, unforeseen disturbances occasionally derailed observations (Figure 5.2).

Visibility at GIRA was also limited due to vantage point. Observations were made from the parking lot during the first several weeks of the study and observations were made from the blind on top of the observation tower (Figures 5.3-4) starting in May 2014 and continuing until the end of the study period. From the parking lot, it was difficult to see avifauna approach from the north and west sides. And at a greater distance from the array, positive ID's were more difficult to achieve. Ability to view flight between test roof structures was also limited during parking lot observations. From the tower, overall visibility increased because the tower provided a bird's eye view of the entire array. Not surprisingly, flyovers did become more challenging to spot from the tower because the burlap and *Ligustrum sinense*-covered platform drastically narrowed the available field of view and created a very effective blind.

Figure 5.1 View from the Handycam lens on March 18, 2014 showing the general extent of visibility for rooftop observations

Note: Birds landing on the structure surrounding the staircase were not counted in the study as birds landing on the green roof; however, the structure was often utilized as a perch for various avifauna.

Figure 5.2 View of a disturbance event at OCHM from the Handycam lens on April 28, 2014

Figure 5.3 View of GIRA array with respect to observation tower and blind from the original observation point

Figure 5.4 Observation tower height compared to height of GIRA array.

Note: Height and placement of the tower allowed for closer viewing of the roofs and a better vantage point from which to observe avian behavior. Once this became a fixture in the landscape, it was utilized often by birds to perch.

Towards Advancement in the Discipline of Landscape Architecture

The surge in green technology implementation to mitigate impacts from anthropogenic change is occurring globally. Green roof design focuses on the often forgotten 5th façade, where developments in stormwater management (Berghage et al., 2009), advancements in substrate and vegetative performance (Dunnett et al., 2008; Emilsson, 2008), offsetting UHI (Gago et al., 2013; Sailor, 2002), and understanding the green roof's role in urban biodiversity (Baumann & Kasten, 2010; Brenneisen, 2006; Gedge & Kadas, 2005) across as many climate regions as possible helps architects, landscape architects, engineers, and other designers understand how anthropogenic development patterns are impacting the natural world.

Similar to other observational studies of avifauna and green roofs, it was confirmed through direct observation that regardless of the vegetation present on the roof, the mere presence of vegetation means wildlife will find it and take advantage of the available habitat niche (Gedge, 2003; Lundholm, 2006). The results of this study indicate vegetated roofs, regardless of class, invite and encourage biodiversity and offer more in terms of ecosystem services than conventional roofs. Though the results of this study did not indicate whether either site was capable of successful nesting and breeding success, it does indicate potential for these activities if habitat quality improves (Baumann & Kasten, 2010). Bauman and Kasten's 2010 study had two objectives: the first was to improve green roof vegetation; the second was to assess how vegetation impacted breeding success of *Vanellus vanellus* (NOLA) and *Charadris dubius* (LRPL). The results of their three year project claimed vegetative improvement between 90-100% and increased LRPL chick survival by five to ten days in the 2nd year of study. By enhancing the green roof vegetation, Bauman and Kasten made an impact on one of their target species. Perhaps comparable results could be achieved if vegetation at GIRA or OCHM were enhanced.

The results of this study can be helpful to landscape architects and designers in a number of ways. First, beginning to understand the relationship between avifauna and green roofs in the humid subtropical climate region will aid in the development of improved design guidelines for improving the biodiversity of green roofs in this region. A thesis examining green roof design in terms of biodiversity in Iowa (Narigon, 2013) observed avifauna behavior at ten green roofs with the intent of determining how birds were utilizing green roofs in the reported green roof area threshold of 2000 m^2 where species observations notably increased for larger roofs. The scale of the individual test roofs at GIRA has been debated as a limiting factor for nesting success and overall site biodiversity. EUST has taken advantage of structural elements (i.e.: gutters and flashing) for nests on multiple occasions, only to have them destroyed during routine maintenance. The 16 m^2 surface area of green roof is by no means a large patch of habitat and may fall below the minimum spatial threshold requirements of species which might otherwise find it attractive (Bennett et al., 2001). In their study, Bennett et al., (2001) explain that the pattern and process of habitat fragmentation "is a natural phenomenon in untouched landscapes at many spatial scales" but when fragmentation results in increasingly small habitat patches, and distance between patches increases, some species may not be able to find suitable habitat therein. In the greater landscape matrix, combined habitat fragmentation and habitat loss pressures ecosystems and wildlife populations (Bennett et al., 2001; Fahrig, 2003). So while the rooftop avian behaviors observed in this study are similar to observations by Eakin (2012) and Narigon (2013), patch size may limit how and which avifauna utilize available green roofs in this region.

Second, knowing which species are adapting to use green roofs is valuable for progression towards designing more favorable habitat areas where certain, specific populations can be targeted for conservation. Bibby (2002) explains the value of bird conservation in terms of economics: as a hobby, bird watching and hunting generate revenue because people will invest in equipment, books, and resources to enhance these activities. Bibby (2002) makes a case for ecotourism because it supports conservation and improves the economics of the local destination area. During observations at OCHM, public curiosity about the green roof dislodged observation sessions on more than one occasion. Although it was disruptive to data collection, it indicated that for Starkville, MS, green roofs may provide a unique destination for local tourism, but also an opportunity for public education and outreach.

And finally, the results of this study indicate the green roofs are successfully contributing to the habitat requirements of several generalist species in the area, including NOMO, MODO, EABL, RWBL, EUST, and UNSP. Specialist species that were occasionally identified utilizing roofs at GIRA, such as EAME, occasional flyover species observed such as KILL, or unofficial visitors like the unidentified hummingbird (UNHU) that was observed mid-June could become objects of green roof habitat conservation. Lundholm (2006) proposed a habitat template approach where green roofs are designed based on the region within which they are located in order to promote utilization of native species. Gedge and Kadas (2005) developed habitat on green roofs in London for the *Phoenicurus ochruros* based on their biodiversity design principles that call for varied substrate depth and biomass densities and differences in structural diversity.

A recent proposal for biodiverse roofs suggests selecting multiple target species and then designing habitat areas for each (Myers, 2012). In his thesis about the design of green roofs for biodiversity, Myers (2012) provides design guidelines for four green roofs tailored to different two avifauna species and two different types of pollinators. Myers proposes a different roof design for each of the four species that his proposal caters to. A combination of methods employing the habitat template approach and designing future green roofs for desired target species may result in the roofs being colonized by those desired target species.

Conclusions

The results of this study indicate there is a statistical difference between the 3 roof treatments examined where the *Sedum* and prairie roofs are statistically different and "better" than the control with respect to mean number of birds landing. There was no statistical difference *Sedum* and prairie vegetated roof types with respect to mean number of bird visits. This finding suggests green roofs positively impact biodiversity because their creation changes the physical land use from habitat loss (control type) back to a habitat fragment or patch (living roof type).

The results of this study indicate there is a link between green roofs and habitat for avifauna in the humid subtropical climate region. In both the urban and rural contexts, green roofs are being utilized by multiple species for a broad scope of activities and behaviors. While no nesting was observed directly on the green roof, the structure itself provided many opportunities for urban-adapted species like EUST to take advantage.

This study indicates that the presence of vegetation on test roofs produced a higher mean use by avifauna on these types when compared to the control roof mean value for avifauna use. The results suggest the presence of vegetation on roofs has potential to increase the local biodiversity of avifauna in the humid subtropical climate.

Suggestions for Further Research

This study only begins to address the relationship between green roofs and avifauna in the humid subtropical climate and should be continued and improved upon. The potential for green roofs to act as vectors of biodiversity is still largely unexplored. In doing this, the research might identify differences in the biotic responses of roofs where biodiversity is the focus of the design goal.

Other studies could focus on the relationship between other biota and green roofs. For instance, investigations regarding available food types and forage items in the test roofs could be investigated. Or studies interested in understanding the relationship between green roofs and other animal taxa, such as Rodentia, Lepidoptera, or Hymenoptera could be undertaken. Identification of which insects or other creatures are colonizing green roofs in this region may provide a more holistic understanding of the potentials of these constructed ecosystems.

Green roofs as a niche habitat for pollinators or other species could be an extremely valuable untapped resource in this rapidly urbanizing world. Identification of acceptable habitat conditions and vegetative palettes for biota on green roofs in this climate region and others should be continuously explored and expanded. In addition, other test roof treatments should be developed for GIRA. Hybrid green roof systems (Werthmann, 2007) that blend characteristics from intensive and extensive green roof types or wetland green roof systems (Song et al., 2013) would provide an interesting backdrop for biodiversity research in the humid subtropical climate region. Studies focusing on avifauna could expand to include more sites across the southeast for an enhanced comparison of site use across a broader range. While green roofs are gaining popularity, they are still not widely used in this region, so the identification of existing roofs and newly constructed roofs should also be a recurring task for researchers.

A feeder study may also provide interesting clues to understanding avian response to green roofs (Riffell, personal discourse). A feeder study could help answer whether birds respond differently to roof types or may indicate a preferable roof type. In a feeder study focusing on NOCA in Davidson, North Carolina, Millican, McGovern, and

Stanback (2012) observed five feeding sites composed of two feeders each for a total of sixty-eight observation hours. Feeders were filled with two different food types known to attract NOCA and observed in order to explore social dynamics and feeder response. The results of their study provided a complex and detailed picture of avian social dynamics with respect to feeder choice and indicated an overall preference for black-oil sunflower seeds versus safflower seeds. Knowing that food is a limiting factor for avian populations (Holmes et al., 1986), landscape architects with intentions to develop and enhance avian populations on green roofs should first consider developing the green roof system utilizing design principles for biodiverse roofs utilized by Gedge and Kadas (2005) which requires planned variations in substrate depth, biomass densities, and differences in structural diversity of the green roof system. Then, by the addition of supplemental feeding, a designer could tailor their constructed ecosystem so that it supports desired wildlife species. At GIRA, a similar feeder study could indicate whether certain species prefer different feeder types and food sources on each of the different test roof treatments. This might help inform designers whether a certain species might have a preference towards visiting a specific feeder type on a particular green roof treatment and help identify other species which might respond to habitat enhancements.

Improvement on this particular study could come through altering the sampling periods from the study's current format. While the near-daily observations occurring at random times in the morning did allow the researcher a glimpse of understanding of how the sites were used by avifauna, the same information and understanding might have been gained with longer observation sessions occurring less frequently. In the study conducted by Eakin (2012), each site was visited only a couple of times each and site visits consisted of three-hour surveys beginning at dawn. A series of three counts is then undertaken, where seven-minute long observation sessions come after just a two-minute settling period before hand. In addition, three points at each study site were sampled to maximize coverage of the observed areas. If directly observing GIRA or OCHM in the future, more vantage points should be identified and secured in order to reduce bias from sampling from the same point every time.

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APPENDIX A

BIZARRE OBSERVATIONS

Figure A.1 Dead snake at OCHM: May 27, 2014

Note: A dead snake with one apparent puncture wound was found on the stair leading up to the OCHM green roof.

Figure A.2 March 18, 2014: *Bombycila cedrorum* (CEDW) feathers on OCHM roof

Note: Four individual clumps of feathers were found during this incident. Three of the four clumps were down feathers. This clump was the only one that included primary flight feathers.

Figure A.3 Egg shell fragment at GIRA: April 23, 2014

Note: No apparent nest was nearby. No other fragments were observed or located in the vicinity.

Figure A.4 Detail of egg shell found on April 23, 2014

Figure A.5 Detail 2 of egg shell found on April 23, 2014