Rethinking Urban Green Infrastructure as a Means to Promote Avian Conservation

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This Master's Project

Rethinking Urban Green Infrastructure as a Means to Promote Avian Conservation

by

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ABSTRACT

There is an under-recognized potential for cities to use urban green infrastructure to contribute to avian biodiversity conservation. At the global scale, climate change and growing urbanization are primary global drivers leading to decline and homogenization in world bird populations. Birds are fundamental and intricate species in ecosystems, and even in urban areas, act as indicator and regulator species contributing to healthy ecosystem function. While many cities have recognized the economic and social benefits associated with green spaces, such as the vast benefits ecosystem services provide to the urban dweller, the use of green spaces to concurrently contribute to avian conservation through habitat provisioning is currently deficient. This research provides a global comparative analysis to determine crucial variables in urban green spaces necessary to provide ecosystem services for the urban dweller while simultaneously supporting urban bird populations, particularly forest, grassland, and generalist bird species. It pushes for reform in existing management, norms, and principles that restrict green spaces' contribution towards avian conservation and acts as an ecological and conservation dialogue for policy makers, design-build and related professionals, and urban residents. The necessary abiotic, biotic, design, and management variables for urban forests and parks, residential gardens, and green roofs to support avian diversity are discussed, and management strategies and approaches are defined. Using these green spaces has the potential to create valuable avian habitat within our urban areas, which is increasingly important in light of growing urbanization and changing climatic conditions.
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1.0 Introduction

Urban green infrastructure, broadly defined as the network of all green spaces within a city, provides substantial economic, social, and ecological benefits. Economic benefits have been closely quantified and evaluated for cities, often having significant cost-savings compared to more traditional gray infrastructure (Box 2011, see Costanza et al. 1997 and Foster et al. 2011). Social benefits of green spaces have long been recognized by health and related professionals (Box 2011; Kabisch et al. 2015; Wolch et al. 2014). However, while there is growing attention and recognition of green spaces for their contribution to biodiversity, there is a general lack of guidance for urban planners, developers, stakeholders, and residents to understand how to use urban green infrastructure create habitat and provide resources for biodiversity (Hostetler 2012; Sadler et al. 2011; Threfall et al. 2016). Cities are originally constructed for humans, not for biodiversity, resulting in social and institutional barriers that impinge on conserving and contributing to biodiversity (Sadler et al. 2011). The purpose of this paper is to provide guidance for all urban users and stakeholders on how to properly construct habitat for birds in various urban green spaces. Urbanization has lasting effects on native species and habitat as cities and infrastructure continue to persist and typically expand through time (McKinney 2002).

Globally, urbanization and land cover change causes habitat destruction and will likely continue to be some of the greatest drivers of biodiversity loss (Seto et al. 2012). When coupled with projected human population growth, it is stated that how we construct and manage our urban areas through year 2030 will have the most lasting effects on land-use and future sustainability (Seto et al. 2012). This period in time is "the window of opportunity to shape future urbanization" (Seto et al. 2012, pg. 16085). We have already entered an unprecedented era of expansion and urbanization that will shape the future of cities.

Throughout much of ecological history, we have focused on conserving rural, natural, and intact ecosystems that are distanced from urban areas (Nielson et al. 2014). Recent growing attention to urban landscapes has recognized the range of biodiversity found in urban green spaces and its potential to foster diverse bird communities (Belaire et al. 2014; Nielson et al. 2014). However, it is often difficult to change existing urban landscapes and green spaces, especially at city centers.
that tend to be more urbanized (McKinney 2002). These urban cores tend to foster less native species diversity as non-native species are frequently selected by urban users; these city centers have difficulty reestablishing native populations as they are further removed from natural ecosystems that allow recolonization (McKinney 2002). Urban sprawl, the concept of cities expanding into adjacent rural and semi-rural areas to accommodate intra-city population growth, is a particularly crucial moment for cities to expand in ecologically sustainable methods as this expansion can have lasting effects on the future of urban biodiversity (McKinney 2002; Sadler et al. 2011).

City stakeholders have the capacity to structure urban bird populations because local habitat conditions in cities have been found to influence avian species richness and diversity on the more finite scale, that is, birds are attracted to more local habitats and the resources provided (Evans et al. 2009; Latta et al. 2013). This provides unique opportunities for local stakeholders, such as urban planners and residents, to act as urban avian conservationists.

1.1 Methodology

This research conducted a qualitative global comparative analysis to answer the main research question:

What design, abiotic, and biotic variables are necessary for urban green infrastructure to provide habitat and other resources to support urban avian biodiversity?

Issues and recommendations regarding management variables and strategies were also compiled. Peer-reviewed articles were gathered through the database Environment Complete. Additionally, relevant articles cited within literature selected were also used in this research as well. These articles were used to form a non-quantitative analysis of consistent and emergent patterns in the literature forming strategies or findings on how to construct, enhance, or manage urban green spaces to promote avian habitat and conservation — this is the objective of this research.

The breadth of urban ecological studies has been conducted since the year 2000 (Niemela 2014). Appropriately, the majority of the peer-reviewed research articles used for this paper have been limited to post-2000, aside from more pivotal studies that established concepts in urban ecology.
and theory. Articles selected for review focused on more species and habitat in temperate forests, grasslands, and generalist ecosystems. The recommendation section combines relevant frameworks found within the extensive literature review conducted for this project.

1.2 Paper Overview

Broadly, this paper targets a range of urban stakeholders and users who plan, design, manage, and even use green spaces. The purpose is to provide an overview of urban ecology, the value of biodiversity and, specifically, concentrates on how to utilize urban green spaces for avian biodiversity. Framed around three urban green infrastructure types; urban forests and parks, residential gardens, and green roofs, this paper discusses the most important design, abiotic and biotic variables before describing necessary management recommendations. Foremost, cities are built for the human user, and so it is important to describe the value of green spaces through the ecosystem services they provide. City stakeholders should increase and enhance urban green spaces for the benefits provided by ecosystem services to the urban dweller while also knowing the extensive local and global value biodiversity provides as well.

Green spaces in rural and urban ecosystems provide a range of ecosystem services. The 2005 Millennium Ecosystem Assessment defined ecosystem services as "the benefits people gain from ecosystems (MA 2005, pg. V). Ecosystem services are broadly listed as:

1. Provisioning: provide resources like food, water, timber, and fiber.
2. Regulating: contributes to the control of climate, flood, disease, public health.
3. Cultural: creates recreational, spiritual, and aesthetic benefits.
4. Supporting: affects natural ecological processes; photosynthesis, soil formation, and nutrient cycling (adapted from the MA 2005).

The following background chapter briefly introduces urban ecology and describes the importance and contribution of biodiversity. This chapter emphasizes that urbanization and climate change are the global drivers of avian biodiversity loss, similar to many other taxa, and the pressing challenge of preventing global avian biodiversity loss. The relevance of the life stages of birds is reviewed and connected with the role of cities for birds. Stakeholders are
described in order to encourage their engagement on improving urban green spaces for avian biodiversity.

Chapter 3 begins by providing an overview of three natural and constructed habitats; urban forests and parks (both natural and constructed), residential yards (more constructed), and green roofs (completely constructed). Trees are "keystone structures," often shaping urban landscapes, and their contribution is described in more detail in this section (Manning et al. 2006). The ecosystem services for these habitat types are also highlighted at length. As novel, constructed habitats, the history and design of green roofs are covered.

Chapter 4 evaluates the most important design, abiotic, and biotic variables in urban green spaces that influence avian biodiversity. Variables are described for all habitat types collectively, and as necessary, described separately. The most important design variables described in the literature includes patch size and preventing habitat fragmentation by enhancing connectivity (Beninde et al. 2015). Following, vegetation structure and composition are biotic variables likely to have high impacts towards avian biodiversity. The vegetation composition section includes a discussion on the use of native, non-native, and exotic plant species in urban settings.

Accordingly, Chapter 5 leads into recommendations for urban green spaces that satisfy the variables in Chapter 4. It also synthesizes the recommendations found within the scientific literature and describes commonly used frameworks for understanding urban biodiversity.

Chapter 6 leads into social, cultural, and institutional barriers that are common issues in urban areas that impinge on green spaces' ability to maximize resources for birds and humans. Issues like social equity of green spaces are discussed.

2.0 Background

2.1 Introduction to Urban Ecology

Urban ecology, in a general sense, focuses on the 'ecology of the city,' using a multi-disciplinary approach to understand the interaction of how cities' organisms, habitats, and ecosystem interact at different scales (James 2011). Using different disciplines of natural sciences with social
sciences, combined with areas of art and technology, such as architecture, urban ecology aims to study, understand, and improve the urban environment for its living organisms as well as contribute to urban users and residents (James 2011).

The urban environment is a natural ecosystem superimposed by the urban city and residents, blended with anthropogenic and natural factors, creating dynamic changes to natural biotic system by human disturbance, management, and built infrastructure (Nowak 2010). The urban city is composed of built habitat (buildings, impervious and sealed surfaces; roads), managed vegetation (typically in residential, commercial, urban parks, etc), ruderal vegetation (more spontaneous vegetation, such as in empty lots and abandoned areas), and natural remnant vegetation (remaining areas of original vegetation) (McKinney 2002).

Anthropogenic factors can influence urban ecology at different scales, local management factors such as mowing, tree planting, application of herbicides, pesticides, and fertilizers, changes the vegetative structure and composition at more finite levels (Nowak 2010). At larger scales, policies and ordinances can shape vegetation at larger expanses and infrastructure, such as roads, highways, buildings, etc, alter the movement, colonization, and establishment of plants and animals (Nowak 2010). Almost every detail within cities is shaped directly or indirectly by humans, resulting in how urban biodiversity is established (Nowak 2010).

Urban biodiversity reflects all the living organisms within the urban matrix, focusing on the plants and animals within the city (Nowak 2010). In urban areas, biological diversity contributes to a range of social benefits, ranging from food resources, medicines and contributing to environmental health and quality, to socio-cultural benefits for urban dwellers, such as improved aesthetics and mental health (Nowak 2010). Having robust biological diversity, along with maintaining healthy ecosystems, is critical for normal city function (Nowak 2010). Vegetative structure and composition are two of the greatest factors influencing biodiversity in general, and within cities, trees play a particularly important role.
2.2 Importance of Biodiversity

Biodiversity is the measure of all living organisms and takes into account inter and intra-species variation, as well as diversity of species from all ecosystems (MA 2005). Humans have anthropogenically altered biodiversity across the planet; we now manage cultivated ecosystems that extend over 24% of the world's surface, greatly altering previous ecosystems and their biodiversity (MA 2005). Accordingly, the greatest historical and projected global driver of biodiversity loss is habitat conversion (Fig. 1), with other drivers including invasive species, overexploitation, and pollution, particularly nitrogen and phosphorus (MA 2005). Climate change is an emerging driver of biodiversity loss with variable global impacts (Nowak 2010).

![Fig. 1](image)

**Fig. 1**: The estimated historical and projected conversion of major terrestrial biome types are described from 1950 to 2050. *Source: MA (2005).*
Human well-being is inextricably linked to biodiversity as biodiversity positively influences the range of critical ecosystem services provided to humans (MA 2005). The loss of biodiversity, coupled with the deterioration of ecosystem, will impact humans in these areas; greater food insecurity, heightened vulnerability to natural disasters, decline in human/public health, decreased energy security, and decline in clean water availability and quality (MA 2005). In more socio-cultural aspects, loss of biodiversity can reduce freedom of choice, weaken social (spiritual and religious) relations, and lead to losses in livelihoods that are dependent on gathering sustenance goods (sustaining on gathering plants, animals, fungi) (MA 2005).

There are many metrics for measuring biodiversity and the most widely used is species richness (MA 2005). Species richness is a metric reflecting the total number of species found in a specific area. It is important to use species richness with other metrics, for example, species evenness measures the distribution and proximity of species within a specific area (MA 2005). Species diversity is the biodiversity metric combining species richness and evenness.

2.3 Global Challenges

Within urban ecology, one of the greatest challenges of the 21st century will be sustaining our urban biodiversity in light of changing climatic conditions and increasing atmospheric carbon concentrations (Nowak 2010). Plant composition and natural regeneration will change and it is projected that the range and composition of natural tree species will shift (Nowak 2010). Certain species, including invasive and noxious species like poison ivy (*Toxicodendron radicans*), have increased growth due to higher carbon dioxide levels (Nowak 2010). Similarly, trees, herbaceous plants, weeds, and other plant communities experience higher growth and productivity, suggesting changes to urban biodiversity will also result in changes to vegetation management (Nowak 2010).

2.3.1 Climate Change on Cities

Cities are unique, distinct environments due to the intersection of natural areas with built infrastructure. General projected patterns of climate change impacts on cities, with regional variation, are (from Nowak 2010):
1. Cities will have warmer days and nights; there will be fewer cold days.
2. Increased frequency in hot days and nights.
3. More frequent and intense heat waves.
4. More frequent heavy precipitation events.
5. Greater areas impacted by drought.

Broadly, the energy system and hydrogeological system are modified in cities, creating challenges that will be exacerbated by climate change. Energy exchange is altered in cities due to decreased vegetative surfaces and expanses of built infrastructure. Surface temperatures typically increase in cities and become trapped, causing a phenomenon known as the "urban heat island effect (UHI)," where city temperatures can raise 1-6 °C warmer than surrounding rural/natural areas (Gill et al. 2007; Nowak 2010). Variations in temperatures are influenced on different daily and seasonal cycles (Gill et al. 2007). Other factors that increase UHI includes wild speed, less cloud cover (more solar penetration), greater city size, larger/denser populations, higher absorptive surfaces and heat storage, lack of evaporative cooling, and generation of heat sources (Nowak 2010). UHI connects to the energy system as higher temperatures require greater energy demand to cool buildings, and also causes health-related illnesses and pollution (Nowak 2010). UHI impacts animals at different scales: at the more finite scales, abnormal temperatures can impact their physiological/metabolic system. At the larger habitat scale, UHI can influence vegetation and the hydrological system.

Adapting to modified hydrological systems is a major challenge for cities. Cities are covered with expanses of impervious surfaces, such as buildings and roads, and surfaces impenetrable by storm water creates high influxes of rainwater that can overload aging city storm water infrastructure. Increased precipitation patterns typically occur due to changes in the local meteorological system (see Shepherd 2005 for explanation). The most socio-economically disadvantaged areas of cities often have the lowest levels of tree cover, and these areas will experience some of the highest impacts from UHI (Gill et al. 2007). Urban green infrastructure is a multifunctional approach that addresses these multi-faceted urban issues. For example, the
urban tree cover section explains the use of urban trees for climate adaptation potential, provision of public health benefits, and support for avian biodiversity.

2.4 Historical Context of Avian Conservation

In 1962, the widespread decline in global bird populations was brought to national attention by Rachel Carson's influential book, *Silent Spring*, which is widely recognized as sparking the modern environmental movement. Carson informed the public regarding the use of DDT (Dichlorodiphenyltrichloroethane), an indiscriminate pesticide that, among many other health and ecological effects, resulted in eggshell thinning that destroyed eggs during incubation by reducing their ability to support weight. While most populations of birds have now recovered from near-extinction levels, birds now face new existing and emerging threats towards survival. Similar to other species, widespread habitat loss and degradation is reducing viable habitat for birds, especially due to urbanization and densification (Goddard et al. 2009; Sadler et al. 2011). Second, climate change is expected to impact birds by shifting native ranges and changing habitat conditions (Niemela 2014). The National Audubon Society estimates 344 out of 588 North American Bird species examined may lose over half their native ranges within this century (Distler et al. 2015; Langham et al. 2015; Schuetz et al. 2015). The North American Bird Conservation Initiative, a multi-national commitment by Canada, United States, and Mexico, indicated that 37% of all 1,154 North American bird species are...
vulnerable to extinction unless conservation measures are undertaken (Fig. 2) (NABCI 2016). Historically, scientists focused on conserving natural habitats and ecosystems; urban areas were largely ignored as valuable habitat for wildlife due to the high level of human disturbance and fragmentation (Nielson et al. 2014). Unfortunately, cities have been traditionally built in areas of high biodiversity and continue to expand in these biodiverse hot spots, impacting some of the most diverse and sensitive habitats in the world (Aronson et al. 2014; Goddard et al. 2014; Seto et al. 2012). Ignoring urban areas and focusing solely on conserving neighboring or distant natural areas is not adequate as the impact of urbanization extends into neighboring rural areas, suggesting maintaining urban areas is critical for wildlife refuge (Goddard et al. 2009). Urban areas cannot be ignored in conservation. Cities need to be aware of their impact on native ecosystems and should incorporate efforts to mitigate the loss of biodiversity, especially considering the projected growth of cities in the near future (McKinney 2002).

2.5 Importance of Birds

As literal canaries in a coal mine and "biological barometers" (as referred to by Smithsonian Institute forensic ornithologist, Carla Dove), birds are frequently indicator species that have fundamental roles in ecosystems. The life history and general ecology of many bird species are well researched. Trophic guilds are similar species that typically exploit similar resources, behavior, and/or habitat (González-Salazar et al. 2014). For example, birds can be grouped in trophic guilds based on feeding strategies (e.g., insectivore, granivore, nectivore) or on foraging habitat (e.g., terrestrial, arboreal, pelagic) and numerous guilds can overlap in geographical space (González-Salazar et al. 2014; Koch et al. 2011). This overlap provides insight on which species are utilizing the space, and the ability to detect the presence of birds by sight or sound aids their monitoring (Koch et al. 2011). Broadly, common bird species act as better indicator than rare species because common species more readily reestablishes disturbed areas, comprise of more of the biomass, and typically influences ecosystem more due to their abundance (Koch et al. 2011). Birds often act as regulators to vegetative communities by consuming and dispersing seed, acting as pollinators, and consuming insects and other prey. The presence of certain bird species can suggest the presence of respective food resources, such as insects, seeds, nectar, etc, and maturity
of the habitat (González-Salazar et al. 2014). Seabird populations and seabird colony behavior have been shown to have a curvilinear relationship to marine food supplies (Cairns 1988). In the United Kingdom, decline in farmland birds resulted in the government using farmland bird species population trends as a headline indicator, alongside fourteen other headline indicators for habitat condition (Gregory et al. 2003). Species are inextricably linked and loss of a species or genus can have profound impacts that ripple through other species and respective ecosystems.

2.6 Anthropogenic Impacts on Urban Avian Biodiversity

2.6.1 Urbanization Impact on Bird Diversity

Urbanization is resulting in decreased global biodiversity and is causing species to homogenize within cities and beyond their borders (Aronson et al. 2014). With 50% of the total human population already living in urban areas in 2010, 70% of the human population is expected to migrate in urban areas by 2050, causing further expansion of urban areas and/or increased densification (Haaland and Bosch 2014). Densification and urbanization, both historically and projected, are viewed as the greatest urban driver of biodiversity loss (Haaland and Bosch 2014; Sadler et al. 2011; Threfall et al. 2016; Whittaker and Marzluff 2012) and the encroachment and development in distant and adjacent areas, such as for agriculture and resource gathering, has also severely impacted broader biodiversity (Goddard et al. 2009). Densification and urbanization that encroaches or develops on existing green space is rarely replaced with construction of green spaces elsewhere, suggesting one of the greatest challenges is not only to prevent the decline of green space quality but also to improve existing and future green space habitat quality, e.g., providing supporting services of nesting, roosting, and feeding value (Haaland and Bosch 2014; Nielson 2014).

2.6.2 Climate Change Impact on Bird Diversity

The loss of habitat is further exacerbated by climate change. Climate change is described as one of the most important drivers of global avian biodiversity loss (Niemela 2014). Climate change will impact the abiotic and biotic components of cities, such as changing atmospheric temperature, changing hydrological regimes, and changing vegetative communities (Niemela
UHI, storm water runoff, and pollution from urban areas will also affect avian populations. What forms of climate adaptation and mitigation cities implement will greatly influence the impacts felt or mitigated from climate change; for example, incorporation of adequate green spaces and street trees can reduce temperatures and UHI effects (Niemela 2014). This duality of climate change is an opportunity for cities to use green infrastructure to address issues that have never been fully addressed, have been delayed, and/or postponed (Barona 2015). For example, the onset of increasing inner city temperatures can pressure cities to finally construct adaptation strategies that have been delayed, such as increasing street trees and green corridors. This continually growing recognition and allocation of resources towards improving and constructing urban green spaces as climate change adaptation and mitigation strategies poses a unique opportunity to simultaneously improve habitat for avian, and other, biodiversity within cities through a multifunctional approach.

### 2.6.3 Other Impacts

There are numerous ways cities can act as population sinks or deter different bird species. Source-sink dynamics describes how species population can decrease when migrating or living in habitats of low quality that causes death. In urban areas, primary causes of avian fatalities include window strikes (collisions) that result in an estimated 100 million to 1 billion fatalities per year, resulting in an estimated 1% to 5% loss of total migratory populations (Audubon NYC 2015; Gelb and Delacretaz 2009; Milius 2014), urban light pollution resulting in disorientation, fatigue, and death in, most commonly, night-time migratory birds (Gelb and Delacretaz 2009), and urban noise pollution altering normal bird song and communication and deterring species from entering cities (Gelb and Delacretaz 2009). Many cities recognize these impacts and have active policies to reduce these fatalities. For example, San Francisco adopted standards for bird-safe building designs since July, 2011 that reduce bird collisions, and similarly, Chicago, Toronto, Minnesota, Michigan, and other cities incorporate different bird-safe or bird-friendly policies (SF Planning 2011).
2.7 Life Stages of Birds

Birds complete different life stages after hatching from the egg, with variation according to species, genera, and guilds. After hatching, birds are in the nestling phase where most species are not feathered and altricial. The fledgling stage represents the intermediate stage between being a nestling and gaining the ability to fly. Many birds, especially songbirds, require leaving the nest to the ground in order to develop wing musculature for flight. Fledglings are rather defenseless, aside from their watchful parents, and require a few days or longer before being capable of flight. The survival of fledglings greatly influences population dynamics of bird populations, especially songbirds, as low fledgling survival trends reduce population dynamics. In green spaces, habitat planning and management need to improve fledgling survival for enhancing songbird populations in urban areas (Loyd et al. 2013).

Migratory songbird population dynamics can be affected at different annual life stages, both naturally and anthropogenically (Mattsson and Cooper 2007). Conservation efforts for migratory songbirds include improving wintering grounds and migratory routes, however, these management efforts tend to be expensive (Mattsson and Cooper 2007). In urban areas, cats and other domestic or feral pets, vehicular collision, impervious surfaces (from nestlings falling out of nest onto hard surfaces), and even humans reduce fledgling survival (Smith et al. 2016).

Research in urban ecology is growing to determine if species establish viable, sustaining populations within cities, or if cities act as sinks for certain species and rural populations continue to repopulate urban areas (Smith et al. 2016). Predator dynamics change within cities, for example, while snakes are a major predator towards fledglings and other life stages of birds, cities often are sparse in snake populations (Smith et al. 2016). With the presence of humans, many other predator species tend to flourish, particularly the domestic cat (*Felis catus*), that can have profound impacts on bird populations (Smith et al. 2016).

In a study where owned, indoor-outdoor cats (n=55) were monitored with attached cameras (Kittycam, data/photos available at www.kittycams.uga.edu) for a period of 7 - 10 days, the authors found that predation rates are higher than previously estimated predation rates, possibly by two or three fold (Loyd et al. 2013). Because of the songbird nestling and fledgling life
stages, and use of human-provisioned bird feeders, songbirds are more prone to cat predation in urban areas as compared to other bird groups (Loyd et al. 2013). Whether trap-neuter-release programs for feral cat populations are effective at managing or reducing populations is debated; it is believed that feral cat populations can continue to grow despite these programs (Smith et al. 2016).

2.8 Role of Cities for Birds

Broadly, research and literature focusing on understanding how urban areas affect local ecosystems should be used in two ways; assimilating the ecological principles into city conservation efforts and enhancing public awareness as a means to drive local policy and decision making (McKinney 2002). Similarly, the primary aim of this project is to establish best management guidelines for cities to understand the necessary components for creating habitat in green infrastructure, and secondarily, to inform the audience of the reasoning and ethos of conservation in urban areas. This is important because even in incidents where cities or agencies recognize the importance of biodiversity, construction and development plans lack any explicit direction or indication on how biodiversity will be benefited. When considering the extent of habitat degradation and loss from urbanization, managing residential and other planned vegetation in urban areas can be a significant contribution towards biodiversity, locally and globally (McKinney 2002).

Often, the term biodiversity is ambiguously or deceitfully added to "green" projects to mislead the public or readers into believing the project will benefit biodiversity though, whether due to dishonesty or being ill informed, has no intention or means to do so. As stated in Williams et al. (2014, pg. 1643), "the biodiversity benefits of green roofs are frequently promoted on websites and product literature with little reference to ecological evidence and are often ascribed to all green roofs."

Generally, there is a lack of understanding in management ideals for cities and conservation, resulting in negative impacts towards biodiversity (Goddard et al. 2009). Government planning agencies and related stakeholders control the urban landscape which heavily impacts
biodiversity, however, these governmental agents frequently lack expertise in wildlife biology (Gagne et al. 2014). In a survey of three major US metropolitan areas, including Seattle, Washington, Des Moines, Iowa, and the Research Triangle, North Carolina, less than five percent of city planning staff were dedicated to biodiversity conservation (Miller et al. 2009).

Managing the urban landscape is critical to biodiversity conservation. Residential landscapes can cover large areas in urban areas and can contribute significantly to offset the negative impact of urbanization by providing refuge and resources for wildlife (Goddard et al. 2013). Maintaining habitat heterogeneity is important for maintaining different taxa in cities, for example, gardens, parks, and other green spaces in Prague, Czech Republic, contributed to the survival of butterfly and moth species (Goddard et al. 2009). This research explores how green infrastructure can similarly utilize green spaces to create valuable habitat that can be used by birds.

2.8.1 Green Infrastructure for Bird Habitat

This research focuses solely on evaluating the value of habitat for birds in green infrastructure for the following reasoning. First, birds are highly mobile, and even migratory, allowing them to easily access fragmented or disconnected habitats in urban and suburban areas that may be inaccessible to species unable to navigate the congestion of urban areas. Having flight allows birds to easily transverse through gardens and other green spaces often surrounded by buildings, fences, and other physical barriers. Second, even if birds become extinct within the urban area, established populations outside of urban areas can re-establish urban areas once viable habitat is established. Third, cities are recognizing their impacts on bird populations and actively creating and implementing policies that reduce their impact on birds. Utilizing green infrastructure to create bird habitat can be one means to do so. Lastly, the presence of birds, as well as other wildlife, can increase aesthetics, improve mental well-being, and enhance the experience of the urban dweller with nature.

2.9 Stakeholders

Landscape architects, planners, policy makers, and urban residents are faced with three startling challenges for the 21st century; first, meeting the needs of robust human population growth,
second, the increasing urbanization and migration of the human population into cities, and third, changing human activities that are negatively changing natural ecosystems, landscapes, and biodiversity (Steiner 2014). In terms of urban development and conservation, three main stakeholders can be grouped as 1) homeowners and residents, 2) policy makers, and 3) design-build and related professionals, the latter representing the range of professionals that plan, design, and construct urban infrastructure (e.g., developers, planners, landscape architects, firms, etc) (Hostetler 2011).

These stakeholders also influence urban ecology on different scales. Policy makers have a "top-down effect" where they set regulations and guidelines that govern design-build professionals and homeowners and residents (Belaire et al. 2014; Kinzig et al. 2015). Policy makers have the most lasting effects on urban ecology as their rules can shape the urban landscape for decades. Design-build professionals implement policies but can also affect wildlife throughout the planning, construction, and post-construction process (Steiner 2014). This is directly related to whether mitigatory actions are taken by design-build professionals and conservation initiatives are implemented. At the smaller, local scale, homeowners influence local biodiversity on the residential scale, a more "bottom-up effect," particularly around their own homes and local communities (Belaire et al. 2014; Kinzig et al. 2015). Homeowners have greater control of their own residences' vegetation and can also voice their opinion on neighborhood vegetation schemes, such as street tree selections and communal gardening, and can have more immediate short term impacts (Hostetler 2012).

These stakeholders have different roles in meeting these challenges; urban policy (decision) makers need to identify and renew degraded urban areas while urban residents and dwellers need to engage with their communities to raise awareness of biodiversity and habitat conservation, such as improving gardens for habitat (Steiner 2014). Design-build and related professionals need to actively implement green infrastructure and incorporate ecosystem services to mitigate and adapt to these changes (Steiner 2014).
2.9.1 Incentive for Green Infrastructure

Understanding the strong economic and financial incentives for conserving biodiversity and green spaces in urban areas can be the greatest impetus that drives changes to urban planning, legislation, and human behavior (Box 2011). At the global scale, ecosystem services provide an estimated $33 trillion per year (based on 1994 prices), with the range being $16-54 trillion (Box 2011, see Costanza et al. 1997 - the first estimate valuing global ecosystem services). At the local scale, conversion or expression of ecosystem services in terms of economic or social benefits can elicit value of green spaces that can help improve all stakeholders' interest and knowledge of increasing urban biodiversity and enhancing green spaces (Box 2011). Table 1 provides an overview of ecosystem services provided by urban green infrastructure.

Table 1. General ecosystem functions provided by green infrastructure. Adapted from: MacIvor et al. (2016).

<table>
<thead>
<tr>
<th>Functions</th>
<th>Performance Benefits</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water capture</td>
<td>Reduces amount of run-off (Mentens, Raes &amp; Hermy 2006)</td>
<td>Green roofs capture rain water decreasing strain on sewers</td>
</tr>
<tr>
<td></td>
<td>Plants with higher transpiration rates and greater productivity capture more water</td>
<td>Bioswale stores run-off after a storm</td>
</tr>
<tr>
<td></td>
<td>(Wolf &amp; Lundholm 2008)</td>
<td></td>
</tr>
<tr>
<td>Pollution mitigation</td>
<td>Plants intercept and assimilate pollutants in urban air, soil and water (Hunt et al. 2008)</td>
<td>Street trees capture CO₂ and NO₂</td>
</tr>
<tr>
<td></td>
<td>Many pollutants rendered inert or harvested from plant biomass</td>
<td>Bioretention pond filters polluted water; stops flow to streams</td>
</tr>
<tr>
<td>Thermal regulation</td>
<td>Shading and evapotranspiration cool buildings (Del Barrio 1998) and insulate in the winter (Lundholm, Weddle &amp; MacIvor 2014)</td>
<td>Green walls reflect sun, and cool building via evapotranspiration</td>
</tr>
<tr>
<td></td>
<td>Reduction to the urban heat island (Georgescu et al. 2014)</td>
<td>Street trees provide shading</td>
</tr>
<tr>
<td>Habitat</td>
<td>Green infrastructure provides resources for wildlife and can be designed for species of concern (Brenneisen 2006; MacIvor &amp; Ksiazek 2015)</td>
<td>Urban gardens support many birds and insects</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Green roofs as nesting habitat for birds</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>Attractive; improve public space</td>
<td>Viewing a green roof from an office window</td>
</tr>
<tr>
<td></td>
<td>Contribute to stress reduction and attention restoration (Tzoulas et al. 2007; Lee et al. 2015)</td>
<td>Immersion in nature on an urban roadside trail.</td>
</tr>
<tr>
<td>Food production</td>
<td>Growing food locally improves food security, community engagement and development of life skills among diverse communities</td>
<td>Community gardens where citizens cultivate edible plants</td>
</tr>
</tbody>
</table>
2.9.2 A Call for Action

While there is an urgency and incentive for all stakeholders to increase and enhance green spaces, there is a general lack of ecological knowledge and expertise in non-experts, including design-build professionals, as many of these professionals do not receive training or are unaware of urban ecology (Sadler et al. 2011; Threfall et al. 2016). Design-build professionals may lack the scientific expertise in interpreting dense scientific literature that describes how to benefit birds and preserve habitat (Hostetler 2012). More broadly, there is a global movement in governments to increase green spaces to benefit biodiversity, however, they lack information on best vegetation management practices (Threfall et al. 2016). As a more specific example, initial surveys pre-development may suggest certain bird species are absent at the location, contrarily, the site may be visited and utilized by seasonally migrant birds and other species that can go unrecognized in non-experts (Sadler et al. 2011). Combined with the lack of easily accessible research and guidelines for understanding development spatio-temporally, it creates difficulty for stakeholders to know what best mitigation practices to follow (Sadler et al. 2011).

At the broader scale, design-build professionals should be challenged to enhance derelict urban areas, such as underused and degraded sites, that have compelling potential for areas of habitat construction while contributing to climate change adaptation and mitigation strategies (Sadler et al. 2011). However, it is important to note that it is the role of ecologists and other academics to inform design-build and other professionals on how to construct these spaces for biodiversity (Marzluff 2002).

3.0 Urban Green Infrastructure

This research selected three contrasting natural and constructed habitat types within cities as they describe the variation in how humans manage, design, and alter urban habitats. The first section broadly describes trees and urban forests and parks, as trees provide critical components of ecosystems. While trees are not typically "habitats" themselves, in many ways, they serve as micro-habitats that provide valuable structure and resources for birds and other wildlife. Urban trees are one of the most influential biotic components in the urban landscape. This section progresses into describing the broader urban forests. Urban forests, hereafter, are broadly used
here to encompass areas formed mainly of trees, such as woodlands (low-density forests) and parks (variation in tree density) in cities. Residential yards are used to refer to the collection of residential green spaces often encompassing gardens and/or front and backyards, essentially green spaces owned or managed by the residential user. Unlike urban forests, residential yards have more flexibility and control by the local user, allowing changes to occur more rapidly and sporadically. Green roofs are completely novel, constructed habitats with many abiotic and biotic constraints due to the design of the roof. Green roof installation in many parts of the world and their contribution to avian biodiversity is still developing; this research forms a dialogue and review of their current use and support for biodiversity.

Because green spaces are primarily constructed and/or managed for the human user, this paper also outlines the economic and environmental incentives (ecosystem services) provided by the different green spaces. This is to provide motivation and value for the reader/user to understand how green spaces contribute to public and ecosystem health. Knowing this importance, the crux of this paper is to simultaneously convince the user that contributing to biodiversity conservation with these spaces also provides more public health benefits and ecosystem services, often at low costs related to management. In urban areas, the three predominant vegetation management approaches to increase urban biodiversity include: 1. increasing the density of trees, 2. increasing the amount of native vegetation, and 3. increasing the vegetative complexity of the understory (Threlfall et al. 2016).

The following sections for each green space type are generally framed to provide an introduction, the current uses and benefits; ecosystem services, and outlook. Because green roofs are unique, constructed habitats, the history and design of green roofs are also described. In the latter section, the most important abiotic, biotic, design, and management variables are described from this research's extensive literature review.

3.1 Urban Tree Cover and Urban Forests

Within cities, trees are one of the greatest biotic factors of cities that influences the landscape, governing other aspects of biodiversity and acting as vital green infrastructure (Fig. 3 as an example) (Nowak 2010). Tree species and form are greatly dictated by urban management and
their management sets precedent on providing ecosystem services, including habitat for biodiversity (Barona 2015). At the global scale, trees mitigate climate change by sequestering carbon (Barona 2015). At the local, urban scale, trees are the most prominent natural elements of cities, providing significant ecosystem services and their value continues to grow throughout its lifespan considering their modest investment (Barona 2015; Nowak 2010).

![Fig. 3: An example of how urban trees often contribute to large portions of green space in cities. Taken in San Francisco - the large linear green space is Golden Gate Park, a completely cultivated park from 1870. Photo by Allen Lau.](image)

The geographic location of cities can predict the amount of urban forestry: particularly, cities that were built or surrounded in forested areas generally have more urban tree cover (Nowak 2010). To illustrate, in US cities, urban tree cover in forested areas have about 34% coverage; grassland areas have 18%; deserts have 9% (Nowak 2010). Habitats within cities become fragmented from urbanization, creating patches of remnant habitat or patches newly constructed habitat. This
section focuses on urban forests as areas predominately shaped and governed by trees in the landscape.

3.1.1 Ecosystem Services of Trees

Per dollar invested per tree, a higher economic return is given at an average $1.50 to $3.00 per dollar invested (Foster et al. 2011). Ecosystem services and benefits provided by trees and urban forest cover are attractive incentives for cities to understand, moving forward, urban tree cover greatly influences biodiversity and these shared benefits should be maximized (Livesley et al. 2016). These themes need to be communicated to local authorities to improve our towns and cities.

A summary of ecosystem services provided by trees (based on Nowak 2010, unless noted):

1. Improves air and water quality by intercepting and filtering pollutants
2. Improves thermal performance of buildings through shading; conserves cooling demand and energy consumption
3. Alters local microclimate; mitigates UHI, decreases air temperature, and absorbs ultraviolet and solar radiation.
4. Increases storm water retention and filtration
5. Influences meteorological conditions, including air temperature, precipitation, and wind speeds.
6. Act as wind breaks, reducing wind speeds up to 65-75% in some instances.
7. Increases property value and aesthetic appeal, especially with native vegetation (Barth et al. 2015).
8. Provides habitat, including refuge, shelter, food resources.
9. Increases habitat connectivity, forms patches of habitat (Kang et al. 2015).

3.1.2 Urban Tree Cover and Biodiversity

Large scattered remnant trees can act as "keystone structures" in the landscape as they contribute significantly to the landscape and habitat provided to wildlife (Manning et al. 2006). As keystone structures, scattered trees increases the amount of tree cover, provides connectivity for animals,
and act as reservoir habitats of previous landscapes (Manning et al. 2006). The loss of these trees can cause ecological regime shifts (Manning et al. 2006).

Large trees can differ greatly from small trees in terms of size and habitat structure, mature trees provide more structural aspects, such as having wider, expansive branches (Le Roux et al. 2015). The maturation process of trees creates structures that are attractive to birds, such as shedding woody debris and branches, and producing flower, fruit, and nectar (Le Roux et al. 2015).

Trees situated in urban areas face unique natural and anthropogenic challenges. Natural influences include altered natural biotic interactions (e.g., seed dispersal, colonization, pollination, and plant herbivory), local climate changes, and altered geology (Nowak 2010). Anthropogenic influences overlap these changes to the natural system with the impact of people and infrastructure, including roads, buildings, and management decisions (Nowak 2010).

Many of the factors affecting urban trees are generally beyond the limits of human control. Climate factors, like temperature, precipitation, and local moisture regimes, are not easily influenced at the local scale (Nowak 2010). Even many of the biotic factors are not easily managed, such as pollinator availability (aside from creating pollinator habitat), regulating herbivores and pests, and managing existing soil types (Nowak 2010). The greatest influences humans can have on urban forest cover are through management and species selection.

### 3.2 Residential Yards and Gardens

In cities with private residential yards, front and backyard gardens form a large percentage of the residential landscape and contribute to large areas of city land cover (Goddard et al. 2013). Gardens contribute to the urban ecosystem matrix, linking with adjacent habitats to form an interconnected network (Goddard et al. 2009). Urban areas are now encroaching on rural habitats, especially due to agriculture, and reduces native flora while pushing native fauna into urban areas to seek refuge and habitat (Goddard et al. 2009).

Gardens are 'socio-ecological systems,' influenced by greater social norms and stratification that trickle down to the residential level (Goddard et al. 2013). Residential gardens are typically
managed at the residential level and have been recognized for their ability to support certain bird species depending on the age of the garden, vegetation structure, and complexity (Goddard et al. 2009). More top-down influences come from non-governmental organizations, non-profits, governments, and related agencies that have increased awareness and promotion of wildlife-friendly gardening, though current promotions can be guided with limited ecological knowledge or research (Belaire et al. 2014; Goddard et al. 2009). This section begins to describe social and ecological drivers and motivations for gardening practices then analyzes existing literature to develop best management standards for private gardens by determining what abiotic and biotic factors are necessary to support avian biodiversity.

### 3.2.1 General Benefits

Some cities without biodiverse ecology are facing an 'extinction of experience' and creating a disconnect between their residents and nature (Goddard et al. 2009). Gardens are one of the most immediate spaces individuals can interact with nature and even if residents do not actively manage their gardens, some wildlife is typically present (Goddard et al. 2013). In a mixed-method survey study of households (n=526), 65% of individuals enjoyed the plants and flowers in their gardens while 41% enjoyed watching or attracting wildlife (Goddard et al. 2013). Respondents stated satisfaction and wonderment was received when wildlife was attracted to their gardens (Goddard et al. 2013). Many respondents stated they did not have enough information on 'wildlife-friendly gardening' (Goddard et al. 2013).

### 3.2.2 Wildlife Resources

Goddard et al. (2013) evaluated residential gardens by using a thirteen-criterion wildlife resources index (Fig. 4). Aspects of vegetative structure and complexity are described in the middle column. Abiotic variables include water availability and more structure provisions, such as artificial nest boxes.
Table 1: Wildlife-friendly criteria. Adapted from: Goddard (2013).

<table>
<thead>
<tr>
<th>Bird feeder/table</th>
<th>Berry-bearing plants</th>
<th>Pong</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bird bath/water</td>
<td>Flowering plants</td>
<td>Log pile</td>
</tr>
<tr>
<td>Bird nest box</td>
<td>Hedge/shrubs</td>
<td>Wild/uncultivated area</td>
</tr>
<tr>
<td>Nest box for other taxa</td>
<td>Trees &gt;2 m in height</td>
<td></td>
</tr>
<tr>
<td>compost or leaf pile</td>
<td>Native plants</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 4:** Wildlife-friendly criteria. Adapted from: Goddard (2013).

### 3.2.3 Constraints

Two socio-norm barriers to wildlife-friendly gardening are lack of knowledge within the neighborhood (including residents) and the need for gardens to follow 'neighborhood mimicry,' where residents followed established socio-standards for maintaining their yards in terms of tidiness, species, etc (Goddard et al. 2013). A solution to these socio-norms is to acknowledge and reverse garden management into a 'conservation ethos,' that is, develop standards amongst neighbors to create gardens that benefit biodiversity and even establish friendly competition amongst neighbors to further promote environmentally friendly gardening (Goddard et al. 2013; Warren et al. 2008). Top-down influences can improve gardens if greater communication and information is provided to the residents, such as fostering workshops and community awareness; improving gardens for biodiversity needs to occur at the grass-roots level, also motivating children in schools (Goddard et al. 2013). Local authorities and the community should take into account the existing social norms for gardening, establish environmental and biodiversity friendly gardening schemes, then diffuse this information into the community (Goddard et al. 2013).

### 3.2.4 Outlook

Because private gardens are typically beyond the scope of government authority, except in the rare instances of strict zoning, management of gardens as bird habitat is typically at the discretion of the homeowner or resident (Belaire et al. 2014). Residential gardens are greatly shaped by socio-economic factors, such as wealth and status, lifestyle behavior, and social ideals (Goddard et al. 2013). At the individual scale, garden plants are typically selected based on
personal favoritism rather than their value towards birds (Niemela 2014). At the larger residential and community scale, residential landscapes are greatly influenced by conformation to the neighboring social and cultural norms (Goddard et al. 2013). This is exhibited in Baltimore, US where residents followed an "ecology of prestige" by following ecological social ideals similar to others vegetative landscapes (Goddard et al. 2013). Overcoming this may require collective community efforts and increasing awareness of bird-friendly species, possibly through a "conservation ethos" that develops a neighborhood's understanding and ethic towards creating wildlife habitat (Goddard et al. 2009). Yards offer the most habitat potential in urban areas when their planning is collectively managed, that is, yards should enhance habitat connectivity and increase vegetative composition and structure at the neighborhood scale (Belaire et al. 2014).

Nationally, there is increasing attention towards gardening for wildlife, especially for pollinators. For example, the Million Pollinator Garden Challenge (millionpollinatorgardens.org) is a campaign raising awareness for planting pollinator-friendly gardens and targets registering one million yards in the US. To date, over 200,000 sites have been registered. Unfortunately, in Great Britain, there is a growing trend for the conversion of gardens into hard surfaces (Evans et al. 2009). The contribution of gardens is crucial to biodiversity, as the estimated 28.7 million trees estimated in urban gardens accounts for roughly a quarter of all living trees in Great Britain by the Forestry Commission (Davies et al. 2008).

Importantly, gardens can threaten biodiversity when improperly managed. Bird feeding can have negative repercussions, such as concentrating and spreading avian and other wildlife diseases (Goddard et al. 2009). Domestic cats are a major source of predation on urban bird populations, with an estimated 1.3 - 4.0 billion birds killed annually by free-ranging domestic cats, with a greater percentage due to feral populations (Loss et al. 2013).

3.3 Green Roofs

Broadly defined as roofs designed with growth medium to support vegetation, green roofs are a means to convert conventional impermeable roof tops into spaces for human use and/or provide ecosystem provisioning, including the potential to create wildlife habitat in urban spaces (Vijayaraghavan 2016). Globally, there is variation in the terminology for green roofs, referred to
also as eco roofs, living roofs, natural roofs, roof gardens, sod roofs, and vegetated roofs. The construction of green roofs has increased in many countries as a partial remedy to combat urbanization and densification that results in the reduction of urban green spaces (Xiao et al. 2014; Vijayaraghavan 2016). There has also been increasing focus on the ability of green roofs, along with other green spaces, to store carbon in its vegetation, leading to advocacy for its climate change mitigation potential (Niemela 2014; Xiao et al. 2014). In cities, green roofs have the potential to create habitat for birds, along with other man-made habitats, such as parks, gardens, and fragmented natural habitat spaces, if properly planned, constructed, and managed (Washburn et al. 2016). See Table 2 for a list of benefits that can be provided by green roofs.

Frequently, green roofs are stated to create habitat that can provide resources for biodiversity though it is seldom explicitly indicated how the roof intends to do so (Fernandez-Canero and Gonzalez-Redondo 2010). Because birds are highly mobile, it is hypothesized that they are able to use green roofs. However, green roof research in relation to biodiversity conservation is still premature and needs more research (Williams et al. 2014). Caution should be exercised when stating green roofs can create habitat for bird species unless the green roofs were developed with sound ecological expertise and consulting, also considering the level of uncertainty regarding whether specific bird species or groups will use the roof after establishment (Williams et al. 2014). There are supporting studies indicating insects and other species colonize and/or utilize green roofs (MacIver and Lundholm 2011; Washburn et al. 2016) with evidence that some bird species also visit green roofs for forage, resting, and nesting (Brenneisen 2006; Fernandez-

Table 2. Potential benefits of green roof infrastructure to the private and public sectors.

<table>
<thead>
<tr>
<th>Building owner benefits</th>
<th>Public benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings</td>
<td>Urban heat island effect mitigation</td>
</tr>
<tr>
<td>Satisfaction of a portion of stormwater policy requirements</td>
<td>Storm water retention</td>
</tr>
<tr>
<td>Roof membrane protection and life extension</td>
<td>Improved stormwater runoff quality</td>
</tr>
<tr>
<td>Sound insulation</td>
<td>Reduced emissions of greenhouse gases</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>Air cleaning</td>
</tr>
<tr>
<td>Improved public relations</td>
<td>Creation of habitat</td>
</tr>
<tr>
<td>Provide added amenity space for the occupants (Accessible green roofs)</td>
<td>Biodiversity enhancement</td>
</tr>
<tr>
<td>Food production (agriculture)</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Fernandez-Canero and Gonzalez-Redondo (2010).*
Canero and Gonzalez-Redondo 2010). In urban developed areas, roofs can account for over a third of the horizontal surfaces (Oberndorfer et al. 2007), and it can be hypothesized that green roofs, when thoughtfully planned, constructed, and maintained for birds and other wildlife, can contribute to valuable habitat for birds.

### 3.3.1 History of Green Roofs

Germany is attributed to being a pioneer of modern, functional green roof use and began vegetating roofs to improve the longevity of the roof by reducing incoming solar radiation from the beginning of the industrialization period of the 1900s (Oberndorfer et al. 2007). Green-roof technology continue to be developed and adopted in Germany in the latter Twentieth century due to the increased concern towards growing environmental issues (Fernandez-Canero and Gonzalez-Redondo 2010). This progressed into technical guidelines for green roofs in 1982 and modern building laws requiring urban centers to have green roofs (Oberndorfer et al. 2007). Germany is often referred to as the world leader in green roofs technology, installing over 13.5 million square meters of green roofs annually (Oberndorfer et al. 2007).

### 3.2 Current Uses for Green Roofs

Green roofs are revered for providing benefits to building owners and the public with ecosystem provisioning, resulting in urban planning and policy incorporating more green roofs in areas throughout the world (Fernandez-Canero and Gonzalez-Redondo 2010).

Three main public and private ecosystem provisions are provided by green roofs, including storm-water management, energy conservation/enhancing thermal performance, and creation of habitat (Oberndorfer et al. 2007). While the benefits from the first two provisions are well understood and continues to improve with research, the full dynamics of creating habitat with green roofs is not yet fully understood (Washburn et al. 2016). However, understanding ecological dynamics, life histories, and carrying capacities of birds and their respective habitat allows us to describe how different abiotic and biotic components in green roofs can contribute to habitat creation for birds by providing food, water, cover, and space (Fernandez-Canero and Gonzalez-Redondo 2010; Shaw 1985).
3.2.1 General Benefits

Green roofs have been shown to increase aesthetic values (Washburn et al. 2016), and being urban green spaces, can improve mental and physical wellbeing, and promote public health (MacIvor et al. 2016; Wolch et al. 2014). Having green roofs enhances sound insulation of the building and can reduce ambient outdoor noise by absorbing sound waves in the vegetation and substrate layers (Oberndorfer et al. 2007). Green roofs can capture atmospheric pollution and assimilate it in the biotic layers or retain it in the abiotic (soil/substrate/media) layers. When utilized for food production, green roofs can aid in community and local food production and also engage those communities (MacIvor et al. 2016). Though the cost of green roofs is greater than that of conventional roofs, green roofs increase the lifespan of the roof membrane, leading to cost-savings in the long run (Xiao et al. 2014).

3.2.2 Ecosystem Services

Storm Water Management

When compared to typical constructed roofs that lack storm water management and retention (aside from when rainwater is diverted to gardens or stored in rain barrels), green roofs provide public ecosystem services by retaining storm water and reducing storm water runoff into local water treatment plants or ecosystems (Washburn et al. 2016). Captured water is stored in the growing medium and transpired back into the air through evaporation and transpiration from the soil and vegetative layers (Xiao et al. 2014). Growing human population in cities is straining aging storm water and sewage infrastructure and the storm water mitigation potential of green roofs can help reduce the burden of increasing effluent (Berndtsson 2010).

Reducing storm water runoff is beneficial to local ecosystems as it typically becomes concentrated with pollutants as it contacts impervious surfaces that retain pollutants. Peak-flows from storms can damage aquatic habitats into which the water is released, including lakes and rivers, as impervious surfaces decrease the lag time for water to reach water bodies (Oberndorfer et al. 2007). The amount of water retained from the green roof depends on the slope of the roof, the depth of the substrate layers, vegetative composition, and local rainfall regimes (Oberndorfer
et al. 2007). Moran et al. (2005) found green roofs in Portland, Oregon and East Lansing, Michigan with 10 cm substrate layers was able to retain 66% to 69% of rainfall.

**Thermal Performance**

Green roofs can improve the energy efficiency of buildings by increasing insulation properties and reducing solar heat penetration, mainly through shading and reflection by plants (Vijayaraghavan 2016; Xiao et al. 2014). Having overlying plant and substrate layers above the roof blocks and distributes incoming solar radiation, assisting in the regulation of the interior building climate (Oberndorfer et al. 2007). This reduces energy needed for cooling the building during warmer periods but also reduces heating requirements by in cooler periods by acting as insulation to the building (Xiao et al. 2014). The transpiration of water from the vegetative and soil layers cools the surrounding atmosphere and can reduce urban heat island effects (Xiao et al. 2014).

**Urban Habitat Provisioning**

Green roofs provide a unique opportunity to potentially create or enhance available bird habitat in cities by creating vegetated areas in place of conventional barren roofs (Brenneisen 2006). It is hypothesized that there is a high likelihood species abundance and diversity increases on green roofs, as compared to conventional roofs, though it is not fully understood the full capacity green roofs can support various plant and animal taxa (i.e., provide valuable habitat and resources) (Williams et al. 2014). There is evidence that spiders, beetles, bees, and other insects have been able to colonize and establish on green roofs (Williams et al. 2014, see also Coffman and Davis 2005 and MacIvor and Lundholm 2011), though there are fewer studies completed on birds.

Green roofs are novel habitats in the sense that they are elevated at variable heights from the ground. This can be attractive to some species while it may deter others. For example, green roofs can be attractive to more sensitive species as being elevated from ground level can remove the habitat away from human activity, disturbances, and certain less-mobile, terrestrial predators (Eakin et al. 2015). Green roofs will have variation in the amount of water and food available to birds, where food sources can include insects, seeds, berries, nectar, pollen, etc (Fernandez-
Canero and Gonzalez-Redondo 2010). Studies have demonstrated the potential of birds using green roofs as habitat, for example, Eakin et al. (2015) states 29 bird species were found nesting on green roofs throughout Europe and North America.

3.3 General Design of Green Roofs

When designing roofs for habitat and biodiversity, it is important to understand that the characteristics of the biotic variables will be directly influenced by the abiotic variables planned and constructed on the green roof. In particular, the abiotic soil/substrate layer of green roofs governs which vegetative composition and structure (both biotic factors) is possible. Therefore, whether green roofs are designated to be habitat requires planning and design before construction of the roof (Baumann 2011).

Overall, all green roofs must be water resistant, requiring a waterproof membrane to be installed at the lowest layer of the roof (Fig. 5) (Xiao et al. 2014). A root barrier is then either incorporated within the waterproof membrane or above it to prevent root penetration (Xiao et al. 2014). Four essential layers are then incorporated: from the bottom up, these are the drainage layer, webbing/geotextile filter, soil layer, and vegetation layer (see Berndtsson 2010 or Xiao et al. 2014 for more design details). While these layers vary in materials and thickness, the drainage layer, aptly named, allows for proper drainage of the roof while the webbing/geotextile filter prevents clogging of the drains by stopping passage of materials from the upper layers (Berndtsson 2010). The growing medium and vegetative layers are the most important biotic factors that affect bird and other animals.

Roofs are generally categorized as extensive or intensive, with the classification dependent

Fig 5. General profile of green roof components. Source: Vijayaraghavan et al. (2016).
on the substrate depths and supporting vegetation (Table 3) (Vijayaraghavan 2016). These green roof classifications can determine what resources are provided for birds based on the overlying vegetation. Semi-intensive roofs are intermediate between extensive and intensive roofs. Extensive roofs are typically constructed with shallow substrate levels, limiting plant species that can be supported with the shallow growth media (Berndtsson 2010). Compared to intensive roofs, extensive roofs can be favored for their lower costs, lower weight, and nominal maintenance requirements (Vijayaraghavan 2016). *Sedum* sp. or other plants and shrubs adapted to drought conditions with shallow rooting systems are frequently used on extensive roofs (Eakin et al. 2015) and *Sedum* sp. can grow in substrate depths as little as 2 to 3 cm (Oberndorfer et al. 2007). Other benefits of having extensive roofs is reduced maintenance after establishment, though fertilization and watering may still be necessary in certain circumstances (Berndtsson 2010). See Fig. 6 and 7 for examples of intensive and extensive roofs.

**Table 3.** Comparison of the characteristics between extensive and intensive roofs.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Extensive roof</th>
<th>Intensive roof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose</td>
<td>Functional; storm-water management, thermal insulation, fireproofing</td>
<td>Functional and aesthetic; increased living space</td>
</tr>
<tr>
<td>Structural requirements</td>
<td>Typically within standard roof weight-bearing parameters; additional 70 to 170 kg per m² (Dunnett and Kingsbury 2004)</td>
<td>Planning required in design phase or structural improvements necessary; additional 290 to 970 kg per m²</td>
</tr>
<tr>
<td>Substrate type</td>
<td>Lightweight; high porosity, low organic matter</td>
<td>Lightweight to heavy; high porosity, low organic matter</td>
</tr>
<tr>
<td>Average substrate depth</td>
<td>2 to 20 cm</td>
<td>20 or more cm</td>
</tr>
<tr>
<td>Plant communities</td>
<td>Low-growing communities of plants and mosses selected for stress-tolerance qualities (e.g., <em>Sedum</em> spp., <em>Sempervivum</em> spp.)</td>
<td>No restrictions other than those imposed by substrate depth, climate, building height and exposure, and irrigation facilities</td>
</tr>
<tr>
<td>Irrigation</td>
<td>Most require little or no irrigation</td>
<td>Often require irrigation</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Little or no maintenance required; some weeding or mowing as necessary</td>
<td>Same maintenance requirements as similar garden at ground level</td>
</tr>
<tr>
<td>Cost (above waterproofing membrane)</td>
<td>$10 to $30 per ft² ($100 to $300 per m²)</td>
<td>$20 or more per ft² ($200 per m²)</td>
</tr>
<tr>
<td>Accessibility</td>
<td>Generally functional rather than accessible; will need basic accessibility for maintenance</td>
<td>Typically accessible; bylaw considerations</td>
</tr>
</tbody>
</table>

*Source:* Oberndorfer et al. (2007).

Intensive roofs have deep soil levels that can support more diverse plant selections, such as trees, herbaceous perennials, and shrubs and have a greater capacity to create habitat (Brenneisen 2006; Eakin et al. 2015). Whereas the deeper soil level allows for larger plant selection, intensive
roofs require more maintenance as compared to extensive roofs, such as watering, weeding, trimming/pruning, and fertilizing (Berndtsson 2010; Vijayaraghavan 2016).

There is variation on categorizing roofs as intensive and extensive based on soil thickness. Extensive roofs can range anywhere from 2-15 cm (Berndtsson 2010) whereas 3-25 cm is used in German green roof standards (Fernandez-Canero and Gonzalez-Redondo 2010). Berndtsson (2010) indicates some authors describe intensive roofs can have 10 cm or higher thickness while others must have at least 50 cm or greater. Vijayaraghavan suggests a 20-200 cm depth can be used, whereas German green roof standards require a thickness of 15 cm or more (Fernandez Canero and Gonzalez-Redondo 2010).

Fig. 6: Example of an extensive roof composed of Sedum lineare. Source: Li (2008).
Fig. 7: Example of an intensive roof in Guangzhou, China. Photo by: Allen Lau.

4.0 Inherent Variables Influencing Avifauna in Urban Green Infrastructure

Increasing the area of existing habitat patches is one of the most effective management measures for urban bird conservation although high costs and time for construction can deter patch expansion; cities often do not expand habitat area due to financial and spatial constraints (Kang et al. 2015; Threlfall et al. 2016). Cheaper alternatives include limiting human disturbance in urban forests and enhancing vegetation complexity, such as planting shrub layers (Kang et al. 2015). Improving habitat connectivity is another alternative, where linking forest patches, such as through street trees, can increase forest bird populations (Kang et al. 2015).

4.1 Patch Size

In parallel with natural ecosystems, patch size is often the strongest predictor of biodiversity and positively influences species richness and abundance (Beninde et al. 2015). Larger patch size unequivocally can support larger and more stable avian populations with more functional guilds due to the larger available range and size of habitats (Evans et al. 2009; Goddard et al. 2009; Kang et al. 2015). This species-area relationship is critical in urban areas as many North American birds will not utilize spaces under a minimum width threshold (Evans et al. 2009).
Increasing or retaining large patch sizes and enhancing the connectivity between these patches is the best strategy for preserving or increasing urban biodiversity (Beninde et al. 2015). Unfortunately, expansion of these patches is often difficult due to impracticality in urban settings, though one possibility is to enhance the periphery of the patch as this can extend the perimeter of the patch edge (Evans et al. 2009; Kang et al. 2015). Increasing patch size and performing revegetation can be an effective means to increase urban bird populations, however, cost and time are two limiting factors (Kang et al. 2015).

Spatial scale is particularly important to consider with birds. While larger habitat patches are beneficial, more local-scale resource provisions can influence the presence of birds more than the broader city-scale (Evans et al. 2009). In American studies, Buxton and Benson (2015) found greater patch sizes positively increased grassland bird species populations in Chicago, IL. Latta et al. (2013) determined patch size, along with edge densities, is an important variable influencing avian assemblages and species richness. In another US study, the body size of birds can provide an approximation of the local scale utilized for seeking resources, ranging from 0.2 to 85 km$^2$ for most species (Hostetler and Holling 2000), providing implications that gardens can contribute to the broader, city-scale habitat availability for birds. In the UK, it is suggested that green spaces be a minimum of 10 ha to support the greatest number of urban bird species whereas Kang et al. (2015) suggests forest patches of 3.5 to 5.0 ha. Particularly, insectivorous birds are more sensitive to smaller patch size with less connectivity: this is because insect abundance also reduces with fragmentation and decreased habitat connectivity (Kang et al. 2015). It is recommended that parks in isolation be at least 10 ha as it can still retain bird species richness if variation in habitats and microhabitats is provided (Nielson et al. 2014). Areas of small patch sizes tend to experience decline in species richness though urban-adapater species are still likely to persist (Beninde et al. 2015).

Predator dynamics change in urban areas in relation to human disturbance and land cover change. In particular, large mammalian species, less mobile predators (i.e., snakes), and urban-sensitive species populations decrease in highly urban settings and meso-predator populations increase (Buxton and Benson 2015). Urban-adapted meso-predators, like raccoons (*Procyon*
lotor), become particularly abundant in urban settings as natural predators are removed (Buxton and Benson 2015). In relation to patch size, smaller patch sizes result in greater nest predation rates for birds, especially for grassland bird species (Buxton and Benson 2015). Larger patch size can also reduce predation of grassland bird nests because nests found along the outer edges of have been found to have reduced predation by thirteen-lined ground squirrels in Chicago (Buxton and Benson 2015). Because some nest predators, like these ground squirrels, reside in the inner areas of habitats, birds nesting along the edges were away from the area the ground squirrels frequent (Buxton and Benson 2015).

Whether a species can colonize a green roof depends on the size of the roof, as there is great variability in the area necessary for different species (Brenneisen 2006). The amount of space provided on the roof manages which species may use the roof and whether permanent communities can establish on them (Fernandez-Canero and Gonzalez-Redondo 2010). While it is difficult to increase the size of roofs in residential areas, industrial and commercial roofs can contribute greatly to bird habitat if greening takes on a consistent approach (Brenneisen 2006). Nesting success on roofs may be linked to roof size when considering necessary home range requirements for certain bird species (Eakin et al. 2015).

4.2 Fragmentation and Connectivity

Urban habitats are often fragmented, with habitats scattered throughout the city in a mosaic patches and pockets (Fernández-Juricic 2000). Habitat or landscape connectivity refers to the linkage of individual patches of habitat that either allows or restricts their movement in the landscape (Fernández-Juricic 2000). The "island biogeography theory" (MacArthur and Wilson 1967) has been applied to urban ecosystems due to the fragmentation of habitat patches in urban areas (Le Roux et al. 2015). The theory describes two main points, first, habitats of larger size will support greater species and population size due to species-area relationship, and second, greater isolation of patches has a negative impact on species richness due to habitat-isolation relationships (Le Roux et al. 2015).

Wildlife, including birds, naturally needs to disperse, migrate, and evade disturbances in urban areas, and fragmentation of habitats interferes with this (Hong et al. 2013). Different life-history
strategies of birds can determine how much movement occurs in the urban landscape, for example, frugivores may require more movements throughout the city in search of adequate food resources whereas certain birds, such as granivores, can find food resources at smaller scales (i.e., bird feeders in gardens) (Whittaker and Marzluff 2012). Connectivity between isolated urban patches of habitat can be especially crucial for post-fledgling bird dispersal as this dispersal life-stage relates to source-sink population dynamics (Whittaker and Marzluff 2012). Increasing forest cover and reducing impervious surfaces can enhance the connectivity of habitats that allows post-fledgling dispersal, as well as adult forest bird movements throughout the urban landscape (Whittaker and Marzluff 2012). Having connectivity between patches for cities along major avian flyways can be critical for allowing the movement of migratory birds (Oliver et al. 2011).

In residential yards, at the coarser level, connectivity amongst gardens is more critical than individual patch size because yard sizes are often defined and limited to urban property lines, and thus cannot be easily influenced by the resident. Some areas in Britain have over 50% of their green spaces contributed by domestic gardens (Evans et al. 2009). Unfortunately, most of this green space is non-continuous (Evans et al. 2009). Plant species richness is typically high in residential yards, resulting in high abundance of food sources that include insects, fruit, and seed (Kang et al. 2015) so increasing connectivity of residential yards into the greater urban habitat network can provide valuable food resources (Rega et al. 2015). Insect abundance also has a negative relationship to forest fragmentation, suggesting insectivorous bird abundance would similarly decrease due to fragmentation and would benefit from connectivity (Kang et al. 2015).

Reducing fragmentation between habitats and increasing the connectivity between gardens and urban forests can improve the heterogeneity of the landscape (that is, to provide varying resources and habitat) (Goddard et al. 2009). Because mobile species, like birds, can forage at larger scales, having connective habitats with heterogeneity can attract a larger range of bird species and guilds (Goddard et al. 2009). Optimistically, networks of gardens would be managed as a larger residential ecosystem, moving gardens away from being independent units — this emphasizes the collaboration of all stakeholders Goddard et al. 2009).
Fragmentation of habitats has a negative influence on species richness, and whenever possible (though difficult), stakeholders should improve connectivity of habitats. Caution should be exercised in light of climate change; managers need to not only plant more trees but also plant trees strategically that will persist from climate change (Barona 2015). Because not all bird species use or benefit from habitat corridors, managers should evaluate existing habitats and whether targeted bird species would utilize new habitat corridors (Hong et al. 2013). Caution should be exercised not to create corridors that can potentially increase the movement of invasive species (Hong et al. 2013). As trees are vulnerable to climate change, there should be particular consideration given to which tree species or populations in urban areas may shrink or die off, resulting in loss of connectivity (Barona 2015).

Considering all green roofs functions as parcels of fragmented habitat, planning green roofs should recognize adjacent man-made and natural habitats and contribute to them (Fernandez-Canero and Gonzalez-Redondo 2010). If green roofs can provide expansive areas of vegetation, green roofs can potentially contribute to improving landscape connectivity and decreasing fragmentation (Eakin et al. 2015).

The height of the roof can either attract or detract certain bird species. Because the roof is elevated, species may be attracted to the roof as it is distanced from human activity found at ground level, as well as ground predators that may not be mobile enough to access the roof (Eakin et al. 2015). For roofs too high for less-mobile species to establish, creating green corridors from the ground level can improve the colonization of insects, small lizards, and other species that can attract birds (Fernandez-Canero and Gonzalez-Redondo 2010).

Habitat corridors act as linkages between patches of habitat and the vegetative complexity and size of these corridors vary. In urban settings, the use of wooded streets with trees is often valued for potentially creating functional corridors (Fernández-Juricic 2000). Habitat corridors with less impermeable surfaces are ultimately more beneficial towards birds.

While urban conservation is typically focused on larger, intact expanses of green spaces (i.e., parks and forests), smaller green spaces can contribute to the larger urban matrix when
vegetation creates proper connectivity amongst all patches (Kang et al. 2015). Smaller patches can link larger patches that can be otherwise separated, creating a continuous network for wildlife movement (Kang et al. 2015). Especially when a city has less than 30-40% land cover, having sufficient connectivity can mitigate extinction of certain species (Kang et al. 2015). Importantly, some cities may only be composed of large quantities of small habitat patches (Rega et al. 2015).

Linking smaller, isolated patches with viable habitat corridors creates a larger network of habitat that can be crucial for providing shelter and food resources for birds (Hong et al. 2013). Because it is often difficult or costly to expand patches of urban habitat, a more cost-effective approach for urban planners is to construct strips of ecological corridors linking isolated patches (Hong et al. 2013). For some species, allowing movement between these patches is a cost-effective solution for increasing patch size as urban spaces is often limited or costly (Hong et al. 2013).

The vertical and horizontal spatial distribution of habitat corridors is important for the movement of birds and whether birds use the corridor for nesting habitat (Savard et al. 2000). Dense tree canopy layers are crucial for migratory birds as it provides coverage from mobile predators as they forage (Savard et al. 2000). It is important for residential areas to provide tree canopies that provide structural linkage for the passage of birds (Savard et al. 2000). The surrounding 5 km area around patches can often be an important predictor of whether patches become isolated as these areas are often developed and have a negative impact on bird species richness (Oliver et al. 2011).

Generally, bird species that are most likely to benefit from and use habitat corridors are species that are native residents and forest species that utilize the inner forest habitat (Hong et al. 2013). Unfortunately, trees within habitat corridors often have few nesting cavities for birds and insect abundance is limited as insects are deterred from habitat corridors; habitat corridors can resemble edge habitats that run in straight lines that naturally do not accumulate high insect populations (Fernández-Juricic 2000).
Managers should aim to enhance habitat corridors by improving vegetation complexity, providing structural connectivity, and limiting human disturbance (Fernández-Juricic 2000). When moving water, such as a stream is present, managers should prioritize surrounding habitats as they act as natural habitat corridors for wildlife (Savard et al. 2000). Increasing connectivity from more rural areas can allow movement of bird species into urban habitats (Savard et al. 2000).

Since corridors are often permeated in the urban matrix, such as being located next to traffic, noise can often deter birds or increase stress levels; urban noise can change bird communication by altering songs and calls (Fernández-Juricic 2000). Roads and highways typically have lower abundance levels of breeding birds that are discouraged by traffic (Fernández-Juricic 2000).

**4.3 Vegetation Structure**

Vegetation structure describes the three-dimensional structure formed by vegetation within habitats (Fig. 8). Vegetation structure is one of the most important habitat variables that influence vertebrate and invertebrate abundance and general biodiversity (Goddard et al. 2009; Kang et al. 2015). Vegetation characteristics contributing to structure and complexity include plant species, diameter for woody plants, canopy cover, shrubs, grass, leaf/litter layer, and coarse and fine woody debris (Kang et al. 2015). Having these characteristics available directly contributes to available habitat resources for birds. Herbs, shrubs and trees are the main contributors to vegetation structure, and a global meta-analysis revealed that trees are particularly influential to bird diversity (Beninde et al. 2015). Most studies have been conducted on larger habitat scales, such as parks and agricultural fields, but research also suggests that improving landscape heterogeneity on smaller scales can attract different bird guilds (Goddard et al. 2009). Generally, this is because the life history and body sizes are characteristics of birds that determine necessary spatial scales of birds, such as smaller birds defending smaller home ranges particularly during breeding versus winter foraging (Goddard et al. 2009). Many bird species select their habitat based on vegetation structure as even slight changes in the height or structure of vegetation can allow detection by predators (Evans et al. 2009).
4.3.1 Importance of Understory Vegetation

The understory vegetation, composed mainly of long grasses, herbs, and woody shrubs, is a critical habitat component within almost all urban green spaces (Kang et al. 2015; Threlfall et al. 2016). Shrub layers are important in urban habitats for species diversity, particularly utilized by low-nesting species and fledglings (Kang et al. 2015). Diverse vegetation complexity can attract species by allowing birds with particular nesting requirements to select their nest site, such as closer to the ground level or within the lower shrub layer (Kang et al. 2015). Higher vegetation density improves nest crypsis, that is, where nests are visually hidden more effectively from predators (Evans et al. 2009). Increasing the volume of the understory vegetation has a positive effect on increasing bird species richness. In one study, an understory of 0.0 to 0.5 m in height had a strong positive effect on bird species richness, particularly insectivorous species (Threlfall et al. 2016). See Fig. 9 and Fig. 10 for comparisons of understories.
Fig. 9: A stand of Monterey pines (*Pinus radiata*) in San Francisco with low understory vegetation. Photo by: Allen Lau.

Fig. 10: Dense understory/shrub layer under a Monterey pine. Photo by: Allen Lau
4.3.2 Vegetation Structure in Gardens

One of the most important findings by the Biodiversity in Urban Gardens in Sheffield Project, which sampled garden vegetation, found that the construction of the vegetation complexity determining the three-dimensional layout of gardens can be one of the most important factors influencing diversity and abundance of vertebrate and invertebrate species (Goddard et al. 2009). Within vegetation structure, shrub cover and more extensive canopy height were two important vegetation layers that increase native bird species richness in Australia (Daniels and Kirkpatrick 2006). The presence of trees, especially a mix of evergreens with deciduous species, can improve the vertical vegetation structure and can improve bird species richness by improving habitat complexity at the higher canopy levels that are typically more barren (Belaire et al. 2014).

4.3.3 Vegetation Structure in Urban Forests and Parks

Urban Forests and Parks are typically larger areas of land in cities and can provide more space for birds to nest. Mature trees provide significantly more resources for birds and other wildlife, and when combined with diverse vegetation structure and composition, are the most important variables influencing bird biodiversity after patch area (Kang et al. 2015). Many bird species form low lying nests, and creating or enhancing a shrub layer under trees can increase bird species diversity (Kang et al. 2015). Having greater mean basal areas within the patch, an indicator of more mature forests, also positively increases bird species richness and abundance of primarily ground-nesting and migrant species (Kang et al. 2015). When considering the density of large native trees, bird breeding activity had a strong positive correlation with trees that were more than 81 cm in diameter at 4.5 high, or 81 cm Diameter Breast Height (DBH) (Threlfall et al. 2016).

Urban forest management needs to be more strategic than simply planting more trees and preserving existing trees, it needs to critically plan and evaluate which species are likely to thrive in the new climatic conditions (Barona 2015). Often, it may be difficult to determine (Barona 2015).
4.3.4 Vegetation Structure in Green Roofs

As novel, manmade habitats, the vegetation structure of green roofs are initially completely designed by their managers. If the intention of the green roof is to provide habitat for birds, green roofs need to provide complex habitat structure that increases the amount of food, nesting, and shelter resources available on the roof (Threlfall et al. 2016). Creating diverse vegetation structure needs to incorporate both the vertical-horizontal structure and how plants and other physical aspects are distributed throughout the roof (Fernandez-Canero and Gonzalez-Redondo 2010). Plants, alongside other physical structures like woody debris and other objects, contribute to the structural, three-dimensional layout of the roof which creates the functional and inhabitable space of the roof (Fernandez-Canero and Gonzalez-Redondo 2010).

The ability to create such diverse structural spaces may be limited on green roofs, exclusive to only properly planned intensive roofs. Complex structural habitat structure has been shown to support a wider range of species by increasing the amount of available food, nesting, and shelter resources in the space (Threlfall et al. 2016) and this is difficult to create in extensive roofs with limited capacity for support diverse vegetation. Extensive green roofs typically are composed of Sedum monocultures. Sedum monocultures lack the habitat variables found in grasslands that birds utilize, often having no variation in height (Washburn et al. 2016).

The green spaces that most broadly support bird populations incorporate dense understories by mixing woody shrubs, leaf litter, fallen woody debris, mulch, seedlings, and more (Threlfall et al. 2016). Green roofs that are vegetated with a range of plant species (i.e., incorporating native woody plants and warm-season grasses) that creates variation in height can provide the necessary vegetation structure for different birds (Washburn et al. 2016). Importantly, different bird species will have varying structural and spatial requirements dependent on their life histories and home ranges (Fernandez-Canero and Gonzalez-Redondo 2010). There may be seasonal variation whether birds visit green roofs based on vegetation structure, for example, roofs that do not provide adequate thermal cover for birds in colder months limits the roof's capacity to function as viable shelter from the weather (Washburn et al. 2016).
Planning the spatial distribution of different plants can create micro-habitats on the roof that can allow different plant species to establish in shady or sunny areas (Baumann and Kasten 2010). Aside from contributing to habitat dynamics, plant height and leaf area have positive relationships to enhancing ecosystem services, including enhancing storm water retention and humidification of the surrounding atmosphere through transpiration (Lundholm et al. 2014; Xiao et al. 2014). Continued staggering of the succession rate (planting) of vegetation on green roofs has also been shown to influence bird species by creating temporal changes in vegetation structure and growth that attracts different life stages; green roofs that have their vegetation planted during a short period of time does not allow regular succession and regeneration of plants, especially if the plants are the same age (Evan et al. 2009).

4.4 Vegetation Composition

Along with vegetation structure, vegetation composition also influences bird diversity (Kang et al. 2015). Vegetation composition, being the floristic species makeup of the habitat, determines the dynamics and function of the habitat (Dvorak and Volder 2010). Because of the global variation in urban ecosystems, this section does not describe specific plant species but aims to highlight why vegetation composition is a critical component of bird habitat. Most urban ecosystems are surprisingly similar when considering their overall design, uses, and constraints (Savard et al. 2000) so generalizations are appropriate.

For most woodland/forest and generalist bird species, trees, shrubs, and herbs are important plant groups for bird habitat in urban areas (Beninde et al. 2015). In addition, because cities are highly modified ecosystems, the use of native, non-native, and exotic species are frequently debated in urban systems and warrants discussion in this section. Importantly, spontaneous vegetation, plants that occur and thrive on their own in urban ecosystems, appear to be particularly adapted to the local conditions and should warrant consideration as possible plant selections if they provide habitat value and are not particularly invasive (Tredecic 2010).
4.4.1 Exotic, Native, and Non-Native Species

The use of exotic, native, and non-native tree species, as with other vegetation, is frequently debated in urban areas due to the ecosystem services they provide (Livesley et al. 2016; Tredici 2010). In urban areas, exotic, native, and non-native tree species have great potential to provide faunal biodiversity habitats, especially considering how urban areas are "novel ecosystems" and these urban ecosystems are a departure from more rural and natural ecosystems (Livesley et al. 2016). Tree species richness and diversity in certain cities is completely selected by humans (Nowak 2010).

The native-and-exotic tree debate in urban areas is complex. For example, arguments for the use of exotic or non-native species suggest they may be more resilient and adapted to the future climate, in which the natural ranges for native species will shift (Iverson et al. 1999). Many exotic species tend to thrive in highly urban environments, often adapting and performing better than native species (Nowak 2010). In urban areas, vegetation faces different climatic conditions and urban processes, such as urban heat island effects, modified plant and seed dispersal, changes in pollinator availability and abundance, and human governed vegetation management (Nowak 2010). Considering how highly altered urban environments are, in terms of disturbance, infrastructure, ornamental and managed plant species, the idea of removing exotic species and using only native species "is somewhat of an oxymoron" (Nowak 2010).

Invasive and exotic trees often can provide valuable habitat and food resources for wildlife, especially birds and butterflies that are common in urban areas (Dickie et al. 2014). For example, over 40% of the butterflies found in Davis, CA use mainly non-native, particularly woody plants (Shapiro 2002). Because native plant species can be limited in urban areas, animals may rely on non-native species to provide food and other habitat resources that would otherwise be unavailable (Shapiro 2002). It is important to consider the positive and negative contributions of invasive or non-native trees, particularly some trees and other woody trees that can provide shelter for native wildlife and deters invasive or non-native predators (Dickie et al. 2014). Contrastingly, some trees may appear attractive to birds as nesting habitat but result in low nesting success (Dickie et al. 2014).
Many times, the intention of removing non-native trees is guided by the interest of increasing native species — it should be argued that unless non-native trees significantly impact the environment, such as creating problems or limiting native species (i.e., invasiveness), the benefits of removal should be thoroughly considered (Dickie et al. 2014). Currently widespread and invasive trees were a result of historical plantings to stabilize soils and act as erosion control (Dickie et al. 2014).

4.4.2 Spontaneous Vegetation

Natural vegetation patterns are greatly destabilized in urban areas, and even in more rural habitats, due to widespread transportation and movement of people with the use of cars, trains, bicycles, subways, and so forth (Tredici 2010). This results in the introduction of new plant species, often changing local dynamics and colonization patterns (Tredici 2010). Because areas within the city often house robust spontaneous vegetation that has flourished, some researchers defend these sites since they now contribute to maintaining existing urban biodiversity (Tredici 2010). As climatic conditions change in cities, these naturally occurring species may provide future insight on plant species that can establish readily in cities and possibly offer habitat for birds and other wildlife.

It is important to consider, especially in cities that have fewer economic resources and are facing a loss in population, that the occurrence of spontaneous vegetation may also contribute to valuable ecological resources (Tredici 2010), especially since revegetation can be expensive (Kang et al. 2015). North America has been naturalized by a relatively large number of European plants, where a survey of over 222 of the most common urban plants in northeastern United States indicated 47.5% species came from Europe and Central Asia (Tredici 2010). Some urban cities in the United States have high percentages of non-native species, such as Boston with 45.7% (Tredici 2010). Rather than aiming to remove all spontaneous vegetation that establishes in urban areas, consideration for these plants should balance their contribution to habitat while weighing potential impacts of the plants invasiveness.
4.4.3 Vegetation Composition in Green Roofs

Popularity in designing constructed ecosystems using low plant species diversity or monocultures suggests efficiency, rather than ecological complexity, and is traditionally favored in urban ecosystem design (Lundholm 2015). Greater plant diversity in green roofs has been shown to increase ecosystem multi-functionality; there is a positive relationship between plant diversity and the ability for vegetation to cool and transpire on the roof (Dvorak and Volder 2010; Lundholm 2015). Extensive green roofs, which have shallow-substrate depths, limit the roof's ability to sustain diverse plant species, and in turn, decrease the amount of other ecosystem services and wildlife habitat the roof can provide (Lundholm 2015).

Plants living on green roofs face considerable climatic challenges, including lack and/or excess water availability, higher temperatures as compared to ground levels, increased solar input, and physical damage brought on by greater winds (Oberndorfer et al. 2007). Due to these conditions, plant species used for green roofs can limit and restrict resources and habitat suitable to birds (Oberndorfer et al. 2007). As with other urban, man-made ecosystems, the use of a single or few plant species, which is especially common on extensive roofs, decreases their ability to provide ecosystem provisions, including habitat elements (Brenneisen 2006; Dvorak and Volder 2010; Lundholm 2015). Plant species selected for extensive roofs typically are selected for their ability to withstand these stresses, particularly species that form low and compact growth, having crassulacean acid metabolism (CAM), and develop hardy twiggy systems (Oberndorfer et al. 2007). CAM is a pathway used by certain plants, such as genus Sedum, that decreases water loss during the day by shutting its stomata, the pores on the epidermis of plants, until nighttime when the plant opens the stomata for storing carbon dioxide (Vijayaraghavan 2016). Managers should recognize that roofs designed with Sedum spp. likely will not provide valuable bird habitat.

The survival of native plant species on green roofs is still being researched. The current recommended species for green roofs have been chosen through trial and error based on studies conducted primarily in Germany, Switzerland, and Scandinavia (Dvorak and Volder 2010). Though native plant species are adapted to local climatic conditions, the harsher conditions on roof tops may restrict their ability to thrive, especially on extensive roofs without irrigation and
shallow soil depths (Monterusso et al. 2005; Oberndorfer et al. 2007). For example, Michigan State University conducted a study on eighteen native perennials planted in substrate depths of 10 cm and found only four species (Allium cernuum, Coreopsis lanceolata, Tradescantia ohiensis, and Opuntia humifosa) survived during the three year study (Monterusso et al. 2005). However, it is suggested that if necessary substrate depths and irrigation are provided on the green roof, that theoretically most plants would be able to survive on the roof if it is adapted to the climatic conditions (Oberndorfer et al. 2007). A review of North American green roof vegetation states North America, as compared to European countries, is behind in studying plant application and management on green roofs though studies are increasing (Dvorak and Volder 2010).

Washburn et al. (2016) found green roofs vegetated with Sedum spp. to have low bird diversity when compared to respective natural and man-made grasslands, likely due to the lack of biomimicry in regard to vegetative composition and structure. When restricted to using Sedum spp., green roofs can potentially increase their ability to attract wildlife by using white and biting stonecrops that flower exuberantly and have been shown to attract insectivorous pollinators, particularly bees and butterflies (Ishimatsu and Ito 2013).

Understanding bird life history requirements, especially breeding and nesting behavior, is critical for determining plant selection for the green roof. For example, unless the vegetation is able to support invertebrate communities, such as insects, spiders, etc, precocial bird species cannot survive as the young birds must forage by themselves soon after hatching for food and water (Baumann 2006). Typically, the occurrence of spiders on green roofs indicates the establishment of other invertebrates, as spiders are predatory and rely on available prey species (Ishimatsu and Ito 2013).

Because vegetative composition is directly related to bird communities, creating specific vegetative conditions can be used to attract targeted bird communities, such as grassland habitat for grassland bird species (Eakin et al. 2015). It is important to note that rather than planting more species to increase plant diversity, there should be a basis for selecting plant species to
produce intended results (Vijayaraghavan 2016). Which bird species are likely to nest on green roofs should be investigated and planned for. For example, Killdeer prefer to nest in open areas, typically meadows, fields, pastures, and other grassland habitats without dense vegetation, which in urban areas could include parking lots, graveled roofs, and sand bars (Washburn et al. 2016). These nesting sites tend to be slightly elevated.

4.5 Remnant and Mature Vegetation

Patches that have existed pre-urban development are referred to as remnant patches, whereas new patches are areas constructed from the late 20th through early 21st century (Kang et al. 2015). Thus, the age of the patch greatly influences bird species richness and abundance (Kang et al. 2015). While mature vegetation, specifically native trees, provide greater resources and habitat for birds and other taxa compared to younger vegetation (Aronson et al. 2014; Barth et al. 2015; Kang et al. 2015), urban development frequently replaces standing vegetation during the construction process and replaces it with small and juvenile plantings peri- or post-construction (Barth et al. 2015; Hostetler 2012). Barth et al. (2015) state that bird species richness and abundance is greater in urban parks and vegetated streets that retain remnant mature trees during urban development as compared to streets without them. The study indicated that retained trees were utilized by 58.4% of all observed birds in parks and 71.3% of all birds observed in vegetated streets (Barth et al. 2015). Feeding guilds were expectedly distributed to their habitat, as carnivores were found more in bush and park habitats whereas insectivores were found more in bush areas, likely in relation to prey abundance (Barth et al. 2015).

4.6 Water Bodies

Water bodies in urban areas can consist of ponds, rivers, streams, and seasonal water bodies. Avian species richness, particularly woodland species, tends to increase in the presence of water bodies (Ferenc et al. 2013). Aside from providing water, the vegetation structure around water bodies is likely responsible for influencing avian species richness as it increases habitat heterogeneity by establishing riparian habitat (Ferenc et al. 2013). These riparian plants can provide food resources as well as nesting and refuge for some woodland species. Smaller urban water bodies, however, are not expected to attract wetland bird species (Ferenc et al. 2013).
Other uses for smaller water bodies include bathing for species ranging from smaller sparrows, doves and pigeons to larger Canada geese. Management of water bodies in urban areas should focus on retaining areas of remnant vegetation, reducing human disturbance, and avoiding excessive management activities (Ferenc et al. 2013).

Similar to other habitats, water availability can be an important element on green roofs though there is not enough research linking the establishment of bird populations and water availability on green roofs (Fernandez-Canero and Gonzalez-Redondo 2010). However, because the majority of bird species drink water from the surface, having available water on green roofs can be a valuable resource, especially when/where water is limited (Fernandez-Canero and Gonzalez-Redondo 2010). Some species may not require available water sources if they are adapted to obtaining water from other sources. For examples, there are species able to drink dew, or oriole finches that consume succulent plants, such as *Sedum* spp, for water (Fernandez-Canero and Gonzalez-Redondo 2010), raptors obtain moisture from animal prey, and hummingbirds get water from nectar. If water sources are naturally-pooling on roofs, caution should be exercised to prevent water to be contaminated with phosphate or other heavy metals leaching into the water (Fernandez-Canero and Gonzalez-Redondo 2010).

### 4.7 Specific Variables for Green Roofs

#### 4.7.1 Soil Depth

On green roofs, soil depth and composition directly governs the establishment of plant species in the vegetative layer (Baumann 2011; Brenneisen 2006). Thin substrate layers typical of extensive roofs limit plant selection and reduce water retained in the substrate layers, requiring drought-adapted species that can survive during long periods without water and with the thin soil layer drying out (Brenneisen 2006).

Depending on average precipitation patterns in the area, a 10 cm soil depth has been shown to support vegetation found in meadows, including species of grasses, alliums, lavender, thymes, etc (Baumann 2011). Oberndorfer et al. (2007) states than having substrate depths between 7 to
15 cm could also support more diverse plant communities, such as herbaceous perennials that are drought-tolerate, geophytes, alpines, and different grasses.

For optimal habitat conditions, having varying substrate depths on green roofs allows different biotic communities to establish through the creation of microhabitats (Brenneisen 2006). Staggering soil depths at 6, 8, 10, 15, and 20 cm with inundating hills 30 cm high and extending 2-3 meters can allow soil fauna to adequately "retreat" as necessary (Baumann 2011).

### 4.7.2 Soil and Substrate Composition

Substrates should incorporate a range of natural soils, for instance, incorporating topsoil, sand, gravels, etc, as well as using more structural materials, such as wood piles and rocks (Baumann 2011). Soils that replicate local substrates or are taken from brownsites have been shown to increase biodiversity; spider and beetle diversity has been shown to increase when using natural soil substrates (Brenneisen 2006). Whenever possible, the top 15 cm of soil in sites being redeveloped, such as brown fields, should be salvaged for the green roofs as it improves the natural seed bank and transfers some of the existing vegetation and established soil biota to the new roof (Brenneisen 2006). Transporting soil also improves the survival of native seed mixtures that can allow vegetation to spontaneously establish on the green roofs (Baumann 2011).

Vijayaraghavan (2016) details the range of substrate mixes that can be used on roofs and suggests tailoring roofs based on local conditions and intended plant communities. One of the most important soil variables is to have low densities when the soil is completely dry and water-logged as both of these weights determine the load on the building throughout the year. For organic material, 4-8% and 6-12% composition for soils is recommended for extensive and intensive roofs, respectively, based on German guidelines established in Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) (Vijayaraghavan 2016). Application of hay mulch helps retain rainwater by increasing the biomass on the top substrate layer while also benefiting the germination process of plants (Baumann 2011).
5.0 Collective Recommendations

This chapter provides recommendations following many of the variables described in Chapter 4. The recommendations are outlined in steps, prioritizing the most valuable and crucial recommendations first. Towards the end, bullet points are provided for collected strategies that can be important for certain circumstances.

Step 1: Inventory Habitats

The most critical and practical first step before biodiversity conservation occurs is for cities to inventory habitats found within, and even neighboring, its boundaries (Savard et al. 2000). This should outline all habitat types, including urban forests, parks, water bodies, corridors, etc. Mapping these habitats is necessary to understand how birds and other species can move and occupy the urban green spaces.

Cities can use an existing biodiversity assessment framework or develop one for their city. This requires collaborative, integrated efforts between experts in urban planning and conservation, as well as education (Aronson et al. 2014). The depth and precision of the framework will vary depending on each city and available resources. Many authors have previously described general guidelines or frameworks. Two following examples provided include: Hostetler (2011) that provides a general guideline and approach for cities; Local Governments for Sustainability (ICLEI) that developed the only global biodiversity index for cities.


Spearheaded by a team of University of Florida scientists in 2004 from a range of scientific backgrounds, the Program for Resource Efficient Communities (PREC) was created with the goal of increasing sustainable principles into the community's design and management. PREC aimed to increase energy efficiency and reduce water consumption, as well as conserve biodiversity. Recognizing that the local communities were not adopting ecological and conservation principles into local management and design, PREC was a necessary dialogue that assimilated education and resources into the local developments.
Critical Steps:

1. Initially, reach out to developers who are receptive to improving design, construction, and management practices that conserve bird habitat. An incentive noted for the developer is that the developmental review will often be easier since the construction mitigates damage towards bird habitat (Hostetler 2011). Caution should be exercised that developers do not falsely adopt mitigation practices only to hasten the development review process. An example of conservation strategies is retention ponds that were built with littoral shelf zones that allowed wading bird species to forage, and the endangered Florida Sandhill Crane (*Grus canadensis pratensis*) to nest. Another mitigatory example includes creating an undeveloped buffer zone around the shoreline of a 500-acre lake reserved as wildlife habitat. The area of the town is roughly 11,000 acres and over 7,700 acres is reserved for water bodies, conservation areas, and other green spaces (harmonyfl.com/community).

2. Homeowners and residents need to be aware of local avian habitat and species. This is especially important in new developments that may converge into avian habitat. When developments take on conservation actions, homeowners and residents are often receptive and appreciative to learn of these measures. Developments can use signs, flyers, and/or websites to continuously engage its users with outreach. Workshops and community outreach are also vital for integrating conservation into the public.

3. Proper conservation requires mitigation and management in all stages of development — pre-construction (planning and design), during construction, and management after construction.

4. A multidisciplinary team should be formed that encompasses multiple urban specialties, such as wildlife, energy, water, transportation, etc. This team should be knowledgeable of local issues and also engage local policy-makers and other stakeholders in the value of green infrastructure and biodiversity.
Example 2: Local Governments for Sustainability (ICLEI).

ICLEI developed the City Biodiversity Index (CBI) as the only global biodiversity index for cities to use to determine government participation in conservation action and mitigating the loss of biodiversity. The aim of CBI is to allow cities to monitor and evaluate urban biodiversity practically for an objective and scientifically sound approach. CBI should be used for cities where they have the resources to perform an extensive review of the twenty three biodiversity indicators. CBI does not provide recommendations to curtail the loss of biodiversity; CBI is a tracking mechanism for biodiversity and can be used as preliminary step to determine local biodiversity and habitats. Optimally, CBI should lead into planning and management of its biodiversity and ecological resources.

Step 2: Set Achievable Biodiversity Goals

Stakeholders should recognize what bird species or functional guilds their green spaces intend to provide resources for. As a word of caution, the scope of biodiversity is extensive, and cities should be realistic when setting goals to benefit biodiversity (Savard et al. 2000). Often, cities use staple statements that are too general, ambiguous, or misleading in their conservation statements. For example, Savard et al. (2000) suggests statements like "our goal is to enhance urban biodiversity" is too vague as it does not set concrete, achievable goals. More appropriate targets can describe specific bird groups, habitats, and biodiversity indicators (Savard et al. 2000). An example can be to increase forest bird species within urban forests. Importantly, species diversity should not be confused with biodiversity as biodiversity encompasses all broader genetics, species, and habitat while species diversity focuses only on species richness and occasionally species abundance (Savard et al. 2000). In our modernized, urban society, not all species are of equal importance since keystone, umbrella species can have greater effects on the local and regional ecosystem and food web (Savard et al. 2000).
Step 3: Retain Existing Vegetation

Retaining existing vegetation, particularly large and mature trees greater than 81 cm DBH, is one of the most efficient and cost-effective strategies for benefiting avian biodiversity (Aronson et al. 2014; Barth et al. 2015; Hostetler 2012; Kang et al. 2015; Threlfall 2016).

Frequently, high-density housing developments remove existing trees during construction and replace them with juvenile trees along the housing periphery (Barth et al. 2015). Bird diversity is positively correlated to presence of mature trees and replacement with juvenile specimens can take many years to mature, resulting in new housing developments with relatively low bird biodiversity (Barth et al. 2015). The removal of trees pre-construction and replanting with juvenile trees, usually along the housing periphery, peri- or post-construction should be reconsidered (Barth et al. 2015). Whenever possible, existing and mature trees should be retained during construction, especially mature trees that provide valuable resources (i.e., nesting habitat, food resources).

In terms of environmental equity, city areas currently with the lowest green space and tree coverage should be planted first (Livesley et al. 2016). However, in terms of habitat connectivity, these areas may not link to viable patches of habitat to actually support biodiversity. Those in charge of managing urban vegetation should maintain vegetation diversity that can withstand predicated local environmental and climatic changes while selecting plant species and communities that can provide ecosystem provisions (Nowak 2010).

Caution should be exercised when large native species are found along urban areas, particularly streets and recreational parks, as they can cause public safety issues from tree-falls (Barth et al. 2015). Often, the immense social, economic, landscape, and ecological contributions provided by both native and non-native trees need to be considered before their removal; unless non-native trees pose environmental threats, it is important to weigh the benefits and losses associated with non-native tree removal (Dickie et al. 2014). One strategy to retain older trees is to restrict access (e.g., fencing) to prevent human-related injuries (Kang et al. 2015).
Step 4: Increase Patch Size and Improve Habitat Connectivity

Increasing patch sizes and reducing fragmentation of patches is vital for allowing bird migration between habitats, such as post-fledgling movement, and supporting greater species diversity and abundance (Loyd 2013; Savard et al. 2000). Often, increasing patch sizes can be costly as many cities are limited in space and one way to remedy this is decreasing urbanization from the 5 km area surrounding patches (Kang et al. 2015). This can quasi-increase the patch size by linking adjacent habitats with wooded streets/street trees, wildlife corridors, tunnels, bridges, etc. Though birds might not use tunnels and bridges, it allows the movement of more terrestrial species, such as insects, that are foraged by birds.

In gardens, garden management should be coordinated to remove gardens from more 'finite' units into a greater residential ecosystem with mature vegetation with vegetative structural diversity (Goddard et al. 2009). This requires collaborative efforts to reduce fragmentation and small habitat patches between a range of stakeholders, such as academics (social and natural scientists), local policy makers, urban planners and related professions, and resident and community members (Goddard et al. 2009).

There is a strong influence between the location of a green roof and the species composition of birds that can or will utilize the green roof (Washburn et al. 2016). The geographic location of the roof in a city is important to review when considering whether it is likely its placement will be of use to wildlife (Washburn et al. 2016). Considering all green roofs functions as parcels of fragmented habitat, planning green roofs should recognize adjacent man-made and natural habitats and contribute to them (Fernandez-Canero and Gonzalez-Redondo 2010). If green roofs can provide expansive areas of vegetation, green roofs can potentially contribute to improving landscape connectivity and decreasing fragmentation (Eakin et al. 2015).

The height of the roof can either attract or detract certain bird species. Because the roof is elevated, species may be attracted to the roof as it is distanced from human activity found at ground level, as well as ground predators that may not be mobile enough to access the roof (Eakin et al. 2015). Often, it is difficult for less-mobile species to establish on green roofs, such
as certain insects and lizards (Fernandez-Canero and Gonzalez-Redondo 2010), and creating corridors to allow colonization on the roof requires innovation and ingenuity from designers.

**Step 5: Improve Vegetative Structure and Composition**

Aside from retaining remnant trees and vegetation, two other vegetation approaches for improving bird habitat includes improving vegetation structure and composition (Threlfall et al. 2016). The amount of urban landcover has a negative relationship with bird density (species per km²) and increasing vegetation structure is one of the most important strategies for preventing this decline in bird species richness and density (Aronson et al. 2014). Areas without sufficient shrub and tree cover can be targeted to improve vegetation structure and composition as dense understories and canopy layers are vital for many bird species (Smith et al. 2016).

Having diverse shrub and tree species in all green spaces positively influences avian species richness and abundance (Beninde et al. 2014; Evans et al. 2009). Gardens should provide structural diversity by balancing evergreen and deciduous trees. Having trees and shrubs that provide fruits and berries increases bird species richness (Belaire et al. 2014).

Pruning and upkeep of urban trees has led to a decline in nesting space for many birds. Lack of nesting areas for certain bird species has decreased populations, such as common swift and house sparrow populations in the UK (Evans et al. 2009). Providing nest boxes in areas with particularly low availability of cavities, such as tree hollows or buildings without crevices, can be beneficial to nest and cavity breeders (Evans et al. 2009). Optimally, trees should be allowed to mature and retain structural variability that is utilized by birds. Dead standing trees and wood litter are necessary resources for many animals, including for birds to roost.

The use of exotic, non-native, and spontaneous vegetation should be evaluated based on local conditions. Sometimes, they can provide better ecosystem services and potentially support bird diversity in light of harsh urban climates (Dickie et al. 2014; Livesley et al. 2016; Nowak 2010; Tredecı et al. 2010). However, the general trend suggests increasing native vegetation diversity positively increases bird species richness and diversity.
Step 6: Provide and Manage Water Bodies

Water bodies can be valuable resources for birds, especially in urban areas with high levels of impervious surfaces that may not retain clean water sources. Managers should prioritize naturally occurring standing and moving water bodies in cities (Savard et al. 2000). Moving water bodies, such as streams, create natural habitat corridors that are often already protected and undeveloped, allowing diverse vegetation to form (Savard et al. 2000).

Pollution runoff from managed landscapes, such as amenity grasslands, can accumulate in water bodies. To reduce eutrophication and filter run-off entering water bodies that may be a resource for birds and other wildlife, creating vegetative buffers surrounding water bodies can improve water quality (UCD 2008). Typically, down-slope or low-grade open water bodies scarce of vegetation can become sources of chemical and pollutant accumulation (UCD 2008).

Other Considerations

Limiting human disturbance in new patches is critical to allow local colonization of bird species as frequent disturbance will lead to disturbance-tolerant species, including exotic species, homogenizing the area (Kang et al. 2015). Fencing can be a physical barrier that reduces disturbance to sensitive areas (Kang et al. 2015). Areas of human use and disturbance negatively impacts bird biodiversity. In forested areas, patches of remnant vegetation typically have less human disturbance as newly vegetated patches are often spaces utilized more heavily by urban dwellers (Kang et al. 2015). Smaller patch sizes also increases human disturbance as these areas more likely to be visited for walking since walking off trails is more common in smaller patches of forested areas (Kang et al. 2015). Often, it can be difficult to determine exact ecological impacts of human traffic, including the dogs that can disturb nests and inflict injuries and mortality (Evans et al. 2009).

Domestic and feral cat populations have been described as the greatest loss of birds with emerging literature indicating they may predator on birds in higher quantities than previously estimated (Loyd et al. 2013). Cats more commonly predator on songbirds as fledglings are defenseless targets; whenever possible, cats should remain indoors (Loyd et al. 2013).
6.0 Considerations for Social, Cultural, and Institutional Barriers

Most city stakeholders are interested in maximizing benefits for humans though it is important to stress that biodiversity conservation is also valued by city-dwellers as biodiversity provides many social, physical, and psychological benefits that are frequently under recognized (Schwartz et al. 2014). Because green spaces are multifunctional, it is important for cities to critically evaluate their urban areas to determine what areas need more quality or quantity of green spaces, both in terms of biodiversity conservation and delivering associated benefits.

Some of these benefits are difficult to quantify economically, but can be described qualitatively. For example, Ulrich (1984) pivotal study documented twenty three surgical patients that recovered quicker post-operatively and required less pain medication when they were placed in rooms overlooking natural sceneries, as compared to monotonous brick walls. It became documented that proximity to green spaces contribute to general health, improves social interaction and improves mental well-being (Fuller et al. 2007). Continued research indicates that there is a positive correlation between plant species richness, to a lesser extent bird species richness, and measurable physical and psychological benefits received (Fuller et al. 2007). Because cities often are focused more on the human residents and users, rather than the biodiversity, this is an important angle to leverage.

Hostetler (2011) suggests urban biodiversity conservation is generally limited by two socio-cultural and institutional barriers, first, there is a lack of adoption of best management and design guidelines by policy makers and design-build professionals, which is the main purpose and breadth of this research paper. The second limiting factor focuses on social, cultural, and institutional norms and barriers, such as public perception and awareness (Hostetler 2011). This section intends to outline these problems, while it is not the primary focus of this paper, it is necessary to describe suggested recommendations (when available) to assist the user in understanding these issues when it comes to urban biodiversity conservation.
6.1 Aesthetics and Management

Socio-cultural norms can limit the capacity of habitats to support wildlife due to excessive maintenance and upkeep of green spaces. Often, urban landscapes that are frequently maintained become engrained in the public perspective that they are in good health, however, in terms of ecological health, frequent interference with natural processes detracts from important ecosystem dynamics (Sadler et al. 2011). For example, frequently mowing and trimming of lawns and natural grassy areas can prevent the regeneration of wildflowers, shrubs, and trees while also killing ground-level organisms (Sadler et al. 2011). Similarly, mandatory requirements to maintain homogenous lawns, instead of planting native vegetation and thereby restricting diverse bird species, by homeowner associations or developers impedes creating habitat in large expanses of urban areas (Hostetler 2012). This was also recognized in Belaire et al. (2014) that identified residential yards can cover over 30% of the entire city's landcover though there is a general under-recognition in their urban habitat potential.

Unfortunately, developers, policy makers, planners, and others have the greatest long-term influence over local urban ecology and available habitat by creating, maintaining, or limiting urban green spaces, and their lack of knowledge for best management practices and/or bird-friendly policies can have lasting impacts (Hostetler 2012). In terms of urban forests, trees are often selected and managed based on psycho-social desires, not species that will provide the best long-term ecosystem services in the existing and new climate (Barona 2015).

6.1.1 Recommendations for Aesthetics and Management

When creating or modifying existing habitats, the most sustainable approach is to consider two necessary mitigation criteria; first, understand that the urban users' perception needs to align with the intended beauty and amenity of the space or else the space will be negatively perceived by the public, second, the entire planning process, from development, construction, and management, should constantly evaluate biodiversity and conservation goals (Sadler et al. 2011). Increasing the understanding of natural beauty through community planning and environmental education may be necessary to increase awareness of more natural green spaces, doing so can
help balance the scenic and ecological aesthetic in urban design (Sadler et al. 2011). Reversing such societal norms and barriers includes assimilating education into the community and stakeholders, such as through workshops, consultations, and other programs (Hostetler 2012), changing horticulture practices and engaging participation and feedback from urban dwellers to change aesthetic landscape views (Nielson et al. 2014), and working with the local community-scale as through homeowner associations or other neighborhood organizations (Belaire et al. 2014; Goddard et al. 2009). One such approach can be to create a "conservation ethos" that helps develop the neighborhood's understanding and ethic toward wildlife-friendly habitat that can be assimilated into homeowner or residential associations. For example, mowing of lawns can be reduced by allowing strips of un-mown areas where urban dwellers do not use (i.e., closer to the forests or adjacent to trees (Fig. 11) (UCD 2007).

![Fig. 11](image)

**Fig. 11.** Leaving areas of un-mown grass can allow natural regeneration and maturation of vegetation. Photo by: Allen Lau. Based from: UCD (2007).
6.2 Social Equity

Social inequalities in the distribution of urban green spaces is largely recognized as an environmental justice issue (Haaland and Bosch 2014). Residents and neighborhoods of lower socio-economic status, frequently minority communities, suffer from the lack of access to quality green spaces (Haaland and Bosch 2014). City residents with reduced green spaces access leads to reduced economic and social benefits provided by green spaces, such as the promotion of physical activity and public health (Wolch et al. 2014).

Proximity to green spaces has been shown to improve the quality of life of residents. Broadly, green spaces improves mental and physical health, increases economic benefits to real estate, promotes social and community interaction, and provides environmental benefits with ecosystem services and provisioning (Kabisch et al. 2015). Biodiversity, in particular, has been shown to enhance psychological benefits and mental well-being in humans and lack thereof can deprive residents of these benefits (Fuller et al. 2007).

In some cities, this is a geographical issue as the urban core becomes more developed as compared to the urban periphery that typically extends into the urban-rural boundaries (Haaland and Bosch 2014). While it may not be intentional, urban centers often are inhabited by lower economic groups, for example, Berlin's central parts has low quantities of green spaces and is also inhabited by mostly immigrants (Haaland and Bosch 2014). Increasing and enhancing green spaces too extensively has been shown to increase housing prices beyond what existing lower income residents can afford (Haaland and Bosch 2014; Wolch et al. 2014). This creates a paradox with green urban green spaces as excessive greening can cause gentrification (Wolch et al. 2014).

6.2.1 Recommendations for Social Equity

Because greening can raise real estate prices, care should be exercised not to cause gentrification of the neighborhood through extensive greening that drives out minorities from low income neighborhoods (Wolch et al. 2014). Using a needs-based approach by asking qualitative surveys of local residents can describe the particular needs of the community (Byrne and Sipe 2010). One approach is to design 'just green enough' by meeting the communities needs, such as
environmental remediation and cleanup, while also providing valuable green spaces to the local residents (Wolch et al. 2014).

Local authorities and public bodies, recognizing the economic, environment, and social benefits of biodiverse green spaces, should implement robust policies that ensure the creation or maintenance of green spaces through its city (Box 2011). With increasing densification of cities, it is important to consider that the elderly and children may not have access to green spaces (Haaland and Bosch 2014). Examples include:

1. Paris, France: set a goal of that all citizens must be within 500 m of green spaces. Areas that had unsatisfactory green spaces were identified; derelict houses were purchased to convert to green spaces when necessary (Box 2011).

2. West Midlands, England: established a conservation strategy that aimed to have all residents located within 1 km from wildlife habitat, areas further than 1 km were identified as 'urban deserts' (Box 2011).

3. (By nature conservation agency) England: set a standard that not only should persons not live over 300 m away from natural green spaces but also the green space must be a minimum of 2 ha.

6.3 Institutional Barriers

One of the greatest challenges for green space planning is the lack of established provisions for green spaces (Haaland and Bosch 2014). A general lack of ecological knowledge in non-experts, such as developers and planners, creates a barrier as they can be unaware of what species are present and/or potentially using the habitat, such as seasonally absent migratory bird and butterfly species (Sadler et al. 2011). Unfortunately, developers, policy makers, planners, and others have the greatest long-term influence over local urban ecology and available habitat by creating, maintaining, or limiting urban green spaces, and their lack of knowledge for best management practices and/or bird-friendly policies can have lasting impacts (Hostetler 2012).
6.3.1 Recommendations for Institutional Barriers

The current framework of mitigating against biodiversity loss is ineffective as it does not actively increase populations of species, a proper regulatory and planning framework needs to vigorously aim to increase biodiversity and support robust populations (Box 2011). The most effective city administrations of green space planning have one central department, this allows cohesive organization and implementation rather than having divided responsibilities between agencies that may conflict (Haaland and Bosch 2014).

In Dehli, India, an "Urban Neighborhood Green Index" has been used to compare green spaces at the local neighborhood level as this allows more qualitative and quantitative measures (Gupta et al. 2012). Focusing at this proximate level is important as this is the level that affects residents and their daily lifestyle, and can aid in detailing the differences of green space quality and quantity between neighborhoods (Gupta et al. 2012).

6.4 Outlook

In terms of conserving avian biodiversity, city authorities and decision makers are faced with finding ways to convert mown amenity grassland that provides minimal habitat and resources for birds into diverse, valuable habitats for human dwellers and biodiversity (Fox 2011). Reversing existing societal norms and barriers includes assimilating education into the community and stakeholders, such as through workshops, consultations, and other programs (Hostetler 2012), changing horticulture practices and engaging participation and feedback from urban dwellers to change aesthetic landscape views (Nielson et al. 2014), and working with the local community-scale as through homeowner associations or other neighborhood organizations (Belaire et al. 2014; Goddard et al. 2009).

Many cities can be hesitant to create green spaces specifically for wildlife, but by understanding how green spaces can provide measurable benefits to its citizens can be a leverage point to increase green spaces in cities. Often, city dwellers are connected with nature and there are simultaneous opportunities to benefit biodiversity along with people (Schwartz et al. 2014).
7.0 Conclusion

Climate change and habitat loss are two global drivers that threaten over a third of the North American bird population in the near future unless imminent action is taken; cities are ripe with opportunities to utilize urban green infrastructure to help combat this projected decline in avian biodiversity. Rather than simply accepting urban areas as a loss of natural habitat, cities should strive to mitigate their damage on the natural ecosystem by actively developing urban green infrastructure necessary to create valuable habitat and resources for avian biodiversity at the local scale. There is an interdependence between biodiversity and humans; in urban settings, biodiversity and green spaces provides ecosystem services to the human population, whereas humans need to govern the urban landscape in a way that is conducive for fostering and maintaining biodiversity.

Fundamental to preventing or slowing this decline in avian biodiversity requires the replacement of existing simplistic ideals and norms for our green spaces with concepts of creating complex urban habitats for all wildlife. A confluence of stakeholders and interdisciplinary science is necessary to achieve this. While we have devoted so much of our time pushing for the conservation of avian species in distant continents within rural, natural ecosystems, we have forgotten the conservation value of our urban ecosystems (Marzluff 2002). The growing and emerging field of urban ecology enables us, and requires us, to begin to reshape the urban landscape by blending ecological science. This research project provides direction for urban stakeholders on how to construct and manage our urban green spaces based on some of the most important design, abiotic, and biotic variables. Further, we must continue to pursue ways to forge a more sustainable urban ecosystem to prevent the indiscriminate loss of biodiversity.

How our green spaces will contribute to biodiversity rests upon all urban stakeholders; ranging from the residential gardener creating wildlife-friendly habitat in their yards, to the design-build professionals constructing and managing expanses of urban forests and parks for biodiversity. Urban stakeholders should be cognizant of the species within their territories, be clear with defined biodiversity targets and goals, and develop novel ways to create valuable habitat for biodiversity (Savard et al. 2000). Hopefully, it would not be too optimistic to expect a radical
departure from the current conformity of our urban green spaces as a genuine investment by governments and stakeholders is exactly what we need to help prevent the ecological consequences from biodiversity loss.

### 7.1 Future Direction and Research

This research serves as a dialogue to urban stakeholders to utilize our green spaces for both the urban dweller and avian conservation. As the field of urban ecology only spans the past two decades, there will, and has been, a growing breath of research that will determine how all biodiversity may share our urban spaces. The growing amount of modern scientific research in urban ecology, with a large emphasis on avian ecology, provides a glimpse of the importance of urban green spaces for biodiversity. Urban ecology still needs a better understanding of how socio-demographic, technological, and environmental drivers affect green spaces (Niemela 2014). Our cities still need better approaches and progress at reversing social norms to increase green spaces' ability to foster biodiversity (Goddard et al. 2009).

More research needs to be conducted on how urban green spaces can avoid being population sinks. For example, fledgling songbirds that nest in street trees overlaying traffic, impervious surfaces, and in high areas of human disturbance are destined to high rates of mortality (pers. observation). One way to mitigate this loss is to incorporate dense understories that allow the fledgling to survive. Novel, innovative approaches should be researched to increase nesting and post-hatchling survival, such as integrating bioswales under street trees that create buffer zones of protection for fledglings. There is a global movement with governments increasing their green spaces for biodiversity, and integration of sound scientific research will be paramount for our global biodiversity (Threlfall et al. 2016). Cities should collectively work with each other to approach biodiversity conservation at local, national, and international scales to create networks of valuable green infrastructure.
8.0 Works Cited


Belaire, J. Amy, Christopher J. Whelan, and Emily S. Minor. 2014. Having our yards and sharing them too: the collective effects of yards on native bird species in an urban landscape. Ecological Applications 24 8:2132-2143.


