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Urban Greenway Vegetative Communities and Environmental Drivers in the Southeastern United States

Erika Y. Chin

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by

Erika Y. Chin

Bachelor of Science
The State University of New York at Binghamton, 2010

Master of Arts
The State University of New York at Binghamton, 2012

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Accepted by:

Kirstin Dow, Major Professor

April L. Hiscox, Committee Member

L. Allan James, Committee Member

Adam J. Terando, Committee Member

Cheryl L. Addy, Vice Provost and Dean of the Graduate School

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Abstract

Greenways serve as parks or non-motorized transportation routes for urban residents, but as greenspaces they also have the potential to enhance habitat quality and availability. This dissertation examined two aspects of urban greenways: the motivations for establishing greenways and the structure of vegetative communities found within them. Analysis of greenways plans revealed that the provision of natural resources and societal benefits are not promoted equally. In general, social and recreational functions are prioritized in greenway designs, while environmental benefits and services are expected to be inherently and equally possessed by all greenspaces and greenways. Consequently, specific conservation actions (e.g. habitat management or wildlife conservation) are uncommon in planning guidelines. In addition, despite current interest in greenways' ecological benefits, there is limited fine scale data available to aid in planning decisions.

To better understand how greenway vegetation are influenced by local site conditions and disturbances, a detailed survey of woody vegetation was conducted on an established greenway system in Raleigh, NC. Overall, forest communities in the 40-year-old greenway are diverse, though species distribution

patterns and community structure are highly variable. Higher species richness and diversity are associated with conservation areas and residential zones, while areas with lower exposure to streets contain higher stem densities.

Although anthropogenic disturbances encroach on the entire length of Raleigh's greenway to some degree, intact forest stands with diverse, native vegetation remain present. The use of greenways in conjunction with planning and management techniques can be used to aid in future conservation efforts. The collection of long-term ecological data can better inform the assessment of the stability of greenway communities, particularly in locations outside of existing conservation areas. In conclusion, the findings of this dissertation indicate that greenways can be used as habitat for native vegetation in cities, but their proximity to natural and anthropogenic disturbances makes the prospect of long-term conservation uncertain.

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CHAPTER 1

INTRODUCTION

This last century has seen an unparalleled rate of urbanization and population growth around the world. In the southeastern US, for example, urbanized areas are projected to more than double in extent by 2060 under current growth conditions (Terando et al. 2014). This has led to an increasing recognition of anthropogenic impacts on the environment, which in turn, has brought about many ecologically-minded innovations in urban designs and green infrastructure. However, limited academic research exists on the broader implications of green infrastructure on the health and functionality of plant communities in urban forests.

Greenways, the focus of this dissertation, are one such feature used to enhance connectivity between parks (greenspaces) or undeveloped land separated by the built environment. Their ability to provide recreational areas to cities, as well as the physical and psychological health benefits associated with traditional parks, has bolstered the popularity of greenways over the last few decades.

Throughout the document the term “greenway” will be used to discuss any type of linear, vegetated feature that enhances connectivity between natural areas.

Greenways are differentiated from other types of greenspaces by their ability to support several functions simultaneously, including: recreation and public health (Ribeiro and Barão 2006), transportation (Tillmann 2005), riparian buffers (Jo and Ahn 2014), conservation (Batha and Otawa 2013), and other uses. Within this multi-use functionality, however, the ability of greenways to enhance environmental conditions for native plant species has not been closely examined (Opdam and Wascher 2004; Chetkiewicz and Boyce 2009). While some greenways have been successfully designed as wildlife corridors connecting disjunct patches of habitat, there is limited understanding of how the plant communities of the greenway itself may serve as habitat within the urban matrix (Niemelä 2014). In other words, greenways are often viewed as a way to mitigate the negative effects of urbanization (Fabos 1995; Myers 2013), but planning and development actions may underutilize or overlook some benefits to the urban ecosystem.

Due to the relatively narrow needs of humans compared to all other species in a given ecosystem, most species (though not all) are negatively affected by the process of urbanization (McKinney 2008). As populations of native species decrease with the growth of cities, greenways have been acknowledged as a potential means of conserving urban biodiversity by connecting patches of natural habitat (Firehock 2015). By facilitating movement of plants and animals, greenways are intended to increase available habitat, maintain stable populations, and reduce species extinctions within the urban environment.

This dissertation is presented as a series of three manuscripts which together build a geographic framework for understanding how urban development patterns can impact the structure and diversity of vegetative communities in an urban greenway. Greenway vegetation are examined at the community scale to evaluate the spatial distribution patterns of species across an urban center and to identify the ecological impacts of the landscapes they join. Together the manuscripts will address both the social and ecological roles greenways fill in the urban-ecological interface.

Chapter 2 provides a brief history of greenways and their present-day role in urban environmental conservation. This chapter introduces the broader literature to inform research questions addressed in this dissertation. The relevant theories and concepts from the fields of landscape ecology and conservation biogeography are reviewed to provide a framework from which to examine the ecological consequences of land use change on urban plant communities.

In Chapter 3, the first of the three manuscripts, a qualitative content analysis is conducted to answer the research question: **Are environmental and conservation goals prioritized in the design of multiple-use greenways?**

Planning and managing natural environments in cities is necessary to maintain the ecosystem services they provide to both humans and urban biota (Firehock 2015). Greenway planning documents of major southeastern US cities are closely analyzed to identify trends in social and ecological planning goals and objectives. These results are used to understand how conservation is approached in greenway design. The disjuncture of conservation- and civic-oriented planning objectives found in these documents highlights an area of opportunity to improve the level of integration between urban ecology and the urban planning process. By promoting an interdisciplinary approach to the study and development of greenways, future projects will be in a better position to enhance urban habitat quality and species diversity in the long term.

Chapter 4 provides a methodological structure to **characterize vegetation composition and habitat in an urban greenway**. A field-based vegetation survey data was conducted in the Capital Area Greenway (CAG) in Raleigh, NC to systematically identify woody species adjacent to trails. Types of forest communities were defined based on patterns of species richness and diversity. These greenway communities were then compared to sources of disturbance and human activities to identify potential sources of anthropogenic impacts. Ultimately, native vegetation was found to be successfully established throughout the greenway, demonstrating the potential for greenways to enhance ecological quality in cities. The diverse vegetative communities found in habitat provided by greenways are consistent with principles from island biogeography and metapopulation theory, in that larger, interconnected habitats are better able to support urban biodiversity and ecosystem services (Beninde et al. 2015).

The last manuscript, Chapter 5, examines **how the CAG's community structure and composition may be correlated with patterns of land use and development.** Utilizing the same primary dataset as the previous chapter, the CAG community structure and composition were analyzed in relation to different types of urban land uses to determine how development patterns may influence the structure of urban forests. As current literature presents a limited understanding of how ongoing natural and anthropogenic disturbances influence urban greenways over time, this manuscript helps to define how a local government's policies can affect conservation outcomes and the community and structure of vegetation.

Finally, Chapter 6 discusses the findings of this dissertation and its relevance to the study of urban ecosystems. The broader impacts of the three manuscripts are reviewed to highlight their potential applications to urban planning and greenway design, as well as their overall significance to the fields of landscape ecology and biogeography. In the conclusion, future research directions and areas of opportunity emerging from this dissertation are discussed. People are becoming increasing aware of how urban planning and management impact the local environment. The creation of new greenspaces and greenways in cities presents many opportunities in maintaining, and even improving current ecosystem functions. Ultimately, it is the intrinsic interconnectedness of people and the environment that will improve the well-being of both in the future.

CHAPTER 2

LITERATURE REVIEW

The built environment, including constructed roads, buildings, and other human features, covers less than 1% of the Earth's land area, however, over half of the world's population currently lives in cities (Wu 2014). As city populations grow the surrounding natural (e.g. forests, wetlands) and semi-natural (e.g. farms or pastures) spaces are cleared and converted into built environments for human use. The physical structure that arises from urban development is a major influence on the local climate, and many ecological processes in cities are significantly impaired when compared to rural areas (Walsh et al. 2005; Grimm et al. 2008). Subsequently, the animals, plants, and people in this ecosystem must contend with the environmental stressors created by these conditions.

The prevalence of insulating buildings and paved surfaces in cities, in conjunction with limited vegetation and tree cover, create a unique urban microclimate. Heat emitted from buildings and the ground surface to the cooler air results in an urban heat island effect, in which air temperatures can be several degrees warmer than surrounding rural areas (Oke 1982; Kuttler 2008). Humans and other species are affected by this effect, which can reduce biological productivity (Gehrt and Chelsvig 2003; Neil and Wu 2006) and overall quality of life for humans (Baker et al. 2002). Most plants and animals are negatively affected by conditions created through urbanization, leading to decreased native species diversity (McKinney 2008) and increased non-native species populations (Hansen and DeFries 2007). The dominance of impervious surfaces further leads to numerous impacts on local hydrology, including increased run-off, localized flooding, and impaired water quality (Walsh et al. 2005; O'Driscoll et al. 2010; Nagy et al. 2011). Resources needed to mitigate such impacts are costly, requiring significant manpower and specialized infrastructure (Thomas 2014).

These ecological impacts, however, are not uniform across the urban landscape. Cities and suburbs can expand rapidly over relatively short time periods, leading to highly diverse land covers (Kattwinkel et al. 2011). Once contiguous natural habitat becomes increasingly fragmented, leaving smaller, isolated patches that are much less ecologically valuable. Increased fragmentation reduces the ability of species to migrate between patches, decreasing connectivity and the stability of ecological communities (Saunders et al. 1991; Debinski and Holt 2000). In addition, larger habitat patches have been observed to sustain greater species richness and diversity (MacArthur and Wilson 1967; Theobald et al. 2011), suggesting that habitat value diminishes as the landscape is increasingly fragmented (Calabrese and Fagan 2004).

Although the urban landscape is highly heterogeneous (Jongman et al. 2004), urban land covers can generally be categorized in two groups, developed land and greenspaces (Pickett and Cadenasso 2008). Developed land includes areas that have been modified from their natural state for human use. This may include buildings, paved surfaces (e.g. roads, parking lots, etc.), and brownfields (previously developed land that has fallen to disuse). In contrast, greenspaces are spaces that are minimally developed and are typically preserved in a natural or semi-natural state. Urban greenspaces include parks, gardens, and other vegetated open spaces, and are potential habitats for local flora and fauna (Alberti 2005).

To help mitigate the adverse effects of habitat loss and fragmentation, connectors between greenspaces can be constructed as conservation areas to increase habitat connectivity (Ahern 2013). Also known as greenways, these natural corridors connect patches of habitat to promote the movement of species. Allowing animals and plants to more easily travel between habitat patches increases the area in which they are able to live and find resources, allowing them to maintain more healthy and genetically diverse populations (Bond 2003; Mason et al. 2007; Teng et al. 2011).

A greenway's ability to increase available greenspace also presents many direct and indirect benefits to humans. Previous studies have observed that even small greenspaces, in the form of greenways and urban gardens, significantly reduce ambient temperatures (Yang et al. 2005) and air pollutants, including particulates and heavy metals (Schmid 1975; Pugh et al. 2012). The presence of greenways and small greenspaces has also been shown to provide physical and psychological health benefits to urban residents, including a reduction in stress and blood pressure (Douglas 2011). These and other such benefits have long been enjoyed by city residents throughout history, although the motivation for constructing and visiting them have evolved over time.

Searns (1995) traced the precursors of modern greenways to Europe in the 1700's. Following the style of elaborate, well-manicured parks, landscaped parkways were created as extensions of existing park spaces. With the Environmental Movement still centuries away, the main function of these areas was to provide an aesthetically pleasing atmosphere for people. These early greenways became destinations in their own right, providing visitors with social and cultural experiences as they traveled through the city along these formal boulevards. Potential environmental benefits, like promoting native biodiversity or sequestering carbon, were far from the minds of park visitors. But as societies' attitudes toward nature and the environment began to evolve over time, these paradigm shifts were reflected in the designs and functions of greenways.

In modern times the values of the urban greenway have grown to include benefits provided by the presence of nature itself. Frederick Law Olmstead is largely credited with designing the earliest examples of the modern greenway in the 19th Century (Little 1990; Fabos 1995; Ignatieva et al. 2011). Olmstead's urban parkways in the U.S. brought nature into the city with networks of rustic linear parks and trails (Searns 1995). These early modern greenways were used to bring an element of wilderness to people as a response to the perceived disappearance of nature in cities (Little 1990; Gabriel 2011). Residents of densely populated urban areas were provided with the unique opportunity to escape the city and experience the natural world. While not intended to be wildlife preserves or wilderness areas, the emphasis on preserving natural spaces for human use helped pave the way towards more contemporary greenway designs.

The multi-use greenways commonly seen today incorporate both human- and ecologically-oriented objectives towards an overarching goal of having both people and the environment benefit simultaneously. Flora and fauna can be protected from disturbances through the use of habitat buffers (including riparian corridors) or connective corridors between habitat patches (Linehan et al. 1995; Bryant 2006). The use of these elements is intended to mitigate the negative effects of habitat fragmentation, allowing flora and fauna to be protected from disturbances in the urban environment.

A major challenge in designing effective multiple-use greenways lies in maintaining the quality and diversity of these benefits (Baschak and Brown 1995; Chetkiewicz et al. 2006). Just as spatial variation is exhibited in the mix of developed and undeveloped throughout the landscape, the distribution of species and ecological functions varies across space as well. The physical structure of greenways (in terms of habitat types and vegetative communities) is important in generating environmental services (Douglas 2011), but it is the spatial distribution of these components that is most important in supporting species diversity (Jongman et al. 2004). However, when greenways are discussed as homogeneous connectors (see Chapter 3), their value to the ecosystem as diverse habitat is not fully acknowledged. As greenways can cover a large spatial area, it is inaccurate to assume that the distribution of ecosystem services is the same throughout its expanse. The diversity across a greenway should be acknowledged as it is the complexity of the greenway that provides benefits to species and ecological processes (Jongman 2004)

In examining the specific community structure and populations within a greenway in a major southeastern US city, this dissertation highlights the environmental functions acknowledged in greenway planning document, as well as areas of opportunity within greenway planning. Data on specific species and communities are presented to highlight the diversity of communities present within an urban greenway. Bringing awareness to the biological components of a greenway is important to better assess the functions greenspaces contribute to the local ecosystem and what management may be needed in the future.

Chapter 3

Prevalence of Ecological, Environmental, and Societal Objectives in Urban Greenway Master Plans[1]

3.1 Abstract

The longstanding emphasis on community and public health benefits provided by urban greenways has been joined by growing interests in their environmental and ecological values and benefits, including their role as urban habitat and their ability to enhance connectivity across urban landscapes. Here we examine how societal, environmental, and ecological values were integrated into greenway planning documents from 29 major cities throughout the southeastern United States. Utilizing a qualitative assessment rubric to score the degree to which different greenway functions were integrated into each planning document, we identified specific design objectives and goals as well as broader, more descriptive content about greenways and their benefits. While all of the greenway plans

[1] Chin EY, Kupfer JA (2019) Southeastern Geographer 59(2): 153-171
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touched on a diverse suite of benefits, those functions associated with community development were integrated into specific planning targets far more frequently and in much greater detail, with functions such as improving recreational opportunities, physical health of users, and local economic development specifically mentioned in more 90 percent of all plans. In contrast, an average of 44 percent of the rubric's biodiversity functions were present in the greenway planning documents. Further, while plans often cited potential greenway benefits, they less commonly discussed how intended greenway services would be achieved or methods that would be used to quantify success through long term monitoring and assessments, particularly of species populations. This disparity in the presence and quality of functions in greenway plans illustrates the challenges inherent in managing the needs of both humans and the natural world. Prevalence of ecological, environmental, and societal objectives in urban greenway master plans

3.2 Introduction

Urban greenways are linear, vegetated paths that are set aside as natural- or semi-natural areas embedded within the built environment (Little 1990; Arendt 2004). These features have often been created and are maintained to provide a variety of community and public health benefits, including safe transportation systems for pedestrians and bicyclists and the linking of neighborhoods to business districts.

Greenways may also create connections between recreational and natural areas, provide positive mental and physical effects felt by users (Lee and Maheswaran 2011), and help to protect cultural resources (Fabos 1996; Gobster and Westphal 2004).

Well-designed “multiuse” greenways not only yield human benefits but also enhance environmental quality by allowing humans and the environment to benefit from the same space simultaneously. For example, greenways may benefit urban ecosystems by improving air and water quality, protecting sensitive habitats such as riparian zones, promoting biodiversity, and the continuance of ecological processes (Noss 1987; Hellmund and Smith 2006; Ignatieva et al. 2011). As potential tools for conserving biodiversity, greenways may serve as valuable buffers and connections between patches of disjunct habitats within the urban matrix (Linehan et al. 1995; Bryant 2006), thereby helping to mitigate the negative effects of habitat loss and fragmentation (Bond 2003; Mason et al. 2007; Teng et al. 2011). However, it is important to note that the efficacy of wildlife corridors is highly species-specific and also influenced by the physical characteristics of the landscape (Gilbert-Norton et al. 2010; Doerr et al. 2011).

With the recognition that urban landscape conversion and habitat fragmentation will likely increase in the future due to increasing rates of urbanization worldwide (United Nations Population Division 2018), the ability to effectively and sustainably manage urban ecosystems will be dependent on reconciling a diverse suite of human and environmental goals (van Kamp et al. 2003; Wu 2008; Niemelä et al. 2010). Prevailing concepts from ecologically-minded planning and design disciplines, such as landscape architecture and sustainable urban design, are increasingly encouraging designers to incorporate more comprehensive, eco-friendly planning frameworks for greenways and greenspaces (Hellmund and Smith 2006; Beck 2013). The study of the effectiveness of greenways in ecological conservation is still in its infancy, however. As the popularity of greenways and greenspaces continues to grow in cities nationwide, there is a need to critically evaluate their full range of benefits (Viles and Rosier 2001; Niemelä 2014; Shwartz et al. 2014). Detailed examinations of how biodiversity is integrated into contemporary greenway design plans can characterize the role of nature in modern urban settings and illustrate the degree to which ecological management goals are prioritized in metropolitan areas.

To understand how the environment is discussed and the roles that a greenway might play in meeting environmental or ecological goals, we examined greenway planning and design documents (i.e. greenway master plans) for more than two dozen urban areas in the southeastern United States (US). We focused on two questions: 1) What types of societal, environmental, and ecological functions appear in greenway design plans? and 2) How do the quality and level of discussion for ecological and environmental functions compare to the discussions of societal benefits such as recreational opportunities or economic development? In this study, the term "greenway" will refer to any type of linear, vegetated area that is designed to enhance connectivity across the urban landscape. These areas are often recreational spaces that connect parks and open spaces, but they also include features such as riparian buffers and public rights-of-way. Environmental goals will refer to planning and management objectives that relate specifically to ways in which human activities affect environmental conditions and processes, especially those associated with urban pollution and floodwater management. While related to environmental goals and objectives, ecological goals will refer specifically to planning and management objectives associated with the protection or management of living organisms and their habitats within the greenway and its larger urban matrix.

As prior research has demonstrated a growing emphasis on environmental and ecological principles in urban planning and design, we expected to find associated goals featured in the greenway planning documents. However, since greenway planning has historically emphasized human benefits and recreation, we hypothesized that greenway functions focused on human well-being would be the predominant theme in plans and would be discussed in greater detail within existing greenway plans. Specifically, we posited that the identification of the types of environmental planning goals that are discussed in various plans would help to reveal the intended purpose(s) of urban greenways, environmental priorities of local municipalities, and whether a consensus of ecological thinking exists.

3.3 Methods

We examined design plans of existing greenways in major cities throughout the Southern Appalachian Piedmont ecoregion of the southeastern US, which extends from central Alabama to Northern Virginia (Figure 3.1). Pre-settlement ecosystems in this region were dominated by mixed oak-hickory-pine forests, with species composition structured along gradients of climate, soils, topography, and disturbance history (Martin et al. 1993; Wiken et al. 2011). Beginning with Native American settlement and intensifying following European colonization with rapid deforestation that accompanied agricultural expansion in the 18th and 19th centuries, land conversion has been an important source of anthropogenic disturbance that has reshaped the structure, composition, and spatial distribution of Piedmont ecosystems (e.g., Cowell 1995). More recently, widespread urban and suburban development has led to increased habitat loss and fragmentation, posing risks to native biodiversity (Radeloff et al. 2014). Nearly 25 million people now live in the Piedmont ecoregion, with many residing in one of thirty-three urbanized areas (those containing a population of 50,000 or more people) (U.S.

Census Bureau 2015). Sometimes referred to as the Piedmont "megalopolis," this area's rapid pace of urban development and economic growth brings with it numerous environmental and ecological impacts (Alig et al. 2010; Terando et al. 2014).

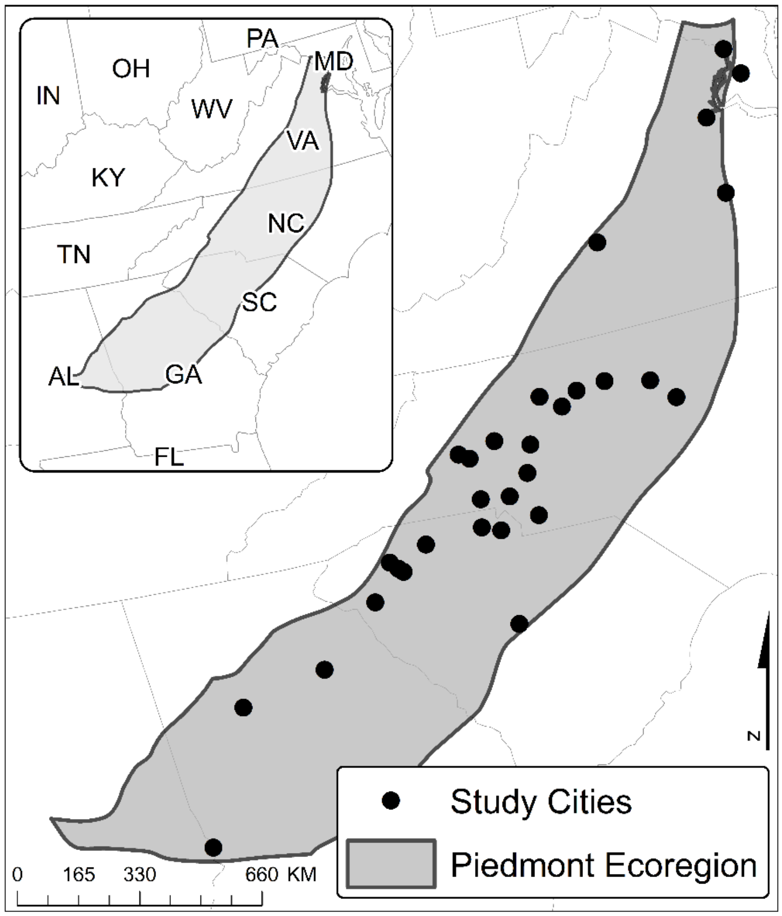

Figure 3.1 Locations of cities with greenway plans examined in this study.

There is no single comprehensive listing of all greenway or trail systems in the US, so an effort was made to locate all greenways in urbanized area in the Piedmont ecoregion. Searches for "greenways" and related features (e.g. "urban trails") were conducted on local government websites (e.g., Departments of Parks and Recreation), the National Recreation Trails database (American Trails 2016), and the Rails-to-Trails TrailLink database (Rails-to-Trails Conservancy 2016). Greenways identified through these searches were then screened to ensure that they occurred in urban environments. We acquired the greenway planning documents that were written by government employees and consultants charged with managing the existing local greenway system. These documents outlined the goals and objectives set by local municipalities, were site specific, and often incorporated public input from local stakeholders. While the information in the documents does not necessarily reflect how the greenways are ultimately managed, the policy frameworks established in the documents reveal the intentions and priorities of the local communities. In all, we collected a total of 29 individual greenway plans, taking care to ensure that we had the most recent version of each plan (see Appendix A for full list of planning documents).

Greenway plans were read in their entirety to: 1) identify planning goals and actions specific to individual greenways, and 2) detect broader objectives and benefits that emerged across all of the greenway plans examined in the study. This was done to contrast differences between the types of functions that were actual planning targets for individual greenways versus broader secondary benefits that may be provided by creating and maintaining greenways. We collectively refer to proposed interventions and planning goals that are designed to foster a specific intended outcome based on the greenway's designs and functions as "planning targets." Benefits that might be realized through greenway implementation but were not explicitly planned for in the documents were referred to as "potential benefits."

Using methods based on Conroy and Berke (2004) and Berke and Godschalk (2009), we developed an original qualitative assessment rubric to score the degree to which different greenway functions were integrated into planning documents. We further subdivided both planning targets and potential benefits into three categories of greenway functions based on planning guidelines and best practices recommended by publications aimed at urban planners and landscape architects (Little 1990; Flink et al. 2001; Hellmund and Smith 2006; Beck 2013). The first category involved societal objectives and community development functions; they emphasized services provided by urban ecosystems to city residents or the local community (Millennium Ecosystem Assessment Board 2005). This category encompassed functions such as the preservation of historic landmarks or the provision of recreational opportunities. The second category involved environmental objectives centered on regulating services—a subclass of ecosystem services—that addresses benefits obtained from the regulation of ecosystem processes (Millennium Ecosystem Assessment Board 2005). Examples include the use of green infrastructure elements such as bioswales to manage stormwater and improve water quality. The third category involved ecological goals centered on biodiversity functions associated with maintaining or enhancing habitats for species living within the greenway and the broader urban environment. Examples include the establishment of wildlife corridors or the removal of invasive species. The full rubric included a total of 11 community development functions, 10 regulating service functions, and 12 biodiversity functions based on topics commonly seen in city environmental planning documents (see **Error! Reference source not found.** for full list of functions and rubric criteria).

We scored the degree of detail and quality in the discussion of each greenway function using the following criteria: absence of discussion (0 points), general suggestion or broad overview of the function (1 point), or in-depth discussion or specific guidance provided to achieve the greenway function (2 points). After coding each function in the rubric, we summed and standardized points by category to facilitate comparisons between categories and across all plans. Higher scores indicated greater incorporation of content discussing functions associated with community development (societal objectives), regulating services (environmental objectives), or biodiversity (ecological objectives). Any type of function scoring a 1 or 2 was also noted as being "present" while functions with a score of 0 were considered "absent" from a plan. The codes used in the analysis are listed in Table 3.1, while the full coding dictionary is provided in Appendix B.

Scoring methods were independently pre-tested on 8 of the 29 plans by the lead author and a research assistant to ensure consistency and replicability of results. We assessed scores from both coders with the intraclass correlation coefficient (ICC) to determine intercoder reliability. The ICC(2,2) value was 78 percent, which is considered to be excellent reliability (Fleiss 1986). All plans were then read and coded by both researchers, and their scores were averaged. Comparisons between individual plans and between the prevalence of different greenway functions overall were made using Welch's ANOVA with a Games-Howell *post hoc* test to assess differences in the means between different groupings of scores. Statistical analyses were performed in IBM SPSS Statistics for Windows, version 25 (IBM Corp, 2017) and the R statistical environment (version 3.2.3) (R Development Core Team 2008) using the car (Fox and Weisberg 2011), irr (Gamer et al. 2012), and userfriendlyscience (Peters 2016) packages.

3.4 Results

Greenway plans were fairly uniform in their structures and major elements. All plans included a general description of greenways and their potential benefits, a discussion of the geography and demographics of the planning region, and recommendations for the plan's greenway. Within a plan, functions were typically discussed as both potential benefits and planning targets or were absent from the plan entirely. Biodiversity functions, regulating services, and community development were all represented across the plans, but the length of discussion and level of detail dedicated to these categories were highly variable between plans.

Across the three rubric categories, biodiversity functions were the least utilized in the greenway plans, with an average of 44 percent (approximately 5 out of 12) of such rubric functions in the documents (Figure 3.2).

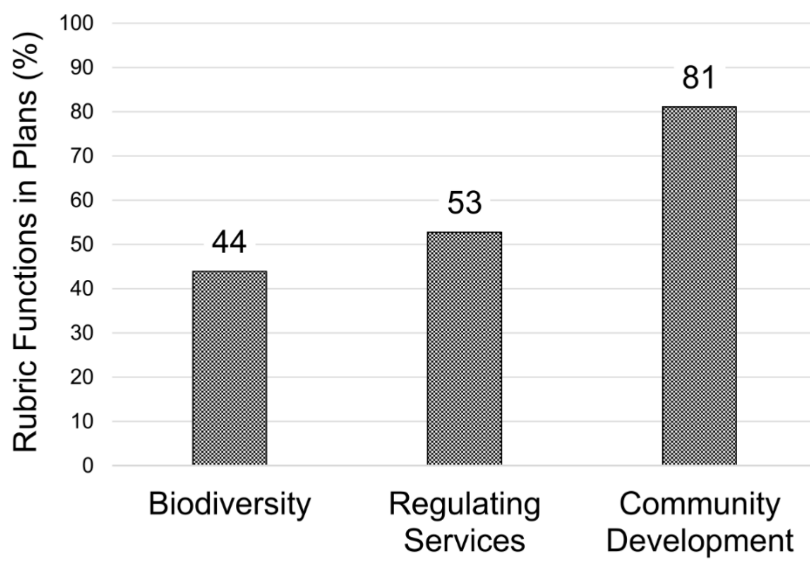

Figure 3.2 Average percentage of greenway functions present in 29 planning documents, grouped by function category. Total rubric functions per category: Biodiversity = 12; Regulating services = 10; Community development = 11.

The biodiversity functions appearing most often were related to natural habitat or habitat quality: habitat conservation (79 percent), the use of vegetated buffers (76 percent), and management of sensitive environments (69 percent) (see Table 3.1). The least mentioned functions were related to management of specific plant or animal species, including native plant conservation (28 percent), management for biodiversity (24 percent), and species monitoring (3 percent, appearing in only one plan).

Table 3.1. Prevalence of greenway functions in greenway plans. Any function with a score of 1 or 2 using the assessment rubric was considered "present" in the document. Percentages indicate how often each function is present across all 29 plans.

Greenway Functions	Plans Present (%)
Biodiversity (Ecological)	
Conserve open space	59
Conserve sensitive environments	69
Habitat conservation/management	79
Invasive species	35
Manage for biodiversity	24
Multiple habitat types	23
Native plant conservation	28
Reduce habitat fragmentation	55
Species monitoring	3
Vegetated buffers	76
Wildlife conservation	41
Wildlife corridors	35
Category average	***44***
Regulating Services (Environmental)	
Air quality	79
Carbon sequestration	31

Flood/erosion control	66
Minimize construction impacts	52
Minimize disturbance	41
Non-structural BMP	35
Reduce carbon emissions	55
Stormwater management	69
Vegetated BMP	21
Water quality	79
Category average	***53***
Community Development (Societal)	
Beauty/scenery	62
Cultural heritage	90
Economic development	93
Environmental education	79
Improve mental health	41
Improve physical health	93
Property value	79
Recreational opportunities	100
Safe user environment	86
Sense of place	86
Tourism	83
Category average	***81***

Biodiversity functions were also discussed in the least amount of detail. The mean standardized scores for potential benefits and planning targets associated with biodiversity functions averaged 36 percent and 26 percent, respectively (Figure 3.3).

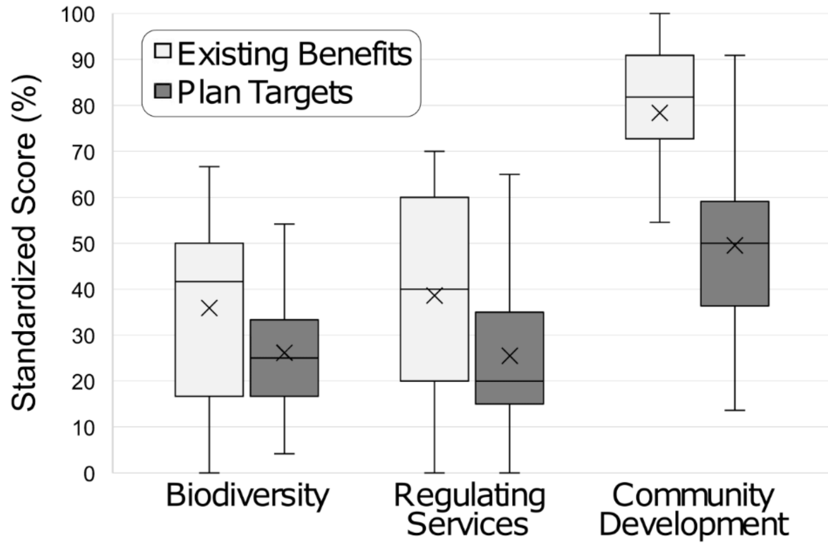

Figure 3.3 Box and whisker plot representing summary statistics of planning document scores (n = 29 plans). Top and bottom of each box represents the interquartile range of the scores. The line and "x" inside each box indicate median and mean, respectively. The highest and lowest scores in each function category are represented by the whiskers. Each pair of plots is grouped by discussion category. A higher percent score indicates more detail or higher level of discussion of greenway functions across all plans.

When potential benefits of greenways for biodiversity were discussed in planning documents, the concepts were often described as qualities possessed by all greenways and green spaces, and connections between these ecological functions and the plan's local geography were rarely seen. The James River Branch Rail-Trail Concept Plan in Richmond, Virginia, offered one such general description of greenways:

> Urban greenway systems provide a vital role in protecting and maintaining natural area values and functions such as managing stormwater, providing wildlife habitat, and recycling nutrients.

> Urban open space assists with flood mitigation, providing a storage zone during periods of heavy rain, increasing infiltration, reducing run-off, and filtering sediment before it enters the waterway. Open space corridors that link larger natural area "hubs," allow plant and animal species to migrate between hubs, reducing the impacts of urban development. (Southside Richmond Rail-Trail Project Team & James River Branch Rail-Trail Citizens Advisory Committee, 2010, p. 7)

Within the regulating services category, an average of 53 percent of rubric functions were used (approximately 5 out of 10 functions). Discussions relating to mitigating pollutants were the most regularly-cited functions, specifically, improved water quality (appearing in 79 percent of plans) and air quality (79 percent). Carbon sequestration (31 percent) and vegetated best management practices (21 percent) were the least commonly observed functions in this category (see Table 3.1 and Figure 3.2).

Community development rubric functions were significantly more prevalent than either biodiversity or regulating services functions (ANOVA with Games-Howell *post hoc* tests ($F(2, 19.86) = 8.32$, $p < 0.01$; see Figure 2). On average, nearly 9 out of 11 community development rubric functions were discussed in the plans (81 percent; see Table 3.1 and Figure 3.2). Plans most often emphasized the benefits to area residents and the community, including discussions on improving recreational opportunities (100 percent of plans), physical health of users (93 percent), and local economic development (93 percent; see Table 3.1). Community development was also discussed in the most detail across all plans and had the highest mean standardized scores overall: 78 percent for potential benefits and 50 percent for planning targets (see Figure 3.3). This is unsurprising given the implicit civic functions of greenways. It is, however, notable that all plans not only included some form of ecological benefits, but also mentioned the ability of greenways to provide multiple types of services to the region in addition to societal benefits.

When comparing potential benefits and planning targets within the same rubric function category, potential benefits were consistently discussed in significantly greater detail ($F(1, 56) = 22.47$, $p < 0.01$, Games-Howell post hoc test: $p < 0.01$). Discussions about benefits often included references to case studies or research papers supporting these concepts, which warranted full scores of "2" on many functions. Descriptions in individual plans ranged from several pages of in-depth discussions citing peer-reviewed research to short paragraphs briefly describing one or more functions.

Given the amount of detail concerning greenway benefits, we expected to find specific planning targets pertaining to any benefits they discussed (such as management recommendations to promote habitat conservation), but this was infrequently the case. Mean standardized scores for planning targets were 10 to 28 percent lower than potential benefits (see Figure 3.3), and many specific planning targets were often discussed briefly and in limited detail (score of "1") or not at all

(“0”). Plans did not typically discuss how intended greenway services would be achieved or methods that would be used to quantify success through long term monitoring and assessments. Several plans simply provided a list of targets and provided no further explanation. We observed a disproportionally low degree of integration between potential benefits and planning targets in both biodiversity and regulating services functions compared to community development functions (see Figure 3.3). Thus, while it appeared that greenway planners and users understood that greenways can provide multiple services to the region and potential benefits beyond recreation, the consistently limited representation of biodiversity functions in greenway plans may be an area of opportunity for improvement in future planning efforts.

3.5 DISCUSSION

This study assessed how a range of potential greenway functions and overall design options are discussed across 29 urban greenway plans in the southeastern US. We believe that the functions included in the evaluation rubric captured the majority of functions discussed in each design plan. It is important to note that our evaluation rubric was not designed to rank documents as being of “good” or “poor” quality; the scores themselves only represent how the documents correspond with the selected rubric functions. The rubric metrics used to evaluate plans were designed to garner a general understanding of the types of discussions that are present in greenway design plans.

We attribute the low individual rubric scores in some plans to the varied assortment of functions between plans. Since different plans discussed some functions and not others, many rubric functions were absent (equivalent to a score of 0). We are currently unaware of any regional or national guidelines for the design and construction of urban greenways. Thus, we expected to see wide variations in the types of functions discussed across all of the greenway plans as each locale will have different needs and priorities. At this broad scale of analysis, it was also not possible to identify the specific local circumstances that may have influenced the plan authors and residents, such as local politics or funding limitations. Despite these dissimilarities, all greenway plans discussed functions associated with community development, regulating services, and biodiversity in some capacity.

Overall, we observed a disparity between the incorporation of ecological objectives in greenway planning and the development of informed planning targets. If greenways are to be adequately developed as multi-use spaces serving societal, environmental, and ecological needs, a greater acknowledgement of the urban ecosystem needs to be established at the planning level (Botequilha Leitão and Ahern 2002; Wu 2014). However, balancing the needs of native species and sensitive habitats, for example, with social and commercial interests is a complex challenge with many unknown variables (Gómez-Baggethun and Barton 2013).

While the majority of greenway plans in this study acknowledged the importance of promoting habitat conservation and reducing fragmentation, only one plan mentioned the desire to monitor habitats or wildlife after the completion of the project. By not assessing the ability of these greenways to fulfill intended conservation actions after their construction, the effectiveness of such projects remains undetermined, thereby limiting the ability of land managers and planners to improve upon it (Gaston et al. 2013). The implementation of strategies such as adaptive management can help managers to adjust actions in light of new information and allow projects to be more effective in the long-term (Holling 1978; Stankey et al. 2005). Adding to these challenges are inherent uncertainties in the processes of planning and plan implementation. The degree to which plans are effectively implemented in the real world is an important question that needs to be addressed further in the planning literature (Brody and Highfield 2005), and improved planning goals and objectives do not necessarily guarantee improved outcomes (Baer 1997; Brody and Highfield 2005; Woodruff and BenDor 2016). Only by clearly defining the intended functions and the specific designs to address these functions can urban ecosystems be managed in a way that improves their environment (Hess and Fischer 2001).

The ecological benefits of urban greenways and greenspaces, including the potential to connect urban habitat fragments. have been well recognized (Angold et al. 2006; Bierwagen 2007; Ahern 2013). The maintenance of greenways is also consistent with approaches that emphasize landscape permeability in human-dominated landscape mosaics (e.g., Kupfer et al., 2006). However, goals focusing on maintaining species diversity, managing for native species, and maintaining or increasing habitat connectivity are among the least discussed functions overall, with each of these appearing in less than one third of the plans examined. Failure to address the ecological processes or intensive management efforts behind these potential benefits can further take away the impetus for deliberate environmental planning and rigorous research in urban ecosystems (Shwartz et al. 2014).

The involvement of organizations and the support of civic leaders and legislators is important, if not necessary, for the successful framing and attainment of environmental and ecological goals in urban development plans (Goode 2015). Often it is through the support of local organizations that it is possible to monitor and evaluate the outcomes of any ecological interventions, thus maintaining habitat quality in the long term (Margerum 2008). Varying management conflicts may arise between local economic interests, conservation actions, or other constituent priorities. Despite these challenges, the deliberate inclusion of environmental and ecological discussions in all of the plans reveals at least an awareness of the need to take a more comprehensive approach to the benefits of greenways when considering the future of urban landscapes.

The current popularity of urban greenways exemplifies the value of nature in the realm of the urban environment, whether such areas are recently planted, successional communities, or older forest remnants. As urban conservation and ecosystem service objectives are increasingly being implemented, the discussion of environmental and ecological objectives must be raised to the level of existing social and economic issues. This recognized need to better articulate related goals and designs in greenway planning documents mirrors the recent inclusion of coursework within some planning and landscape architecture programs that focus on topics such as restoration ecology and ecological design. With greater equality of socioeconomic and ecological discourse in landscape and urban planning curricula, future planning efforts will be in a better position to face the challenge of promoting the resilience and sustainability of cities.

CHAPTER 4

IDENTIFICATION OF ENVIRONMENTAL DRIVERS IN URBAN GREENWAY COMMUNITIES[2]

4.1 ABSTRACT

Urban trails and greenspaces have become ubiquitous features in cities, in part due to their ability to provide ecological benefits to the built-up environment. A major factor in their popularity is their potential to enhance habitat connectivity by bridging the gaps between remnant patches across urbanized areas, however, information on the structure and function of greenways themselves is limited. In this study we examined how greenways serve as distinct habitats in their own right by characterizing the vegetative structure of the Capital Area Greenway (CAG) in Raleigh, NC. We conducted a systematic vegetation survey of woody vegetation along 39 km of trails (354 random plots) in 2016 and identified environmental variables related to site conditions (percent canopy cover, stream

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[2] Chin EY, Kupfer JA Submitted to Urban Forestry and Urban Greening, 8/3/18.

proximity, flood zones), management efforts (designated conservation areas), and local anthropogenic activities (percent impervious surface, street proximity). We performed three types of multivariate analyses (non-metric multidimensional scaling (NMS), multi-response permutation procedures (MRPP), and indicator species analysis (ISA)) to distinguish potential influences on species distribution and community structure. We observed highly diverse riparian, upland mesic, and xeric forest communities within the CAG. Results from NMS and MRPP suggested that vegetation patterns can be differentiated based on local environmental variables. Sites located in conservation areas and floodplains, for instance, were typically found at further distances from streets and were characterized by greater basal area, canopy cover, and higher non-native species richness. Individual study sites were highly diverse and varied even within similar local environments. Our findings indicate that the CAG serves as established natural habitat for native vegetation, supporting the idea that greenways can be used to enhance environmental quality in cities as ecological corridors.

4.2 Introduction

Urbanization results in numerous ecological impacts, including habitat loss, degradation, and fragmentation. Undeveloped areas and unmanaged greenspaces are sometimes viewed as homogeneous 'biological wastelands,' but research suggests that they are better characterized as diverse landscape mosaics offering species a varied range of potential habitats and movement pathways (Pirnat 2000; Kupfer et al. 2006; Ignatieva et al. 2011). An increased awareness of the complexity of anthropogenic impacts and the value of greenspaces within urban areas has led to a growing field of sustainable urban planning and landscape architecture that seeks to incorporate environmental and ecological principles into a more comprehensive planning framework (Cook 1991; Hellmund and Smith 2006; White and Ellis 2007). Following this trend, urban greenspaces in the form of linear parks, also referred to as greenway trails, have become popular features in many cities. For example, communities are investing in forested urban greenways with walking and biking trails to improve recreational and aesthetic values. Such features also help to maintain the health of urban ecosystems by providing natural- and semi-natural habitats embedded within human-developed areas and hold the potential to promote habitat connectivity (Bond 2003; Pino and Marull 2012).

In terms of their benefits to urban species, greenways function on the principle that larger, well-connected habitat patches are more beneficial to ecosystem function than smaller, isolated patches (Davis and Glick 1987; Calabrese and Fagan 2004; Beninde et al. 2015). Habitat value for extant species diminishes as the landscape is fragmented, leaving isolated populations with limited access to resources and at higher risk of local extinction (Johnson 2001; Kupfer and

Franklin 2009). By increasing the connectivity between urban patches via greenways, species should be able to disperse more easily between suitable habitat and maintain more stable and resilient populations.

As the popularity of urban greenways grows nationwide, there is a need for critical evaluations of systems to identify, confirm, and assess their full range of characteristics and benefits. While some strides have been made, there are still acknowledged needs and some common generalizations about greenways that are based in limited supporting evidence. For example, the effectiveness of greenways in promoting ecological conservation is the focus of active, ongoing research, but detailed ecological surveys that can be used to support planning decisions are often limited (Beier and Noss 1998; Viles and Rosier 2001; Shwartz et al. 2014). Further, while it is recognized that urban greenways and greenspaces serve as a stop-gap to environmental impacts brought about by urban development, several investigators have noted the lack of studies focusing on greenways at community- and ecosystem scales (Opdam and Wascher 2004; Chetkiewicz et al. 2006). Instead, 'urban vegetation' is often loosely associated with fast-growing pioneer species that are better adapted to disturbances found in cities (Angold et al. 2006; Bonthoux et al. 2014). Other generalizations focus on the potential for disturbed urban areas (including greenways) to serve as habitat reservoirs or dispersal pathways that may be exploited by non-native species (Hobbs 2002; Christen and

Matlack 2006; Cutway and Ehrenfeld 2012).

One important step toward defining the ecological value of urban greenways involves clarifying the degrees to which 'natural' and anthropogenic influences shape plant community structure, composition, and diversity, something which has not been closely examined at very fine scales in urban greenways. To address this shortcoming, we conducted a systematic survey and analysis of woody species within the Capital Area Greenway (CAG), which is located in Raleigh, NC. Using that data, we tested hypotheses that the current structure, composition, and diversity of CAG plant communities is shaped by site conditions, management efforts, and local anthropogenic activities because the greenway contains areas of long-established vegetation embedded within a variable landscape matrix. More specifically, we expected that composition would be dominated by more shade tolerant species common to regional species pools in areas of the CAG with less human impact and greater management protection, allowing natural processes of plant succession and stand dynamics to be most strongly guided by plant responses to conditions approximating pre-development conditions. In contrast, we hypothesized that sites with greater exposure to human activities and less restrictive protections would be characterized by a greater presence of pioneer or non-native species that are better adapted to highly disturbed conditions characterized by altered microclimates (e.g., higher light conditions; greater evapotranspirative demand). The creation of such conditions further opens up a recruitment window for non-native species, including ornamentals, that may disperse from nearby properties (Booth et al. 2003; Kupfer and Runkle 2003; Flory and Clay 2009; LaPaix et al. 2012).

To test these hypotheses, we surveyed woody species within an urban greenway trail network in Raleigh, NC, which is located in the Southern Appalachian Piedmont ecoregion of the Southeastern US. Historically this area was dominated by Oak-Hickory-Pine mixed forests and patchy fire-dependent grasslands, but land conversion has been a major source of disturbance beginning since Native American settlement (NatureServe 2015). Due to the rapid urban development this area has seen over the last several decades it is also referred to as the Piedmont "megalopolis" (Terando et al. 2014). The pattern of sprawling development in the Southeast US also increases the potential for many human-environment conflicts such as habitat fragmentation and loss of natural biodiversity (Radeloff et al. 2014).

4.3 Methods

4.3.1 Study Area

Established in Raleigh in 1974, the Capital Area Greenway is one of the oldest greenway networks in the United States. The entire system currently contains 160 km of recreational running/biking trails in an area of 12 km^2 that extends throughout Raleigh's densely populated commercial and urban areas and suburban neighborhoods (Figure 4.1).

Figure 4.1 The Capital Area Greenway Trails pass through a variety of land uses. Top left: Protected wooded areas buffer both sides of the trail; top right: a boardwalk crosses over a section of wetlands; bottom right: section of greenway runs adjacent to a housing development (left) and major road (right); bottom left: the greenway continues along a sidewalk to cross a commercial neighborhood (note trail marker in foreground). All photographs by Erika Chin.

We inventoried woody vegetation during the summer and fall of 2016 along the CAG's House Creek, Reedy Creek, Rocky Branch, and adjoining segments of Crabtree Creek and Walnut Creek. These trails are all linked so that the study area is a subnetwork within the CAG system (Figure 4.2). The study area covers approximately 39 km of trails and 3 km2 of vegetated area.

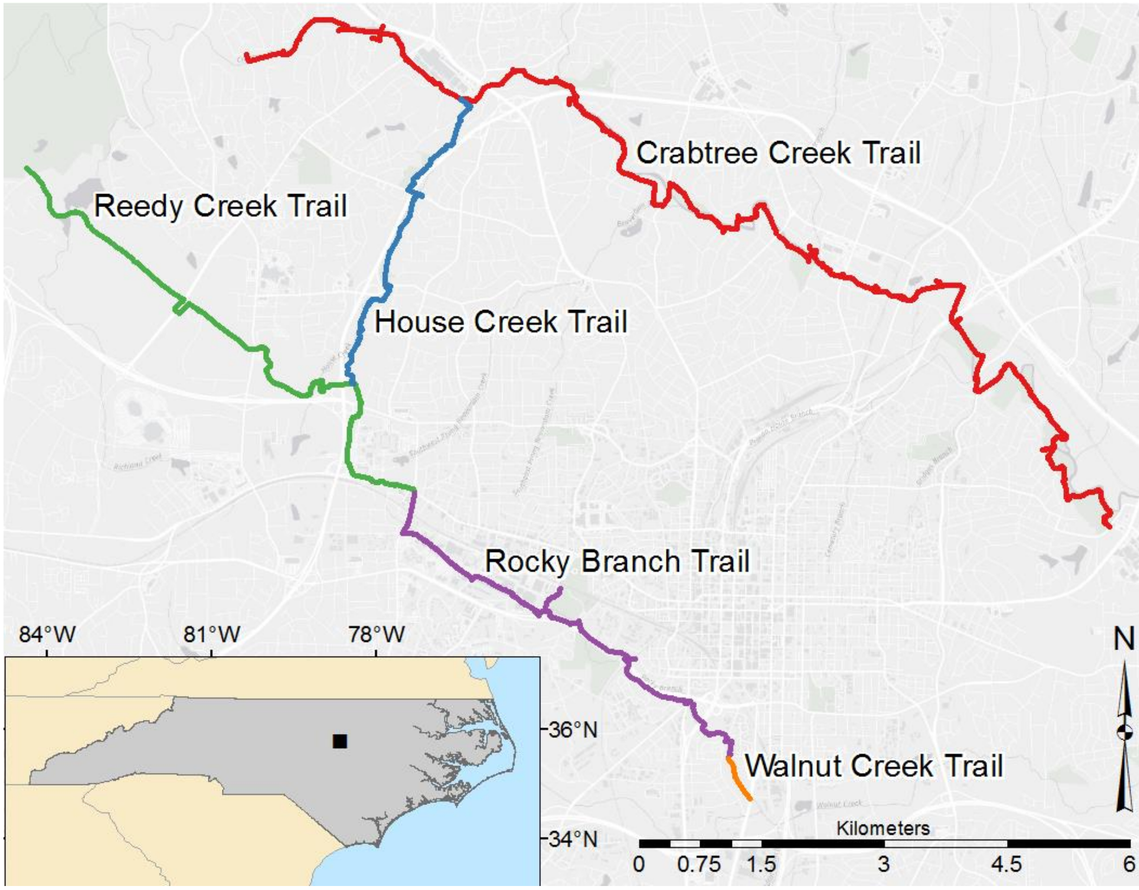

Figure 4.2 Study area: Capital Area Greenway, Raleigh, NC. Labeled trails represent the five trail segments that were inventoried in this study. Trail data from Wake County GIS, 2014; basemap from Esri, 2017; state boundary data from North Carolina Geodedic Survey, 2016.

4.3.2 Data Collection

Patterns of woody vegetation along the greenway were assessed using a field-based survey of plant species composition. The methodology used for surveying vegetation was adapted from the STRATUM inventory protocol (Jaenson et al. 1992; Maco and McPherson 2003), with slight modifications made to accommodate surveying along the greenways. In the field, sample sites were systematically selected along the trail every 200 paces (ca. 200 m). At each site, we established paired 60 m^2 sample plots on each side of the trail. Sample plots bordered the edge of the path (including gravel or grass edging), running 15 m parallel to and 4 m perpendicular to the trail. In total, we collected data from 354 individual sample plots. For analysis we combined data from the two sample plots taken at a location, resulting in a total of 177 sample sites. Species abbreviations used throughout this paper are from the USDA PLANTS database (USDA NRCS 2017).

Within each plot, we identified, measured, and recorded the diameter at breast height (DBH; 1.37 m) of all individuals >2.5 cm in DBH. These measurements were converted to basal area (the cross-sectional area of a trunk) using the formula for the area of a circle. For trees with multiple stems, we determined the basal area of each stem meeting the 2.5 cm DBH size criterion and summed their values for the individual tree. Values from the two sample plots at a site were then summed for analysis.

For each sample site, we calculated two measures of diversity: species richness (the number of species per site) and Simpson's diversity index, which takes into account the abundance of each species as well as the number of species present (Barbour et al. 1998)(Barbour et al. 1998). We also calculated two measures of stand structure for each site: stem density (the number of stems) and basal area (the summed basal areas of all individuals). To quantify site composition, we calculated four measures of abundance for each species: total density and basal area (the number of individuals and summed basal areas for each species), and relative density and importance value (the proportions of site density and basal area, respectively, accounted for by each species). The equations used to calculate importance value are listed below in Table 4.1.

Table 4.1 Formulas used to calculate dominance and relative abundance of each species in the greenway.

Absolute Frequency	$\frac{\boldsymbol{Number\ of\ sites\ where\ species\ X\ is\ preesnt}}{\boldsymbol{Total\ number\ of\ sites}}$
Relative Frequency	$\frac{Absolute\ frequency\ of\ species\ X * 100}{Sum\ of\ absolute\ frequencies\ of\ all\ species}$
Relative Density	$\frac{Number\ of\ individuals\ of\ species\ X * 100}{Total\ number\ of\ individuals\ of\ all\ species}$
Relative Basal Area	$\frac{Total\ basal\ area\ of\ species\ X * 100}{Sum\ of\ basal\ areas\ of\ all\ species}$
Importance Value	$Relative\ Frequency + Relative\ Density + Relative\ Basal\ Area$

The ecological setting for each sample site was characterized using variables that described environmental conditions, potential anthropogenic influences, and management status. For environmental conditions, we determined: 1) whether or not a sample site was located within a FEMA designated flood zone ("flood area") (Federal Emergency Management Agency 2016), 2) the site's proximity to the nearest stream (based on USGS Blue Line

Streams: U.S. Geological Survey, 2017), and 3) the surrounding percent canopy cover. Stream proximity was quantified using both the simple straight-line distance from a sample site's edge to the nearest stream, as well as categorical analyses that divided sites into four representative distance groups (see Table 4.2).

Table 4.2 List of predictor variables & sample groupings.

Predictor Variable	Sample Groups	Number of Sites
BWHA Category	Conservation Priority Area	101
	Low Priority Area	76
Distance to Road	<30 m	66
	30-59 m	33
	60-150 m	56
	>150 m	22
Distance to Stream	<15 m	34
	15-29 m	72
	30-150 m	52
	>150 m	19
Floodzone Classification	Flood Hazard Area	105
	Non-flood Area	72
Percent Canopy Cover	<40%	68
	40-74.9%	45
	>75%	64
Percent Impervious Surface	0-9.9%	92
	10-29.9%	42
	>30%	43

Percent tree canopy cover was calculated using the US Forest Service's analytical canopy product (Jin et al. 2013). A 100 m buffer was created around each sample site's centroid, and the percent canopy cover for each pixel within the buffer was then averaged.

Potential anthropogenic impacts are most likely to stem from the conversion of forests to human land uses (particularly impervious surfaces) and the creation of roads, which may impact the fluxes of water, sediment, light and energy, chemicals, and species across a landscape (e.g., Forman et al., 2003). As with canopy cover, we calculated the percentage of impervious surfaces within 100 m of each sample site's centroid, but using the National Land Cover Database (NLCD) developed imperviousness layer product (Xian et al. 2011). The distance of a sample site to public roads was used as a proxy for potential human disturbances. TIGER/Line files were used to identify public streets (U.S. Census Bureau 2015), and as with the process used to quantify the stream proximity variables, we used the straight-line distance from each site's edge to the nearest road as well as a categorical classification based on four distance classes.

To account for the possibility that plant composition differs between sample sites that have been protected and managed for conservation value from those that have not, we drew on the Conservation Planning Tool (CPT) developed by the North Carolina Department of Environment and Natural Resources. The CPT synthesizes several datasets and assessments to rank areas based on their relative conservation value (North Carolina Department of Environment and

Natural Resources 2013). To do so, it uses several components of ecosystem function, including aquatic and terrestrial biodiversity, habitat connectivity, and areas significant to ecological processes such as wetlands and riparian buffers are used as ranking criteria. The resulting Biodiversity and Wildlife Habitat Assessment scores (BWHA) range from one (the lowest relative conservation value) to ten (the highest conservation priority). Additionally, unrated areas are given a score of 0, and highly impervious areas (>20%) are ranked -1. We categorized all sites in areas ranked two or higher as "conservation priority areas," and sites ranked 1 or below as "low priority areas."

4.3.3 Data Analysis

Relationships between site-level measures of forest structure and diversity (stem density, basal area, species richness, Simpson's diversity) and the variables describing site conditions, management efforts, and local anthropogenic activities were first analyzed using generalized linear modeling (GzLM, to distinguish it from the related, but distinct, general linear model). GzLM is a flexible generalization of ordinary linear regression that allows for response variables that have non-normal error distribution models, as is common with certain types of ecological data. They are able to do so by allowing the linear model to be related to the response variable via a link function and by allowing the magnitude of the variance of each measurement to be a function of its predicted value. GzLMs thereby fit linear models to data that do not meet the criteria for linear regression, yet allow them to "blend in well with traditional practices used in linear modeling and analysis of variance (ANOVA)" (Guisan et al., 2002: 90).

Separate analyses were performed for each of the four response variables. In each case, the optimal model for predicting the response variable was identified using a methodology that minimized the corrected Akaike Information Criterion (AICc; Burnham and Anderson, 2004). Overall model significance was assessed by determining the difference in likelihood values between a fitted model and a model with the intercept only. Significant main effects were tested using a Wald chi-square test, and the significance of pairwise comparisons among categorical predictor variables was assessed using a Bonferroni corrected follow-up test. Once the main effects in the optimal model were identified, we incorporated all two-way effects into the model to test for significant interaction effects, once again using improvements in AICc as a guide for model selection. All GzLM analyses were conducted using SPSS v. 24.0.

Patterns of species composition were explored using three types of multivariate analysis: non-metric multidimensional scaling (NMS), multi-response permutation procedures, and indicator species analysis. NMS is a non-parametric ordination method that determines the best position of *n* entities (in this case, sample sites) in a *k* dimensional mathematical space and is commonly used to identify and understand gradients of species composition (e.g. Flory and Clay, 2010; Hart and Kupfer, 2011; Rheinhardt et al., 2013). We used NMS because it makes fewer assumptions concerning the data and has been shown to be more robust to noise in the data, making it well suited for ecological applications (McCune and Grace 2002; Peck 2016).

The location of sample sites in ordination space is determined from a pairwise dissimilarity matrix derived using a measure of species composition (Legendre and Legendre 2012). Here, dissimilarity values were calculated using species basal area values and the Relative Sorensen distance measure (Faith et al. 1987) after first using a cube root transformation to reduce the influence of species with exceptionally high basal areas. We used an initial NMS run with 50 iterations to create a starting configuration for the final ordination. The optimal number of NMS axes was determined by: 1) fitting the data using a 'step-down approach' beginning with 6-dimensions, and 2) plotting the Kruskal stress value, which measures correspondence between the original data and the ordination, in an NMS scree plot. A corresponding species ordination was performed using weighted averaging. Prior to analysis, we removed species that occurred on fewer than three study sites and study sites that contained fewer than two species to prevent such species and sites from having a disproportionate influence on the analyses. The final NMS analysis included 58 species and 128 sample sites.

Because a number of the predictor variables were either categorical or could be placed into groups, we complemented the NMS ordinations with analyses using a multi-response permutation procedure (MRPP) and Indicator Species Analysis (ISA). MRPP is a nonparametric, multivariate method that tests the hypothesis that there is no statistical difference between two or more groups of entities. In this case, we used it to test for differences in species composition between subgroups of the categorical predictor variables, including BWHA conservation status, percent canopy cover, percent impervious surface, flood zone classification, and distance of the sample sites from the nearest road and nearest stream (Table 4.2). All MRPP analyses were based on species dissimilarity values calculated using basal areas and the Relative Sorensen distance measure to make results consistent with those from the NMS.

Indicator Species Analysis (ISA) was used in conjunction with the MRPP to identify representative species for subgroups of categorical predictor variables (Dufrêne and Legendre 1997; McCune and Grace 2002). The resulting indicator values ranged from 0 (for a species that occurs across a range of categories for a variable of interest) to 100 (for a "perfect" indicator species that only occurs consistently in a single category of a variable). Species indicator values with significance levels of $p < 0.05$ as determined using a Monte Carlo randomization test (run with 4,999 permutations) were considered significant indicators. All multivariate analyses (NMS, MRPP, and ISA) were conducted using PC-ORD v. 7.01 (McCune and Mefford 2015).

4.4 Results

4.4.1 Species Overview

We recorded a total of 96 woody species, 14 of which are not native to North America (see Appendix A for the full species list and measures of species density and basal area). Vegetation density was highly variable within the greenway, ranging from sparse roadside vegetation to heavily forested woodlots. Of the 177 sample sites, 22 (12%) did not contain any woody species. Of the 3,474 individuals sampled, nine species made up 52% of the total, with the most frequently recorded species being *Ligustrum sinense* Lour. (Chinese privet) (n=367), *Pinus taeda* L. (loblolly pine) (n=287), *Liquidambar styraciflua* L. (sweetgum) (n=260), and *Acer rubrum* L. (red maple) (n=219).

All the most dominant species were native species characteristic of mixed pine and hardwood forest communities, both of which are common in Piedmont ecosystems (see Figure 4.3). These included *P. taeda*, *L. styraciflua* and *Celtis laevigata* Willd. (sugarberry). While *L. sinense* was abundant in terms of numbers of individuals, it occurred in few study sites and had relatively small DBH values. Other non-native species observed included *Elaeagnus umbellata* Thunb. (autumn olive), *Pyrus calleryana* Decne. (Callery pear), *Albizia julibrissin* Durazz. (silktree), and *Ailanthus altissima* (Mill.) Swingle (tree of heaven). These species are commonly planted as ornamentals, but often naturalize in surrounding areas.

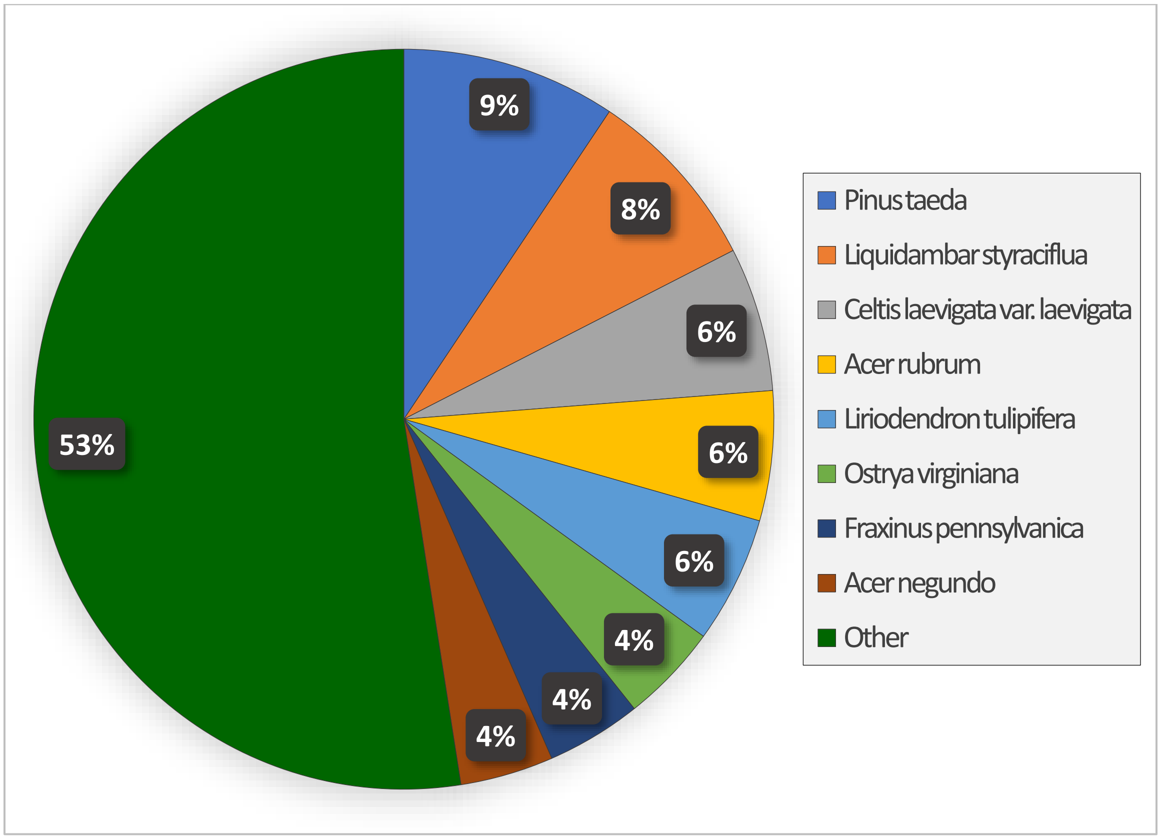

Figure 4.3 Relative importance values of the most dominant woody species in the Capital Area Greenway. Importance value is calculated for each species as the sum of their relative frequency, relative density, and relative basal area. Values presented here are percentages of the total importance value of all species observed in the greenway.

4.4.2 *Sample Site Structure and Diversity*

Results of the GzLM analyses demonstrated that stand structure and composition were related to a suite of natural and anthropogenic factors (Table 4.3).

Table 4.3 Optimal models for predicting stem density, basal area, Simpson Diversity, and species richness. Models were fit using generalized linear modeling, significant main effects were tested using a Wald chi-square test, and the significance of pairwise comparisons among categorical predictor variables was assessed using a Bonferroni corrected follow-up test.

Variable	Source	Wald Chi-Square	Df	Sig.	Follow up Results
Stem Density	(Intercept)	4960.119	1	< 0.001	-
	Canopy Cover	73.91	2	< 0.001	Low < Moderate < High
	Stream Dist.	45.13	3	< 0.001	Distant < Moderate < Near
	Imperv, Cover	42.08	2	< 0.001	Low < Moderate = High
	Road Dist.	23.61	3	< 0.001	Near < Far
Basal Area	(Intercept)	184.75	1	< 0.001	-
	Road Dist.	15.46	3	0.001	Near < Far
	Canopy Cover	13.02	2	0.001	Low < Moderate = High
	Conserv. Prior.	6.36	1	0.012	Yes < No
	Floodplain	4.36	1	0.037	No < Yes
Simpson Diversity	(Intercept)	322.42	1	< 0.001	-
	Road Dist.	10.91	3	0.012	Near < Far
	Floodplain	5.99	1	0.014	No < Yes
	LULC	16.57	4	0.002	Agr. & Pasture < All other classes
Species Richness	(Intercept)	374.7	1	< 0.001	-
	Road Dist.	14.4	3	0.002	Near < Far
	Canopy Cover	25.7	2	< 0.001	Low < Moderate = High
	Imperv. Cover	8.0	2	0.018	Low < Moderate = High
	Canopy Cover * Imperv.Cover	19.3	3	< 0.001	See text

The optimal models for stem density (which used a Poisson distribution and loglinear link function) and basal area (which used a normal distribution and identity link function) were both highly significant (stem density: Likelihood Ratio Chi-square = 352.3; d.f. = 10; $p < 0.0001$; basal area: Likelihood Ratio Chi-square = 64.14; d.f. = 7; $p < 0.001$). Both measures were both positively associated with greater canopy cover and distance from the nearest road (Wald Chi-square: $p \leq 0.001$), while other variables (impervious surface cover, distance from the nearest stream, and location within a designated floodplain or priority conservation area) influenced one measure or the other. As with the analyses for stand structure, the optimal model of Simpson Diversity (which used a normal distribution and identity link function) was highly significant (Likelihood Ratio Chi-square = 69.6; d.f. = 8; $p < 0.001$) and identified significant main effects associated with road proximity, floodplain location, and surrounding land use and land cover.

The model for species richness (Poisson distribution with loglinear link function; Likelihood Ratio Chi-square = 157,15; d.f. = 10; $p < 0.0001$) was more complicated in that it identified three significant main effects (canopy cover, impervious cover, road proximity) and a significant interaction effect between canopy cover and impervious surface cover. Richness was comparatively high when canopy cover was high or moderate, regardless of surrounding impervious cover (Figure 4.4).

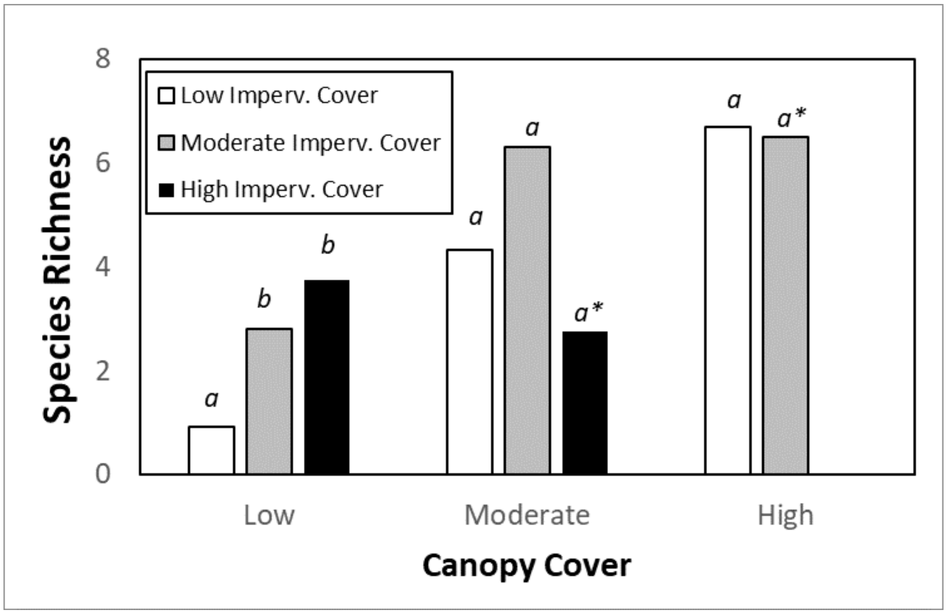

Figure 4.4 Interactions between neighborhood canopy cover and impervious cover for predicting species richness. Superscripts within canopy cover classes denote whether richness was equal among impervious surface classes (* indicates < 4 sample sites within the class).

Overall, it was significantly lower when canopy cover was low (Table 4.3), but it was slightly higher when the amount of surrounding impervious cover was moderate to high. This finding, which may be counterintuitive, occurred because most sites having low forest cover *and* impervious cover were located on stretches of the greenway that ran through agricultural land and pasture, which supported few woody species. In contrast, sites with low canopy cover but greater impervious cover occurred in mixes of wetlands, developed areas, and disturbed forestlands, which led to slightly greater species richness (albeit at levels below those noted in areas with greater canopy cover).

Taken collectively, results from the generalized linear models of stand structure and diversity underscore that forest structure and diversity varied among sample sites along the CAG in response to a complex suite of natural and anthropogenic variables. In general, though, greater canopy cover, a closer proximity to streams and floodplains, and a greater distance from roads led to communities marked by higher stem densities and basal areas as well as greater richness and diversity.

4.4.3 Patterns and Correlates of Community Composition

The optimal NMS solution had 3-dimensions with a moderate stress value of 15.7, suggesting a reasonably accurate representation of sites in ordination space. The three axes captured 53.8% of the variation in the species matrix (Axis 1: 23.8%; Axis 2: 18.6%; Axis 3: 15.8%). Sites with lower NMS Axis 1 values were located closer to streams and at greater distances from roads (Figures 4.5, 4.6). These sites, which were characterized by greater basal area and canopy cover as well as higher non-native species density and richness (Table 4.4), were primarily in conservation priority areas and designated floodplains and were associated with floodplain species such as *C. laevigata* (CELA), *Betula nigra* L. (BENI: river birch), *Fraxinus pennsylvanica* Marshall (FRPE: green ash), and *Acer negundo* L. (ACNE2: box elder) (Figures. 4.5, 4.6, 4.7). Upland sites with less protection had higher NMS Axis 1 values and were more closely associated with *Juniperus* *virginiana* L. (JUVI: eastern red cedar), *P. taeda* (PITA), *Pinus echinata* Mill. (PIEC2: shortleaf pine), and *Quercus marylandica* Münchh. (QUMA3: blackjack oak).

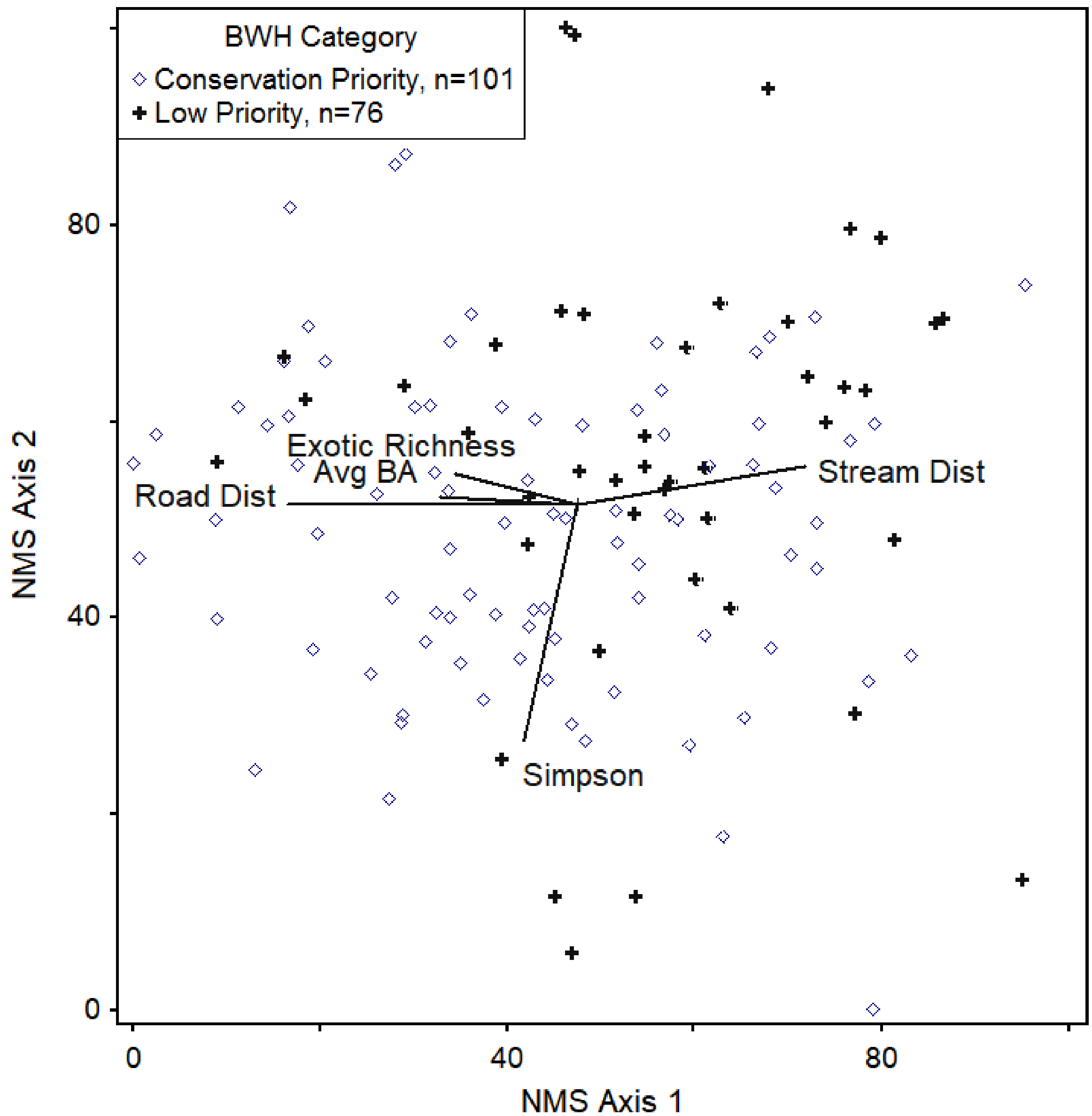

Figure 4.5 Non-metric multidimensional scaling (NMS) ordination of vegetation inventory sites grouped by Biodiversity and Wildlife Habitat Assessment score (BWHA). Joint-plot vectors (lines) indicate direction and relative correlation between study sites composition and ordination axes: Avg BA = average basal area; Exotic Richness = exotic species richness; Road Dist = distance from plot centroid to nearest road; Simpson = Simpson's diversity index; Stream Dist = distance from plot centroid to nearest stream.

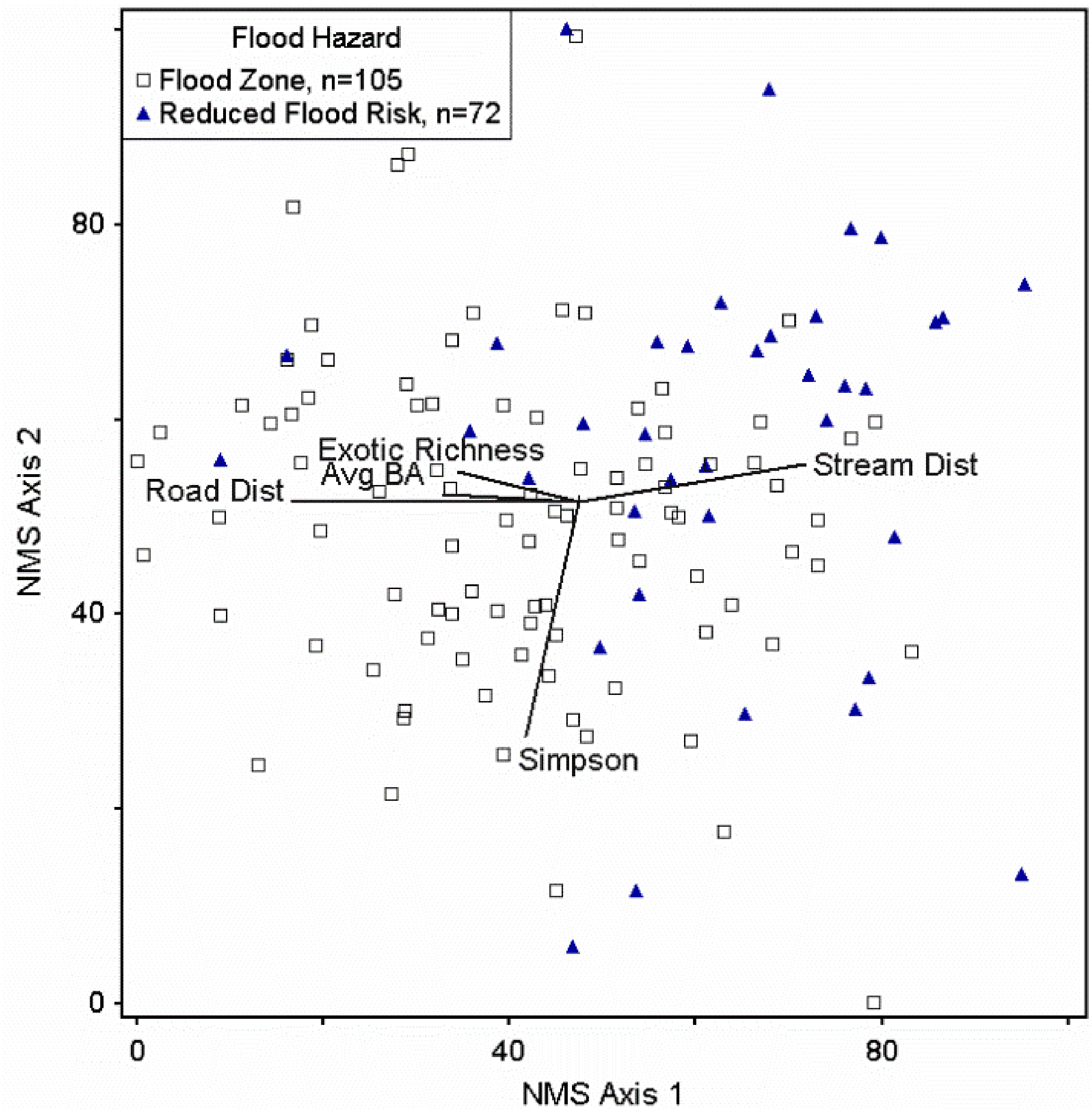

Figure 4.6 Non-metric multidimensional scaling (NMS) ordination of vegetation inventory sites grouped by flood risk. Joint-plot vectors (lines) indicate direction and relative correlation between study sites composition and ordination axes: Avg BA = average basal area; Exotic Richness = exotic species richness; Road Dist = distance from plot centroid to nearest road; Simpson = Simpson's diversity index; Stream Dist = distance from plot centroid to nearest stream.

NMS Axis 2 was not strongly related to any of the predictor variables, but it was associated with an inverse trend in species diversity (Table 4.4). We did observe that species associated with high NMS Axis 2 values such as *J. virginiana, P. taeda* and *P. echinata*, *Taxodium distichum* (L.) Rich. (TADI2: bald cypress), *Ailanthus altissima* (Mill.) Swingle (AIAL: tree of heaven), and *Quercus rubra* L. (QURU: northern red oak) were mostly intolerant or moderately intolerant of shade while species at low NMS Axis 2 values were generally tolerant to moderately tolerant of shade (*F. pennsylvanica* (FRPE), *A. rubrum* (ACRU), *Carpinus caroliniana* Walter (CACA18: American hornbeam), *Cornus florida* L. (COFL2: flowering dogwood), *Cercis canadensis* L. (CECA4: eastern redbud), *Carya glabra* (Mill.) Sweet (CAGL8: pignut hickory), and *Magnolia grandiflora* L. (MAGR4: southern magnolia)).

Table 4.4 Pearson's r Correlations between NMS axis values and environmental variables representing sample site conditions along the Capital Area Greenway, Raleigh, NC.

Variable	Axis 1	Axis 2	Axis 3
Predictor Variables			
BWHA Score	-0.429**	-0.199*	-0.316
Canopy Cover (%)	-0.183*	-0.181*	-0.108
Distance to Road	-0.344**	-0.016	-0.103
Distance to Stream	0.308**	0.122	-0.086
Vegetation Characteristics			
Average Basal Area	-0.237**	0.051	0.017
Non-native Richness	-0.224*	0.114	0.056
Non-native Stems (%)	-0.220*	0.091	-0.047
Plot Density	-0.194*	0.057	-0.008
Simpson's Diversity	-0.151	-0.310**	0.035

*Significance : * p < 0.05; ** p < 0.01*

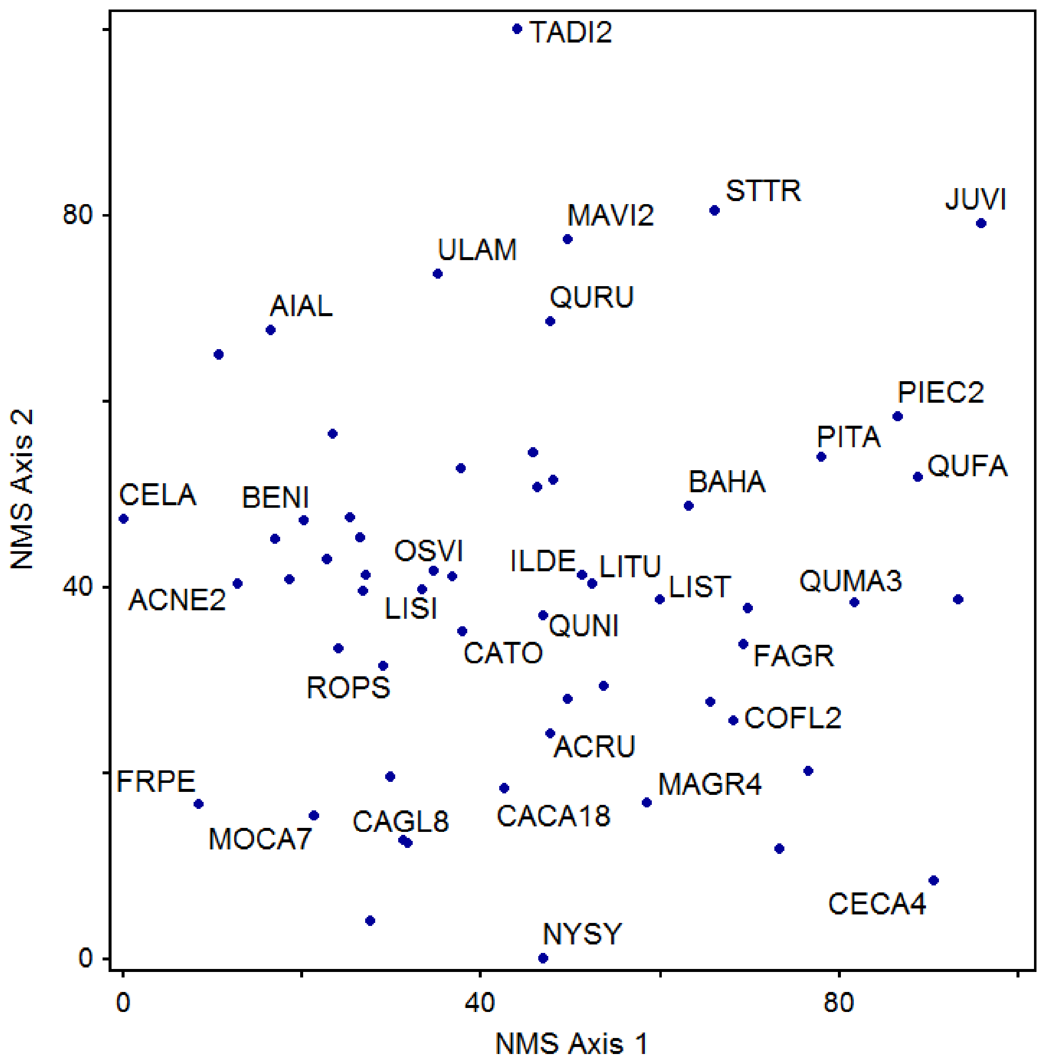

Figure 4.7 Non-metric multidimensional scaling (NMS) species ordination. Selected species abbreviations are USDA PLANTS database symbols (USDA NRCS 2017)**. See Appendix A for full species inventory.**

These results suggest that NMS Axis 2 captures species variations related to an undocumented gradient in light availability or perhaps disturbance history. Axis 3 was not significantly correlated with any variables tested. MRPP results showed significant differences in composition between groups for all environmental variables (Table 4.5).

Table 4.5 Results of multi-response permutation procedure (MRPP) analyses comparing groups within environmental variables for study sites.

Variable	Groups	T	A
Distance to Stream	< 15 m vs. 15-29 m	0.33	-0.001
	< 15 m vs. 30-150 m	-0.555	0.002
	< 15 m vs. > 150 m	-3.643	0.025**
	15-29 m vs. 30-150 m	-2.23	0.005*
	15-29 m vs. > 150 m	-4.302	0.014**
	30-150 m vs. > 150 m	-2.27	0.015*
Flood Hazard Area	Flood zone: Yes or No	-13.478	0.022**
Biodiversity and Wildlife Habitat Assessment Status	Priority conservation area: Yes or No	-9.185	0.015**
Distance to Road	< 30 m vs. 30-59 m	-0.034	0.0001
	< 30 m vs. 60-150 m	-5.936	0.015**
	< 30 m vs. > 150 m	-7.599	0.034**
	30-59 m vs. 60-150 m	-1.628	0.004
	30-59 m vs. > 150 m	-3.905	0.02**
	60-150 m vs. > 150 m	-4.28	0.014**
Percent Impervious Surface	< 10% vs. 10-29.9%	-1.171	0.003
	< 10% vs. > 30%	-6.48	0.014**
	10-29.9% vs. > 30%	-0.97	0.003
Percent Canopy Cover	< 40% vs. 40-74.5%	-1.532	0.004
	< 40% vs. > 75%	-10.102	0.022**
	40-74.5% vs. > 75%	-2.718	0.007*

*Significance: * $p < 0.05$; ** $p < 0.01$*

Specifically, species composition varied between sites that: 1) differed with stream proximity, particularly sites < 15 m vs. those > 150 m from a stream; 2) were located inside vs. outside of designated flood zones and conservation priority areas; 3) differed with road proximity, particularly sites < 15 m vs. those > 150 m from a road, and 4) were embedded within local environments with more or less impervious surface (< 10% vs. > 30%) or forest canopy (> 75% vs. < 40%) cover (Table 4.4). Many of these results thus echoed findings from the GzLM analyses of forest structure and diversity.

The strong separation between environmental factors (test statistic T) and statistical significance (p) indicates the distinctiveness of groups within each variable, suggesting that plant communities can be distinguished on the basis of several of the environmental factors tested. The chance-corrected within-group agreement value (A) is representative of the heterogeneity of individual sites within groups when compared to random chance, i.e. the effect size. The relatively small A values indicate little distinction in species abundance within each grouping, but the heterogeneity between groups was slightly higher than would be expected by chance, which corresponds to the broad spread of sites observed in the NMS ordinations.

Indicator Species Analysis (ISA) identified species that were representative of differing categories of the environmental variables, with the results mirroring and complementing the NMS analyses (Table 4.6). Indicator species typically corresponded to their natural habitat preferences. For example, *Baccharis halimifolia* L. (groundseltree), *J. virginiana, Liriodendron tulipifera* L. (tulip tree), and *P. taeda*, which are all generally found in drier (often disturbed) upland habitats, were found to be indicators of lower flood risk sites and low conservation priority areas. Sites in flood zones and priority conservation habitats, especially those with low impervious surface areas (<10%), and high canopy cover (>75%), were associated with *A. rubrum, C. caroliniana, Carya tomentosa* (Lam.) Nutt. (mockernut hickory), and *Ostrya virginiana* (Mill.) K. Koch (American hophornbeam), all of which are shade tolerant, later-successional species often found in bottomland forests. Sites situated farther from roads (>150 m) and closer to streams (not shown) tended to be associated with trees tolerant of wetter environments, such as *A. negundo*, *C. laevigata*, and *O. virginiana*.

4.5 Discussion and Conclusions

A major focus of urban conservation planning is increasing the connections among fragmented habitats in the midst of an inhospitable urban matrix (Lepczyk et al. 2017). Planners note that the increase of physical connectivity between disjointed habitat patches provides an opportunity to enhance their quality and function. This ability to link natural habitats has been a major factor in the widespread implementation of greenways in urban areas (Ahern 2013).

Table 4.6 Indicator species analysis results for species across the entire study area. Values represent the group and variable for each species indicator.

	BWHA Category	Flood Risk	% Impervious Surface	Distance to Road	Canopy Cover
Acer negundo	-	-	-	> 150 m	-
Acer rubrum	Conservation Area	Flood Zone	< 10%	-	> 75%
Ailanthus altissima	-	-	> 30%	-	< 40%
Baccharis halimifolia	Unprotected	Low Flood Risk	> 30%	< 30 m	< 40%
Betula nigra	-	Flood Zone	-	-	-
Carpinus caroliniana	Conservation Area	Flood Zone	< 10%	-	> 75%
Carya glabra	-	-	-	-	> 75%
Carya tomentosa	Conservation Area	Flood Zone	< 10%	-	> 75%
Celtis laevigata	Conservation Area	-	-	> 150 m	> 75%
Cornus florida	-	Low Flood Risk	-	-	-
Fagus grandifolia	Conservation Area	-	< 10%	-	> 75%
Fraxinus pennsylvanica	Conservation Area	Flood Zone	-	-	-

Ilex decidua	-	-	-	> 150 m	-
Juniperus virginiana	Unprotected	Low Flood Risk	-	< 30 m	-
Ligustrum sinense	-	-	-	> 150 m	> 75%
Liquidambar styraciflua	-	-	< 10%	-	-
Liriodendron tulipifera	Unprotected	Low Flood Risk	-	-	-
Magnolia grandifolia	-	Low Flood Risk	-	-	-
Myrica cerifera	-	-	> 30%	-	-
Ostrya virginiana	Conservation Area	Flood Zone	< 10%	> 150 m	> 75%
Pinus echinata	-	Low Flood Risk	-	-	-
Pinus taeda	Unprotected	Low Flood Risk	-	-	-
Quercus marilandica	-	-	10-30%	-	-
Quercus nigra	-	-	-	-	40-75%
Quercus rubra	-	-	-	> 150 m	-
Robinia pseudoacacia	Unprotected	-	> 30%	-	< 40%
Taxodium distichum	-	-	> 30%	-	-

This focus on physical connectivity, however, may deemphasize species composition, internal structure, and other potential greenway benefits to a city. In fact, contrary to ideas of greenways as simple, homogeneous areas connecting points of interest, this study points toward a diverse urban greenway with a range of potential habitat values in and of itself that are shaped by a suite of variables associated with site conditions, management efforts, and local anthropogenic activities.

Ecological benefits along the CAG will be expressed in part based on the arrangement and characteristics of the representative plant communities. Vegetation appeared in two main community types: riparian forests and upland forests. Some of the most prominent greenway tree species, especially in floodplains and conservation areas, were characteristic of mature regional riparian environments (e.g. *A. negundo, A. rubrum*, *F. pennsylvanica*). These locations were also more densely vegetated with higher species diversity than adjacent upland areas. Thus, despite the highly-developed setting of the greenway, many native, late successional wetland trees are in healthy condition, indicating that a "natural" vegetative assemblage can persist in a fairly narrow area surrounded by development.

Species typically found in upland forests were also present, a number of which occur preferentially in environments more prone to human disturbances.

These communities are less common than floodplain areas near trails and have a more disjunct distribution along the greenway. These areas are also more likely to be separated by riparian areas or urban development, reinforcing the conceptualization of the CAG as a diverse landscape mosaic.

Non-native woody species were less widespread and less correlated with human activity than initially hypothesized. While they were found throughout the greenway, they were relatively uncommon, and the majority of sites (67%) did not contain any non-natives. Where they were present, they often grew together in the same area, particularly *L. sinense.* These results do not support expectations based in previous studies suggesting that greenways may serve as a method of dispersal for non-native species or disease (Hess 1994; Minor and Urban 2008; Orland and Murtha 2013). The disjunct distribution of non-native woody species throughout the greenway instead suggests that different species are being introduced to the greenway from multiple areas and finding isolated areas of suitable habitat, rather than originating from within the greenway.

The correlation between the presence of non-native species overall and their proximity to roads is consistent with previous findings that non-natives are more prevalent along roads due to increased opportunity for dispersal (Hobbs 2002; Christen and Matlack 2006; Skultety and Matthews 2017). This correlation was fairly weak, however, suggesting that other factors not accounted for in this study may play a larger role in their distribution. For example, the limited distribution of non-natives may also indicate that individuals are only recently established and have not widely dispersed from their initial location. Additionally, trail and vegetation management by the city may have influenced the distribution of non-native species in the greenway. The Indicator Species Analysis only identified only one species (*A. altissima*) as an indicator of low canopy cover and high impervious surface area; this result is consistent with the its preference for disturbed areas (McDonald and Urban 2006; McAvoy et al. 2012).

The narrow width of the CAG corridor (typically 15-45m) is less than some minimum buffer widths recommended buffers for aquatic systems (30 m) (Schueler 1995), wildlife (284 m) (Semlitsch and Bodie 2003), or air quality (150 m) (Adams and Dove 1989). By these standards, the entirety of the greenway can be considered to be "edge" habitat, although the greenway corridor was embedded in places in larger forested areas. This view of the greenway as "edge" habitat is further supported by the presence of disturbance-adapted native species and non-native species throughout the greenway. Nonetheless, even as a disturbed natural environment, the greenway is host to a diverse assemblage of species and habitat. We believe that heterogeneity in microclimate and microtopography within and surrounding the greenway in part contributes to the presence of different vegetative communities. Variability among habitat patches in similar environments has been observed in urban areas due to local site conditions (Douglas 2011). Greenways, as linear features extending through developed area, are exposed to more effects of the urban matrix than habitat patches.

While we observed established communities of native species in our study area, our methodology was intended to provide a record of current vegetation patterns and is not able to capture changes in vegetation over time. The limitations of our methodology thus raise several questions for future investigation. In general, more research needs to be done to further understand the condition and successional dynamics of this environment. A rapidly changing landscape is a major challenge that is encountered in an urban setting. For example, present day disturbances to the forest understory may drastically alter future canopy composition as overstory trees that established under very different conditions die off and are replaced, potentially leading to long-term changes in community dynamics or nutrient cycling (Franklin et al. 2009). Monitoring the greenway to understand how greenway communities change over time would help address uncertainties such as the spread of non-native species, or the long-term effect that protected conservation areas may have on species. The ability of the urban trees to persist within the CAG in the long term is unknown, though their successful establishment in the narrow confines of the greenway is encouraging for future landscape planning.

This study focused on the structure, composition, and diversity of vegetation within a greenway, but beyond the potential to benefit natural species and communities, we acknowledge the myriad of other functions greenways perform. A highlight of urban greenways is their ability to serve multiple functions outside of conservation, such as a place for recreation, transportation, or other social functions (Fabos 1996; Opdam 2002; Schiappacasse and Müller 2015). Each of these services have their own requirements and optimal conditions. The ability of a greenway to function as natural habitat in conjunction with these other functions is uncertain, but an important issue to be addressed in future studies.

Finally, our findings illustrate that an urban greenway is able to serve as suitable habitat for native plant communities, supporting the idea that greenways can be used to enhance environmental quality in cities. Even if a greenway's main functions do not include conservation or environmental protection (the CAG, in this instance, also supports recreation and transportation as major uses), the presence of easements still adds to the total overall habitat area of the local ecosystem. The plant communities of a greenway can provide natural cover for wildlife as well, though the ability of urban fauna to persist in these environments is a subject requiring further studies. Examining greenways as potential habitat patches ensures that functional ecosystems are not overlooked as otherwise homogeneous corridors or buffer zones. As greenways are increasingly being utilized in sustainable development and green infrastructure projects, a deeper understanding of their vegetative structure and ecological function is needed to help mitigate effects of habitat fragmentation and to enhance the quality of urban ecosystems.

Chapter 5

Vegetative Structure And Diversity Along An Urban Greenway In Relation To Land Use Patterns[3]

5.1 Abstract

The conservation of forest remnants and native vegetation within urban greenways are thought to help mitigate serious ecological issues associated with urbanization, including habitat loss and species extinction. Previous studies examining the environmental contributions of greenways have largely focused on their role as habitat connectors at the broader regional- or city-scale, however, the ability of greenways to maintain diverse local habitats has not been closely examined. (Opdam and Wascher 2004; Chetkiewicz et al. 2006). The presence of diverse of habitat types and vegetative communities is important in maintaining species diversity and generating environmental services (Douglas 2011). This study examines an urban greenway's community structure and composition

[3] Chin, EY Submitted to Landscape and Ecological Engineering, 5/2/19.

across different types of urban land uses to identify how development patterns may influence the biodiversity of trees in urban greenways. Species richness, stem density, and basal area of woody vegetation were derived from a comprehensive survey along the Capital Area Greenway (CAG), Wake County, North Carolina, USA. These vegetation metrics were examined in relation to four land use variables derived from Wake County property and environmental datasets: 1) building densities, 2) period of development, 3) street densities, and 4) city zoning districts. Kruskal-Wallis H and Dunn-Bonferroni post hoc tests indicated significant differences in all vegetation metrics across different zoning districts and street densities. Mean stem densities and stand basal areas were significantly higher in conservation and residential districts, as well as in sites with low street densities. In contrast, species richness was relatively consistent across most zoning districts, with the exception of agricultural zones which had the least number of species within the CAG. These results illustrate the discontinuous spatial distribution of forested habitat along CAG. Present-day land uses are closely associated with the structure and diversity of greenway vegetation, however, the city's history of strict zoning ordinances and regulations promoting tree conservation has likely influenced the current state of the greenway and allowed patches of diverse forest stands to persist.

5.2 Introduction

Greenways are vegetated paths in cities that are conserved as natural areas, vegetative buffers, environmental preserves, and recreational trails. However, the urban setting of many greenways increases the likelihood of these areas experiencing anthropogenic impacts and other disturbances. Urban development patterns arising though zoning and land use influence land cover distribution and ecosystem function and alter local plant and animal communities (Alberti 2008). While greenways may provide habitats and increased connectivity across patchy urban environments, numerous studies have noted that urban habitat fragments undergo changes in species diversity (McKinney 2008), decreases in ecosystem service functions (Walsh et al. 2005; Grimm et al. 2008), and increases in non-native species populations (Hansen and DeFries 2007) when compared to more contiguous natural areas. Other researchers have observed nonnative and invasive species to spread more readily along greenways (Minor and Urban 2008; Orland and Murtha 2013).

Given the relatively narrow widths of urban greenways and trails (typically 15–45 m in Raleigh, North Carolina's Capital Area Greenway), undisturbed areas in these environments may be very limited or nonexistent, as "edge effects" can readily influence community structure and function more than 50–100 m into a forest (Chapter 4; Douglas 2011; Harper et al. 2005). Undeveloped areas adjacent to streets are regularly exposed to numerous disturbances stemming from an influx of nutrients and pollutants (Valtanen et al. 2014), physical disturbances from traffic or road maintenance (Rentch et al. 2005), and other sources (Forman et al. 2003). Subsequently these impacts can affect the structure and diversity of vegetation present in edge environments. For example, increased stormwater runoff has been connected with the establishment of pioneer species and exotic species in urban forests (McAvoy et al. 2012), while high levels of heavy metals and physical disturbances along major roads correspond with low forest richness and reduced tree regeneration rates (Trammell et al. 2011).

Few studies have focused on specifically on greenways and environmental integrity at a local community scale, and the effectiveness of greenways in improving ecological quality has been debated (Opdam and Wascher 2004; Chetkiewicz et al. 2006). Forested environments do bring numerous benefits to the urban ecosystem, including: lowering concentrations of air pollutants (Yang et al. 2005; Soares et al. 2011), reducing energy usage in buildings through shading and reduced air conditioning (McPherson and Simpson 2003; Sawka et al. 2013), as well as reduction in heat-energy use through wind-shielding (Akbari et al. 2001). Yet even with the greenery provided by greenways, the narrow stands of vegetation present in these environments might not provide the full suite of benefits expected of a forest ecosystem. Furthermore, city planning documents typically discuss greenways as homogeneous connectors (see Chapter 3), which does not acknowledge the value of habitat diversity in maintaining species diversity and generating environmental services (Douglas 2011).

Assessing the value of greenways in terms of their ability to serve as healthy natural habitats in cities will allow for better planning of conservation goals and desired conditions in urban ecosystems (Chapter 3). The goals of this study are to define the species composition of woody vegetation in the Capital Area Greenway (CAG) of Raleigh, NC, and to examine this urban greenway's community structure in relation to surrounding urban development patterns. Specifically, I seek to determine if zoning districts impact the diversity, stem density, and basal area of greenway vegetation. This research also examines how other aspects of planning and development, specifically building and street density and age of development, are associated with the ecological structure of the greenway.

5.3 METHODS

5.3.1 Study Area

Established in Raleigh, Wake County, NC, USA in 1974, the CAG is one of the oldest greenway networks in the United States. Originally less than 40 km of fragmented trails, the trail system was conceived as a response to citizens' concerns over flooding and the loss of natural areas to urbanization (Flournoy 1976). Since then the CAG has steadily expanded throughout Raleigh's densely populated urban areas and suburban neighborhoods. Currently spanning over 160 km, the trails serve as a "highly functional bicycle and pedestrian network for recreation, environmental protection, conservation, and transportation" (City of Raleigh Parks Recreation and Cultural Resources Department 2015).

Inventories of woody vegetation were conducted during the summer and fall of 2016 along preselected CAG trails and adjacent easements. The entire lengths of House Creek, Reedy Creek, and Rocky Branch, and adjoining segments of Crabtree Creek and Walnut Creek were inventoried (Figure 5.1).

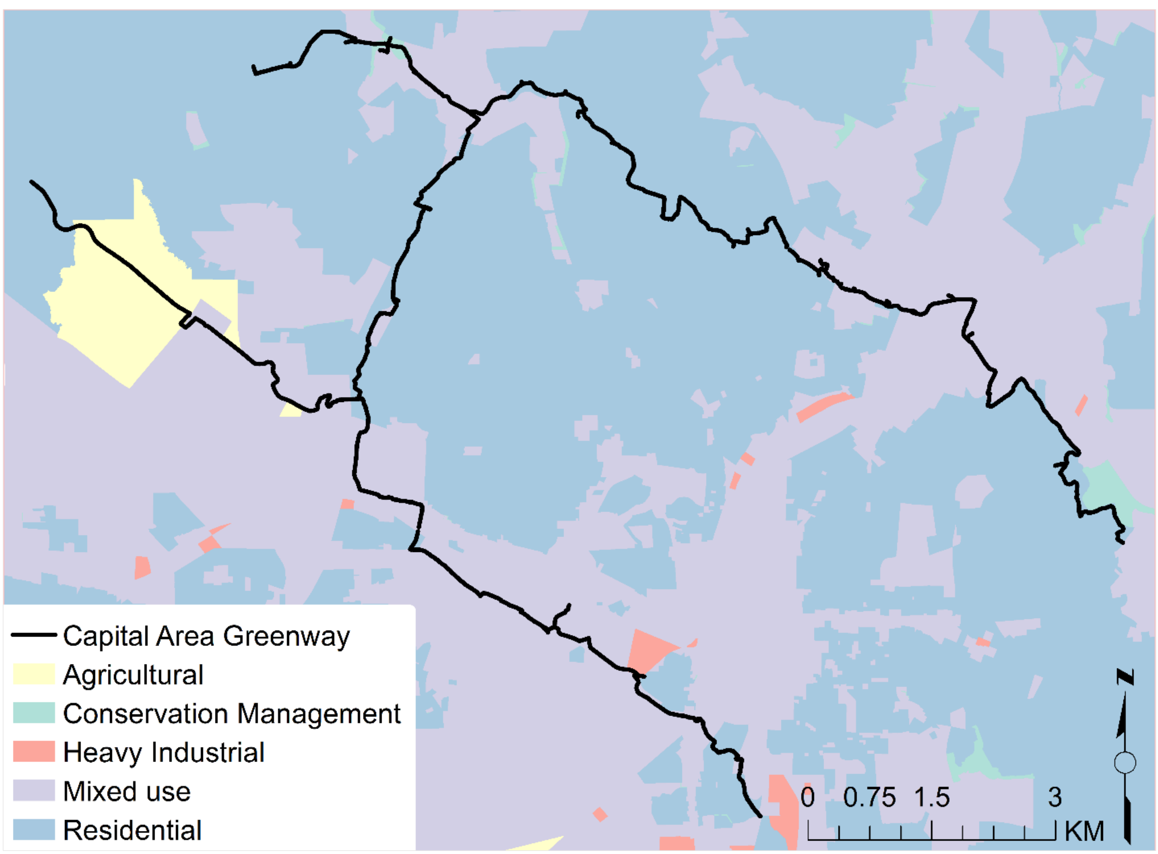

Figure 5.1 Selected Capital Area Greenway trails and zoning districts in Raleigh, NC. One site located in a heavy industrial zone had zero species and was not included in the final analyses.

These trails represent some of the earliest established greenway trails in the CAG, as Crabtree Creek, Reedy Creek, and Rocky Branch were among the first trails conceived in the 1974 greenway plan. The study area covers approximately 39 km of paved trails and 3 km^2 of vegetated area. All study sites are located on public easements, but some trail segments are adjacent to private property, including houses, businesses, and farmland. Trees within greenway easements are generally maintained by the City of Raleigh, but landowners are also responsible for any vegetation on private property (B. Johnson and, Z. Minor, personal communication, May 26, 2016).

5.3.2 Vegetation Data

Vegetation along the greenway trails were assessed through a systematic inventory of plant species. The methodology used for surveying vegetation was adapted from the STRATUM inventory protocol (Jaenson et al. 1992; Maco and McPherson 2003). Jaenson et al.'s random street selection method was omitted in the CAG inventory, as greenway trails were selected *a priori*. At each study site precise DBH measurements were also recorded, as opposed to STRATUM's strategy of using categorical values. In the field, a point on the trail was selected every 200 paces (ca. 200 m). At each point paired 60 m^2 plots were established on each side of the trail. Plots bordered the edge of the path, including gravel or grass edging. Each plot was 15 m parallel to and 4 m perpendicular to the trail. This four-meter width is equivalent to the minimum standard width of some CAG trails. For statistical analyses, inventory data for each pair of study plots was aggregated and treated as one study site. In total 177 sites of 120 m^2 area (354 individual plots) were sampled.

At each site all woody plants with a DBH (diameter at breast height) of least 1 cm (at 1.37 m above ground) were counted and identified. For plants with multiple stems, the total DBH of an individual was calculated as follows: 1) measure the DBH of all stems, 2) square the diameter of each stem, and 3) sum the squared values for the total DBH. In each 120 m^2 site the stem density (number of individuals) and species richness (number of unique species), and basal area (m^2 / ha) were derived to characterize the biodiversity and structure of woody species along the greenway. Site areas used in density ratios were reduced to 100 m^2 for consistency when reporting results. Prior to statistical analyses study sites with zero woody species were omitted. This left 153 sites where woody species were present.

5.3.3 Land Use Characteristics

Many anthropogenic impacts can extend anywhere between 50 m up to 200 m into forested areas (Adams and Dove 1989; Semlitsch and Bodie 2003; Hellmund and Smith 2006). I examined land uses within a 100 m radius surrounding each study site centroid to determine how adjacent land use characteristics might correspond with urban vegetation patterns. This buffer distance corresponded with the maximum width of greenway easements in the study area. Several datasets from the Wake County government (Wake County GIS 2017) were utilized to identify variables representing land use: 1) building density, 2) period of development, 3) street density, and 4) dominant zoning. Individual buildings within each 100 m buffer were counted to provide building density.

Density values ranged from 0 buildings per buffer to 9, though the majority of sites (≈95%) contained no more than five buildings. Building density values were grouped into four intervals, 0, 1–2, 3–4, and ≥ 5, to facilitate statistical analyses and comparisons with other categorical variables.

Average year of development was derived from Wake County property records, which listed the "year built," or when the first permanent structure was constructed on the property. Years in the dataset ranged from 1900–2017. These years were divided into three periods to correspond with distinct periods of major population growth in Raleigh: 1900–1959, 1960–1989, 1990–present (Department of City Planning 2018a). The earliest period (1900–1959) corresponds with Raleigh's period of modernization, with the growth of manufacturing jobs and development of city utility infrastructure (including city water, electricity, and public transportation). This manufacturing boom contributed to a nearly 80 percent increase in the city's population (to approximately 25,000) in just the first

20 years of the century (Ross 1992). Between 1960 and 1989 Raleigh's city limits expanded and suburban areas became widespread. During this time the city's population more than doubled to 212,000 (National Register of Historic Places 2009; U.S. Census Bureau 2015). Since the 1990s, Raleigh's population has continued to increase steadily with the growth of its science and technology industries, and the metropolitan area has become one of the fastest growing in the US (Department of City Planning 2018a). In 2010 the US Census Bureau estimated the city's population to be nearly 404,000, while the Raleigh metropolitan area included over 1.1 million people (2015).

Street density was derived from TIGER/Line files (U.S. Census Bureau 2015). Across the greenway street density values ranged from 0 to a maximum of 5 street segments per buffer. Street densities were grouped in equal intervals, similar to building densities: 0–1, 2–3, 4–5. Both building and street counts were visually confirmed with 2016 aerial imagery (Wake County GIS 2017).

Finally, each buffer was assigned a zoning category based on the dominant zoning district present. The City of Raleigh uses three base zoning districts to regulate urban growth and land use: residential, mixed-use, and special districts (Department of City Planning 2018b). Residential districts control housing density in residential neighborhoods, while mixed-use districts are applied to areas that provide a combination of housing, offices, and commercial activities. Special districts describe a set of separate zoning districts that each require their own specific needs and regulations. Special districts present within this study area are agricultural productive (farm land), campus (college and university property), conservation management (e.g. public open space), and heavy industrial. Of these four, agricultural and conservation management districts were examined as individual zoning categories in this study. Study sites on university campus property (North Carolina State University and Meredith University), were classified as mixed-use zones due the presence of retail spaces and their proximity to residential neighborhoods. Only one study site was in a heavy industrial zone. This site contained zero woody species and subsequently omitted from final analyses. In total four zoning districts were assessed: agricultural, conservation, mixed-use, and residential.

5.3.4 Statistical Analyses

Global Moran's I, a test for spatial autocorrelation, was used to evaluate the similarity of vegetation metrics using ArcGIS 10.2.2 (ESRI, 2014). The non-parametric independent samples Kruskal-Wallis test was then used to determine if there were differences between the vegetation attributes in each study plot and the surrounding land use characteristics. The Kruskal-Wallis test is the non-parametric equivalent of a one-way ANOVA and compares the mean ranks of all test groups to determine if they are equal. Dunn-Bonferroni post-hoc tests were performed on all significant Kruskal-Wallis groups to evaluate if specific pairs of land use categories were significantly different. All statistical analyses were performed in IBM SPSS Statistics for Windows, version 25 (IBM Corp, 2017).

5.4 RESULTS

5.4.1 Overview of Greenway Species

A total of 96 woody species were recorded, representing 3,474 individuals (see Appendix A for full species list). Four species made up nearly one-third (32%) of the inventory: *Ligustrum sinense* Lour. (Chinese privet) (n=367), *Pinus taeda* L. (loblolly pine) (n=287), *Liquidambar styraciflua* L. (sweetgum) (n=260), and *Acer rubrum* L. (red maple) (n=219). Stem sizes ranged from 1 cm to 180 cm, but the majority sampled were relatively small, with 90% having a DBH of < 30 cm (see Figure 5.2).

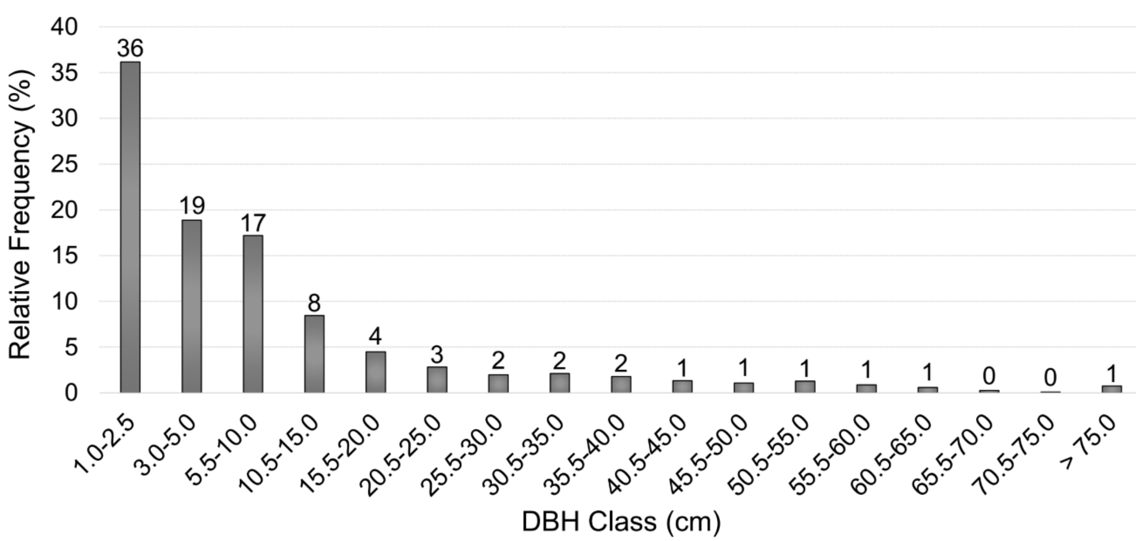

Figure 5.2 Relative size distribution of individual woody plants sampled in the Capital Area Greenway, n = 3,474.

5.4.2 Statistical Analyses

Across the entire greenway study sites contained an average of 5.5 species and had an average stem density of 18.8 stems per 100 m^2. The average basal area was 0.616 m^2/ha. Global Moran's I values showed that stem density and basal area values were randomly distributed across the greenway and did not exhibit any spatial autocorrelation. Species richness exhibited very slight clustering, but this was not highly significant (Moran's Index = 0.509489, $p < 0.10$). Overall, species diversity and community structure are spatially random across the greenway.

Kruskal-Wallis H tests indicated significant differences in vegetation metrics within two land use variables, street densities and zoning districts (see Table 5.1). In other words, the diversity, stem density, and stem size of greenway vegetation are significantly different across varying levels of street density and zoning districts. In contrast, there were no statistically significant differences in any vegetation metric across building densities or periods of land development.

Table 5.1 Kruskal-Wallis H results for mean species richness, stem density, and basal area within land use variables, $X^2(df)$.

Variable	Richness	Density	Basal Area
Building density	1.370(3)	1.688(3)	3.234(3)
Period of development	1.540(2)	0.238(2)	1.913(2)
Street density	3.422(2)	7.155(2)*	6.587(2)*
Zoning district	43.824(3)**	31.564(3)**	34.405(3)**

$p < 0.05$, ** $p < 0.01$

When street densities were examined in detail, mean stem density was highest (21.8 stems per 100 m^2) in sites with the fewest number of streets (0–1 streets) ($z = 19.667$, $p < 0.05$). At densities of 2–5 streets per site both stem density (13.1–14.4 stems per 100 m^2) and basal area (0.301–0.497 m^2 / ha) were lower than the CAG's overall average. Average richness values across all street density subcategories ranged from 4.8 to 5.8 species per 100 m^2, but was not statistically significant.

Across zoning districts the highest mean species richness (7.0 species per 100 m^2) and stem density (25.8 stems per 100 m^2) in the entire study area were observed in conservation districts. Residential districts had the highest mean basal area (0.854 m^2/ha) overall. Additionally, the lowest vegetation values were all found in agricultural districts: average richness (0.9 species per 100 m^2), stem density (3.3 stems per 100 m^2), and basal area (0.030 m^2/ha) (see Table 5.2).

5.5 Discussion and Conclusions

Overall the results show a correlation between the vegetative structure of the greenway and local zoning and street density. As zoning districts and street density categories are non-collinear, vegetation richness and diversity are influenced independently by both of these land uses. The random spatial distribution of richness, density, and basal area across the greenway suggests that greenway community structure is more susceptible to local site conditions from adjacent land uses and disturbances than smaller scale, regional development patterns.

Table 5.2 Frequency distributions for land use variables and mean richness and density area values per 100 m². Highlighted values (in green) represent significant Kruskal-Wallis results, where vegetation values are significantly different across land use subcategories.

Building Density (buildings within 100 m of study site)	Number of Sites	Mean Richness (species per site)	Mean Stem Density (stems per site)	Mean Stand Basal Area (m²/ha)
0	65	5.3	19.3	0.727
1–2	44	5.2	18.6	0.501
3–4	20	6.1	18.1	0.673
≥ 5	24	5.9	18.6	0.482
Period of Development	**Number of Sites**	**Mean Richness**	**Mean Stem Density**	**Mean Stand Basal Area**
1900–1959	32	4.9	18.0	0.758
1960–1989	93	5.5	18.8	0.566
1990–Present	28	6.0	19.8	0.623
Street Density (street segments within 100 m of study site)	**Number of Sites**	**Mean Richness**	**Mean Stem Density**	**Mean Stand Basal Area**
0–1	93	5.8	21.8	0.717
2–3	49	4.8	14.4	0.497
4–5	11	5.4	13.1	0.301
Zoning District	**Number of Sites**	**Mean Richness**	**Mean Stem Density**	**Mean Stand Basal Area**
Agricultural productive	12	0.9	3.3	0.030
Conservation management	5	7.0	25.8	0.299
Mixed-use	56	5.2	16.0	0.430
Residential	80	6.3	22.7	0.854
Overall	***153***	***5.5***	***18.8***	***0.616***

Over half of individual plants surveyed can be considered young trees or shrubs (Figure 5.2) (Newton et al. 2007). Given the unimodal, negatively skewed distribution of DBH classes, woody vegetation along the greenway are aging as expected for an urban forest (Cowett and Bassuk 2014). A closer examination of mean basal areas shows that the largest trees are typically found in residential zones and in sites with low street densities. Stem density values in the CAG exhibit a similar pattern to basal area, though the most densely forested sites are conservation management districts. In contrast, the lower stem densities observed in areas with higher intensity development (i.e. sites in mixed-use zones and high street densities) further establishes the association between forest structure and varying levels of urbanization.

The high stem densities and basal areas in residential and conservation areas are not surprising, given that areas with lower housing density, particularly single-family housing units (the predominant housing unit in these sites (Department of City Planning 2018a)) have been positively correlated with greater canopy cover and tree stewardship (Troy et al. 2007). The City of Raleigh offers many environmental protections and regulations designed to preserve trees and open space within the city (City of Raleigh Parks Recreation and Cultural Resources Department 2015). Tree conservation and the protection of "tree coverage, mature trees and natural resource buffers" is a major aim in the city's

Unified Development Ordinance (p. 9-2). Under current guidelines effective since 2013, all new developments above two acres are required to conserve at least 10–15% of existing trees on the property, however, specific data on the effectiveness of city requirements are not currently available (Department of City Planning 2018b). The average stem density of mature trees (DBH ≥ 5cm) in residential and conservation districts are comparable to tree densities found in other southeastern urban forests, which may in part illustrate a successful outcome of these conservation efforts (Abdollahi et al. 2012; Siderhurst et al. 2012; Blood et al. 2016).

Vegetation in conservation management zones have persisted as mature, late successional wetland communities (see Table 5.2; Chapter 4), but their presence in the study area (and the city) is minimal (Figure 5.1; Department of City Planning 2012). Conservation management districts were originally intended to help preserve open space and environmentally sensitive areas in the city (e.g. floodplains, riparian buffers) by putting strict limitations on development. In recent years conservation zones have essentially become "obsolete" with current zoning ordinances protecting trees and establishing protected buffer zones between development and sensitive environments, though they are still applied occasionally (Department of City Planning 2018b). The two conservation districts within this study area were established in the early 1980's.

Sites situated further from streets (i.e. with low street densities) are also characterized by high stem density and stand basal areas. The higher average basal areas and canopy covers typical of these areas likely represent sites with older trees in more intact forest stands that were not cleared for development. While no data were available on the intensity of road usage or their construction and maintenance histories, other studies have attributed lower street densities and lower levels of disturbance to similar habitats (Dobbs et al. 2013; Nitoslawski et al. 2016).

Agricultural productive zones were the only type of land use that was correlated with low species richness, which is logical as species richness and diversity in agricultural environments is often low due to intensive land management and other social-ecological processes (Ordonez et al. 2014). A history of forest land clearing would also contribute to low mean stem densities and basal areas. Any vegetation that began growing (either naturally or intentionally planted) since the area's conversion to agriculture would be younger, smaller in diameter, and less well-established than forest stands in more stable conservation sites. The low species diversity in agricultural zones provides an area of opportunity for urban forest expansion, though the gradual loss of farmland to development may limit more extensive conservation efforts (Department of City Planning 2012). However, agricultural zoned sites are only located in one section of the study area and function as pasture owned by North Carolina State University (see Figure 5.1). This concentration of low-richness agricultural sites also contributes to the minor spatial clustering of species richness values. When sites in agricultural zones are omitted from analysis, richness values in the remaining three subcategories are spatially random across the greenway ($I = 0.259545$, $p = 0.33$). When the Kruskal-Wallis test is also repeated without agricultural sites, these results are no longer significant ($H = 5.436$, 2 df, $p = 0.66$). In short, the weak relationship between zoning and richness suggests that general zoning patterns across a city do not directly impact species richness within its greenways. Alternatively, the varying management trends and property uses within zoning districts may be more influential on the number and types of species in adjacent greenspaces.

The relatively consistent richness values in residential, mixed-use, and commercial districts may be a consequence of biotic homogenization in urban forest patches. As human needs are relatively limited compared to the needs of all other populations in a region, there is a tendency for native species become extinct while non-natives are introduced in cities, resulting in similar species being found throughout urban areas in as little as 20–30 years (McKinney 2006; Smart et al. 2006; Gong et al. 2013). This is supported by results in Chapter 4, which noted similarities in species assemblage at different degrees of disturbance (e.g. early successional, xeric communities found in disturbance-prone areas). The introduction of species by land managers may also influence the number of species present in residential or mixed-use areas (Nitoslawski et al. 2016). As species richness does not account for the abundance of individuals, the addition of several unique trees by a home owner, for example, would increase the richness of a site and inflate average richness values. Therefore, it is probable that the intentional (and unintentional) species introductions by humans are increasing richness in more developed areas, bringing them closer to levels found in conservation sites (Olden 2008).

Given the detailed planning put into regulating developments and conserving existing forests, more significant correlation between the vegetation variables and both building density and period of development was expected, though this was not the case. This lack of significance may be due in part to data limitations, including factors not captured in this study. Because the full land use and landscaping history of all sites throughout the greenway is unknown, such activities were not able to be distinguished in this study. As species richness was not significantly correlated with any land use variable, it is likely that other factors outside of land use and development intensity are more influential on species diversity. Additionally, the vegetation survey was conducted over a single season, any long term or intermittent changes in community structure and land use is not accounted for. In general more research is needed to understand the mechanisms behind community dynamics in urban forests and homogenization at different spatial and temporal scales (Olden 2008).

The period of development used in this study was based on the initial construction of the first building on the property and does not account for subsequent development or intensity of development. Having more information about individual landowners' management practices over time, such as length of stewardship, or specific management techniques, might reveal a stronger relationship with vegetative structure (Conway and Bourne 2013). Even general demographic information on neighborhood parcels (e.g. length of ownership, homeowners vs. renters, median income) can help to provide insights into local residents' ability to plant or maintain vegetation (Boone et al. 2010). However, obtaining this level of detail for such a large number of properties would be challenging and is beyond the scope of this particular study.

The conservation of land along the CAG provides flora and fauna with habitats that are protected from development, but these spaces are not immune from human disturbances. The CAG's forest structure is negatively affected by urbanization and local changes in land use, as seen in the relationship between stem density and the density of adjacent zoning and streets. Given the relatively small "edge" habitat patches available in the CAG, species face a greater chance of extinction due to increased competition for fewer resources and populations being more vulnerable to random disturbances (Johnson 2001). The protected status of these areas, like in any nature preserve, is not able to prevent the loss of species indefinitely, but is able to slow species extinctions to a degree (McKinney 2002). The city's history of strict zoning ordinances and regulations promoting tree conservation has likely contributed to persistence of these forest patches. Thus, a relationship between land use and species richness might only be observed over the long term.

The recognition of our escalating human impacts has further bolstered the development of innovative urban designs to improve the health of our urban greenspaces and natural areas. According to Raleigh's Department of City Planning, the zoning regulations and tree conservation measures implemented by the city have helped to preserve the urban forest while providing residents with a higher quality of life (2018b). However, this study demonstrates that human impacts can be observed throughout the protected land of the CAG. To develop a better understanding of how vegetative communities can be managed in cities it is necessary to examine how development patterns and conservation outcomes vary over time and space. Research on urban forests and conservation are especially relevant in rapidly urbanizing areas like the southeast US. The ability to maintain both human needs and conservation areas is critical to continue planning for conservation in the long term.

CHAPTER 6

CONCLUSION

The magnitude of human impacts in the Anthropocene has increased the demand for urban development that accommodates both human needs and environmental protection (Lindenmayer et al. 2008). Greenways have become one popular approach to providing recreational spaces for urban residents while attempting to increase the spatial continuity of natural habitats across the developed landscape. Since the use of greenways in ecological conservation is a relatively recent practice, there is limited understanding of how vegetation is established and persists within greenway networks. This dissertation examined two aspects of urban greenways: the motivations for establishing greenways and the conditions of ecological communities within them.

The document analysis of greenway master plans in Chapter 3 identify a common theme: urban residents place a high value on natural areas in their cities, but specific management goals for conservation are not prioritized. In these plans any information or specific guidance for the management of natural areas is scarce compared to designs and considerations for visitor amenities. Instead, ecological functions are often presented as qualities inherently and equally possessed by all greenspaces and greenways. The notion that habitat and biodiversity are passively provided by these spaces allows for the assumption that the mere presence of "nature" is suitable to achieve a city's conservation goals.

This dissertation uses Raleigh, North Carolina's Capital Area Greenway (CAG) as a case study to evaluate greenway diversity and structure within a major metropolitan area (Chapters 4 and 5). Overall, species in the 40-year-old greenway are diverse, though species distribution patterns and community structure are highly variable within the greenway itself. Chapter 4 identifies distinct and diverse riparian, upland mesic, and xeric forest communities within the CAG. Results of multivariate analyses, non-metric multidimensional scaling (NMS) and multi-response permutation procedures (MRPP), suggest that these vegetation patterns are associated with local environmental variables, including proximity to floodplains and percent canopy cover. Study sites located in conservation areas and floodplains are characterized by greater basal area, canopy cover, and higher non-native species richness, for example. Xeric communities, characterized by early successional species, were found in disturbance-prone areas near roads and streams. Out of 96 species observed in the entire study area only 14 are not native to North America. These findings indicate that native forest communities are present and able to persist in the CAG with minimal human intervention.

However, the diversity of CAG communities contradicts the notion that greenways are homogeneous corridors. This finding also challenges assumptions that greenways provide the same ecological functions throughout their network (see Chapter 3).

The forest communities within the CAG are examined in greater detail in Chapter 5 to measure biodiversity across four types of land uses: 1) building densities, 2) period of development, 3) street densities, and 4) city zoning districts. Kruskal-Wallis H and Dunn-Bonferroni post hoc tests indicate significant differences in greenway richness and density within different zoning districts and varying street densities. These results show that the CAG's forest structure is negatively affected by local variations in land use, as sites subject to higher levels of development (residential zones, mixed-use zones, and high street density sites) have lower stem densities than sites that are less disturbed (conservation zones and low street density sites).

The widespread presence of diverse upland and riparian communities throughout the CAG's network initially suggests that city's desire to "preserve natural characteristics of the land" is being met (City of Raleigh Parks Recreation and Cultural Resources Department 2015). A closer look at CAG vegetation reveal disjunct communities and species that are limited in their ability to disperse to new habitats. As the CAG exists now, there is little to no connectivity of habitat along the network. Abrupt shifts in geography along the greenway, such as a sudden transition from a parking lot, to a tree stand, to a grassy park, limits the space available for woody vegetation to expand. In addition, variation in local topography along the greenway likely contributes to changes in habitat due to differences in available sunlight, soil moisture, and other fine-scale climate conditions. Capturing the slope or aspect of study sites in future vegetation surveys may offer deeper insights into environmental determinants of greenway community structure. In short, a greenway network is not heterogeneous simply because of the varied communities found within it, but also because the physical and ecological landscape supporting the greenway is highly variable in space.

Larger core habitats are necessary to maintaining stable, healthy populations of native flora and fauna (Noss et al. 1999; Pfeifer et al. 2017). The disjunct forest remnants in the CAG are regularly exposed to physical and biogeochemical disturbances from their urban surroundings. Exposure to regular trampling, mowing, and nitrogen deposition, for instance, can reduce survivorship of vegetation, particularly among younger individuals (Törn et al. 2009; Valtanen et al. 2014). The lack of connectivity in forest fragments further limits seedling recruitment and the ability of these local populations to sustain themselves in the long-term (Matlack 1994; Coomes and Allen 2007). Although destruction of these forests began over a century ago, populations of large, longlived trees can persist up to 200 years or more, contributing to some of the diversity seen today (Vellend et al. 2006). As vegetation can be affected by numerous other human and environmental disturbances in adjacent parcels (see Chapters 4 and 5), a greenway's ability to maintain its current levels of biodiversity into the future is uncertain. The CAG, like any isolated habitat, will eventually lose species over time (Botkin 1990; Stenhouse 2001).

Species richness was used as the primary metric to analyze community diversity in this dissertation based on its ease of computation and widespread use in the fields of ecology and biogeography. However, if richness and other ecological metrics are to be used to quantify the success of conservation goals, consideration needs to be put into the specific objectives the metrics are applied to and if these metrics are appropriate. In the case of human-dominated urban systems, like the Capital Area Greenway in Raleigh, NC, the presence of more species is not necessarily better; the addition of non-native invasive species can disrupt ecological functions and habitat provided by native populations. Though objective metrics appear to be a logical approach to justify current and future greenway management decisions, the functional or subjective nature of many planning goals (e.g. presence of "quality" habitat) are not straightforward statistics. Community metrics are valuable tools in the biological sciences but should be applied judiciously in the realms of policy and planning.

The unobtrusive presence of greenways may imply that monitoring natural areas is unnecessary, but understanding these areas is crucial to be able to maintain the stability of urban ecosystems (Ahern 2016). Given the relatively recent integration of ecological objectives in greenways, more longitudinal studies are needed to understand population trends and structural changes in greenway communities. Several greenway planning documents acknowledge the importance of monitoring species and engaging in adaptive management to continue accommodating the needs of humans and urban species (Chapter 3). Public conservation sites have the potential to be significant sources of biodiversity in a city, and greenways may even serve as refugia for species that would not otherwise found in the region (Florgard 2009). Initial surveys, like the one presented in this dissertation, can serve to establish baseline community data, while ongoing monitoring of environmental conditions and species distributions would provide urban planners, landscape architects, land managers, and other researchers data for making informed decisions when managing and allocating resources for conservation (Stankey, Clark, and Bormann 2005). However, inherent challenges will always lie in obtaining necessary funding and resources (Flink et al. 2013), thus the ability of greenways to provide environmental benefits is highly dependent on the values and policies of its city and residents (Mason et al. 2007).

This dissertation focused on vegetative communities, but greenways also have the potential to function as wildlife habitat and as refugia for rare and endangered species. Given a variety of different species the consideration of different conditions and management needs is necessary, inevitably leading to challenges in merging human preferences with environmental planning, and policy (Gaston et al. 2013). Future research can better characterize local habitats with the addition of herbaceous vegetation inventories to capture the distribution of forbs and grasses. As many of the original study sites were located in riparian buffers, the early-successional wetland herbs prevalent in these environments would be captured in such an extended species inventory.

The limited fine scale ecological data available on greenways further adds to the complexity in making planning decisions. The study of decision-making and environmental change is a significant field of research with a growing body of literature, particularly due to uncertainties associated with climate change (Brandt et al. 2016; Grote et al. 2016; Lanza and Stone 2016). The vast number of existing greenways across the US, and worldwide, provides many opportunities for ecological research in the near future (Doerr et al. 2011; Meerow et al. 2016). The City of Raleigh also is unique in that a nearly 6,000-acre area of protected forest, William B. Umstead State Park, is maintained at the outskirts the city. The area underwent historic disturbances from agricultural and timber uses, but was then established as public parkland in the late 1930s. Many greenway trails and Raleigh city parks have a similar land use history that allows for Umstead State Park to serve as valuable control site in future studies on Raleigh's urban ecology.

Today, urban conservation and the desire for more "eco-friendly" development is firmly established in the mainstream. As discussed in Chapter 3, coordination between local greenway or environmental organizations and local government is critical for achieving favorable conservation outcomes. Given the diverse social and political climates across the country, it is likely that the nature of greenway priorities also will vary outside of the southeastern US. Further examining the social, economic, and political and context of cities in the southeast US and in other regions (or countries) will further elucidate the motivations behind greenway planning and management decisions.

While the advantages of greenways and greenspaces have been well documented, continued work toward managing these environments will only enhance their benefits and the quality of life enjoyed by urban residents. Defining specific, attainable management goals and strategies can help establish long-term management practices and maintain more effective conservation sites. Actively monitoring and maintaining larger, more diverse forest fragments will help preserve the functionality of these habitats into the near future. The acquisition of additional forest remnants can also serve to enhance a greenway's functional connectivity while protecting environmental services critical to human health. Greenways are not the final solution to maintaining urban biodiversity, but they do bring us further along the path towards more sustainable cities for humans and the natural environment. Even though greenways are first and foremost human constructs, the values people place in nature and public spaces will ensure that greenways will have a place in cities into the future.

References

Abdollahi K, Ning ZH, Legiandenyi TN, Khanel P (2012) Urban Forest Ecosystem Structure, Function, and Value. Baton Rouge, LA

Adams LW, Dove LE (1989) Wildlife reserves and corridors in the urban environment. National Institute for Urban Wildlife, Shepherdstown, WV

Ahern J (2013) Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. Landsc Ecol 28:1203–1212. doi: 10.1007/s10980-012-9799-z

Akbari H, Pomerantz M, Taha H (2001) Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Sol Energy 70:295–310

Alberti M (2005) The Effects of Urban Patterns on Ecosystem Function. Int Reg Sci Rev 28:168–192. doi: 10.1177/0160017605275160

Alberti M (2008) Advances in Urban Ecology. Springer US, Boston, MA

Alig RJ, Plantinga AJ, Haim D, Todd M (2010) Area changes in US forests and other major land uses, 1982 to 2002, with projections to 2062. Portland, OR

American Trails (2016) The National Recreation Trail Database. http://www.americantrails.org/NRTDatabase/. Accessed 1 Jun 2016

Angold PG, Sadler JP, Hill MO, et al (2006) Biodiversity in urban habitat patches. Sci Total Environ 360:196–204. doi: 10.1016/j.scitotenv.2005.08.035

Arendt R (2004) Linked landscapes: Creating greenway corridors through conservation subdivision design strategies in the northeastern and central United States. Landsc Urban Plan 68:241–269. doi: 10.1016/S0169-2046(03)00157-9

Baer WC (1997) General Plan Evaluation Criteria: An Approach to Making Better Plans. J Am Plan Assoc 63:329–344. doi: 10.1080/01944369708975926

Baker LA, Brazel AJ, Selover N, et al (2002) Urbanization and warming of Phoeniz (Arizona, USA): Impacts, feedbacks and mitigation. Urban Ecosyst 6:183–203

Barbour MG, Burk JH, Pitts WD, Gilliam FS (1998) Terrestrial Plan Ecology, 3rd edn. Benjamin/Cummings Publishing Company, Menlo Park, CA

Baschak LA, Brown RD (1995) An ecological framework for the planning, design and management of urban river greenways. Landsc Urban Plan 33:211–225. doi: 10.1016/0169-2046(94)02019-C

Batha V, Otawa T (2013) Incorporating Wildlife Conservation within Local Land Use Planning and Zoning: Ability of Circuitscape to Model Conservation Corridors. In: Fabos JG, Lindhut M, Ryan RL, Jacknin M (eds) Proceedings of Fábos Conference on Landscape and Greenway Planning 2013:Pathways to Sustainability. Department of Landscape Architecture and Regional Planning, Amherst, MA, pp 161–174

Beck T (2013) Principles of Ecological Landscape Design. Island Press, Washington, DC

Beier P, Noss RF (1998) Do habitat corridors provide connectivity? Conserv Biol 12:1241–1252. doi: 10.1111/j.1523-1739.1998.98036.x

Beninde J, Veith M, Hochkirch A (2015) Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. Ecol Lett 18:581–592. doi: 10.1111/ele.12427

Berke P, Godschalk D (2009) Searching for the Good Plan: A Meta-Analysis of Plan Quality Studies. J Plan Lit 23:227–240. doi: 10.1177/0885412208327014

Bierwagen BG (2007) Connectivity in urbanizing landscapes: The importance of habitat configuration, urban area size, and dispersal. Urban Ecosyst 10:29–42. doi: 10.1007/s11252-006-0011-6

Blood A, Starr G, Escobedo F, et al (2016) How do urban forests compare? Tree diversity in urban and periurban forests of the southeastern US. Forests 7:1–15. doi: 10.3390/f7060120

Bond M (2003) Principles of Wildlife Corridor Design. Center for Biological Diversity, Tuscon, AZ

Bonthoux S, Brun M, Di Pietro F, et al (2014) How can wastelands promote biodiversity in cities? A review. Landsc Urban Plan 132:79–88. doi: 10.1016/j.landurbplan.2014.08.010

Boone CG, Cadenasso ML, Grove JM, et al (2010) Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: Why the 60s matter. Urban Ecosyst 13:255–271. doi: 10.1007/s11252-009-0118-7

Booth BD, Murphy SD, Swanton CJ (2003) Weed Ecology in Natural and Agricultural Systems. CABI Publishing, Cambridge, MA

Botequilha Leitão A, Ahern J (2002) Applying landscape ecological concepts and metrics in sustainable landscape planning. Landsc Urban Plan 59:65–93. doi: 10.1016/S0169-2046(02)00005-1

Brody SD, Highfield WE (2005) Does Planning Work? Testing the implementation of local environmental planning in Florida. J Am Plan Assoc 7:159–175

Bryant MM (2006) Urban landscape conservation and the role of ecological greenways at local and metropolitan scales. Landsc Urban Plan 76:23–44. doi: 10.1016/j.landurbplan.2004.09.029

Burnham KP, Anderson DR (2004) Multimodel inference: Understanding AIC and BIC in model selection. Sociol Methods Res 33:261–304. doi: 10.1177/0049124104268644

Calabrese JM, Fagan WF (2004) A comparison-shopper's guide to connectivity metrics. Front Ecol Environ 2:529–536

Chetkiewicz C-LB, St. Clair CC, Boyce MS (2006) Corridors for Conservation: Integrating Pattern and Process. Annu Rev Ecol Evol Syst 37:317–342. doi: 10.1146/annurev.ecolsys.37.091305.110050

Chetkiewicz CLB, Boyce MS (2009) Use of resource selection functions to identify conservation corridors. J Appl Ecol 46:1036–1047. doi: 10.1111/j.1365-2664.2009.01686.x

Christen D, Matlack G (2006) The role of roadsides in plant invasions: A demographic approach. Conserv Biol 20:385–391. doi: 10.1111/j.1523-1739.2006.00315.x

City of Raleigh Parks Recreation and Cultural Resources Department (2015) Capital Area Greenway Planning & Design Guide. Raleigh, NC

Conroy MM, Berke PR (2004) What makes a good sustainable development plan? An analysis of factors that influence principles of sustainable development. Environ Plan A 36:1381–1396. doi: 10.1068/a367

Conway TM, Bourne KS (2013) A comparison of neighborhood characteristics related to canopy cover, stem density and species richness in an urban forest. Landsc Urban Plan 113:10–18. doi: 10.1016/j.landurbplan.2013.01.005

Cook EA (1991) Urban landscape networks: An ecological planning framework. Landsc Res 16:7–15

Cowell CM (1995) Presettlement piedmont forests: patterns of composition and disturbance in central Georgia. Ann Assoc Am Geogr 85:65–83

Cowett FD, Bassuk NL (2014) Statewide assessment of street trees in New York State, USA. Urban For Urban Green 13:213–220. doi: 10.1016/j.ufug.2014.02.001

Cutway HB, Ehrenfeld JG (2012) The influence of urban land use on seed dispersal and wetland invasibility. Plant Ecol 210:153–167

Davis AM, Glick TF (1987) Urban ecosystems and island biogeography. Environ Conserv 5:299–304

Debinski DM, Holt RD (2000) A survey and overview of habitat fragmentation experiments. Conserv Biol 14:342–355. doi: 10.1046/j.1523-1739.2000.98081.x

Department of City Planning (2018a) City of Raleigh Data Book 2017. Raleigh, NC

Department of City Planning (2018b) Part 10A : Unified Development Ordinance. Raleigh, NC

Department of City Planning (2012) Raleigh Zoning Handbook. Raleigh, NC

Dobbs C, Kendal D, Nitschke C (2013) The effects of land tenure and land use on the urban forest structure and composition of Melbourne. Urban For Urban Green 12:417–425. doi: 10.1016/j.ufug.2013.06.006

Doerr VAJ, Barrett T, Doerr ED (2011) Connectivity, dispersal behaviour and conservation under climate change: A response to Hodgson et al. J Appl Ecol 48:143–147. doi: 10.1111/j.1365-2664.2010.01899.x

Douglas I (2011) Suburban mosaic of houses, roads, gardens and mature trees. In: Douglas I, Goode D, Houck MC, Wang R (eds) The Routledge Handbook of Urban Ecology. Routledge, New York

Dufrêne M, Legendre P (1997) Species assemblages and indicator species: The need for a flexible asymmetrical approach. Ecol Monogr 67:345–366. doi: 10.2307/2963459

Esri (2017) Canvas Base. Redlands, California

Fabos JG (1996) The greenway movement: uses and potentialities of greenway. In: Fabos JG, Ahern J (eds) Greenways: The Beginning of an International Movement. Elsevier Science, Amsterdam, pp 1–13

Fabos JG (1995) Introduction and overview: the greenway movement, uses and potentials of greenways. Landsc Urban Plan 33:1–13. doi: 10.1016/0169-2046(95)02035-R

Faith DP, Minchin PR, Belbin L (1987) Compsitional dissimilarity as a robust measure of ecogical distance. Vegetatio 69:57–68. doi: 10.1007/bf00038687

Federal Emergency Management Agency (2016) National Flood Hazard Layer (NFHL). In: FEMA, Flood Map Serv. Cent. https://msc.fema.gov. Accessed 12 Apr 2017

Firehock K (2015) Evaluating and conserving green infrastructure across the landscape: A practitioner’s Guide. The Green Infrastructure Center Inc., Charlottesville, VA

Fleiss JL (1986) The Design and Analysis of Clinical Experiments. John Wiley & Sons, Inc, New York, NY

Flink C, Olka K, Searns R, Rails-to-Trails Conservancy (2001) Trails for the Twenty-First Century, 2nd ed. Island Press, Washington, DC

Flory SL, Clay K (2009) Effects of roads and forest successional age on experimental plant invasions. Biol Conserv 142:2531–2537. doi: 10.1016/j.biocon.2009.05.024

Flory SL, Clay K (2010) Non-native grass invasion alters native plant composition in experimental communities. Biol Invasions 12:1285–1294. doi: 10.1007/s10530-009-9546-9

Flournoy WL (1976) Capital City Greenway. Raleigh, NC

Forman RTT, Sperling D, Bissonette JA, et al (2003) Road ecology: Science and solutions. Island Press, Washington, DC

Fox J, Weisberg S (2011) An {R} Companion to Applied Regression, Second Edition. Sage, Thousand Oaks, CA

Franklin SB, Kupfer JA, Pezeshki SR, et al (2009) Complex effects of channelization and levee construction on western Tennessee floodplain forest function. Wetlands 29:451–464. doi: 10.1672/08-59.1

Gabriel N (2011) The work that parks do: towards an urban environmentality. Soc Cult Geogr 12:123–141. doi: 10.1080/14649365.2011.545139

Gamer M, Lemon J, Fellows I, Singh P (2012) Various Coefficients of Interrater Reliability and Agreement

Gaston KJ, Ávila-Jiménez ML, Edmondson JL (2013) Managing urban ecosystems for goods and services. J Appl Ecol 50:830–840. doi: 10.1111/1365-2664.12087

Gehrt SD, Chelsvig JE (2003) Bat activity in an urban landscape: Patterns at the landscape and microhabitat scale. Ecol Appl 13:939–950

Gilbert-Norton L, Wilson R, Stevens JR, Beard KH (2010) A Meta-analytic review of corridor effectiveness. Conserv Biol 24:660–668. doi: 10.1111/j.1523-1739.2010.01450.x

Gobster PH, Westphal LM (2004) The human dimensions of urban greenways: Planning for recreation and related experiences. Landsc Urban Plan 68:147–165. doi: 10.1016/S0169-2046(03)00162-2

Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. Ecol Econ 86:235–245. doi: 10.1016/j.ecolecon.2012.08.019

Gong C, Chen J, Yu S (2013) Biotic homogenization and differentiation of the flora in artificial and near-natural habitats across urban green spaces. Landsc Urban Plan 120:158–169

Goode D (2015) Biodiversity as a statutory component of urban planning. In: Douglas I, Goode D, Houck MC, Wang R (eds) The Routledge Handbook of Urban Ecology. Routledge, New York, pp 621–629

Grimm NB, Faeth SH, Golubiewski NE, et al (2008) Global change and the ecology of cities. Science (80-) 319:756–760. doi: 10.1126/science.1150195

Guisan A, Edwards Jr TC, Hastie T (2002) Generalized linear and generalized additive models in studies of species distributions: setting the scene. Ecol Modell 157:89–100. doi: http://dx.doi.org/10.1016/S0304-3800(02)00204-1

Hansen AJ, DeFries R (2007) Ecological Mechanisms Linking Protected Areas to Surrounding Lands. Ecol Appl 17:974–988. doi: http://dx.doi.org/10.1890/05-1098

Harper KA, Macdonald SE, Burton PJ, et al (2005) Edge influence on forest structure and composition in fragmented landscapes. Conserv Biol 19:768–782. doi: 10.1111/j.1523-1739.2005.00045.x

Hart JL, Kupfer JA (2011) Sapling richness and composition in canopy gaps of a southern Appalachian mixed Quercus forest. J Torrey Bot Soc 138:207–219

Hellmund PC, Smith DS (2006) Designing Greenways. Island Press, Washington, DC

Hess GR (1994) Conservation corridors and contagious-disease - a cautionary note. Conserv Biol 8:256–262. doi: 10.1046/j.1523-1739.1994.08010256.x

Hess GR, Fischer RA (2001) Communicating clearly about conservation corridors. Landsc Urban Plan 55:195–208. doi: 10.1016/S0169-2046(01)00155-4

Hobbs RJ (2002) Habitat networks and biological conservation. In: Gutzwiller KJ (ed) Appplying landscape ecology in biological conservation. Springer-Verlag, New York, pp 150–170

Holling CS (1978) Adaptive Environmental Assessment and Management. John Wiley & Sons, New York, NY

Ignatieva M, Stewart GH, Meurk C (2011) Planning and design of ecological networks in urban areas. Landsc Ecol Eng 7:17–25. doi: 10.1007/s11355-010-0143-y

Jaenson R, Bassuk S, Schwager S, Headley D (1992) A Statistical method for the accurate and rapid sampling of urban street tree populations. J Arboric 18:171–183

Jin S, Yang L, Danielson P, et al (2013) A comprehensive change detection method for updating the National Land Cover Database to circa 2011. Remote Sens Environ 132:159–175. doi: 10.1016/j.rse.2013.01.012

Jo HK, Ahn TW (2014) Application of natural forest structures to riparian greenways. Paddy Water Environ 12:99–111. doi: 10.1007/s10333-014-0431-5

Johnson DH (2001) Habitat fragmentation effects on birds in grasslands and wetlands: a critique of our knowledge. Gt Plains Res 11:211–231

Jongman RHG (2004) The context and concept of ecological networks. In: Jongman RHG, Pungetti G (eds) Ecological Networks and Greenways: Concept, design, implementation. Cambridge University Press, New York, NY, pp 7–33

Jongman RHG, Külvik M, Kristiansen I (2004) European ecological networks and greenways. Landsc Urban Plan 68:305–319. doi: 10.1016/S0169-2046(03)00163-4

Kattwinkel M, Biedermann R, Kleyer M (2011) Temporary conservation for urban biodiversity. Biol Conserv 144:2335–2343

Kupfer JA, Franklin SB (2009) Linking spatial pattern and ecological responses in human-modified landscapes: The effects of deforestation and forest fragmentation on biodiversity. Geogr Compass 3:1331–1355. doi: 10.1111/j.1749-8198.2009.00245.x

Kupfer JA, Malanson GP, Franklin SB (2006) Not seeing the ocean for the islands: the mediating influence of matrix-based processes on forest fragmentation effects. Glob Ecol Biogeogr 15:8–20. doi: 10.1111/j.1466-822X.2006.00204.x

Kupfer JA, Runkle JR (2003) Edge-Mediated Effects on Stand Dynamic Processes in Forest Interiors: A Coupled Field and Simulation Approach. Oikos 101:135–146

Kuttler W (2008) The urban climate: Basic and applied aspects. In: Marzluff JM, Schulenberger E, Endlicher W, et al. (eds) Urban Ecology: An international perspective on the interaction between humans and nature. Springer, New York, NY, pp 233–248

LaPaix R, Harper K, Freedman B (2012) Patterns of exotic plants in relation to anthropogenic edges within urban forest remnants. Appl Veg Sci 15:525–535. doi: 10.1111/j.1654-109X.2012.01195.x

Lee ACK, Maheswaran R (2011) The health benefits of urban green spaces: a review of the evidence. J Public Health (Bangkok) 33:212–222. doi: 10.1093/pubmed/fdq068

Legendre P, Legendre L (2012) Numerical Ecology, 3rd edn. Elsevier B.V., Oxford, UK

Lepczyk CA, Aronson MFJ, Evans KL, et al (2017) Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. Bioscience 67:799–807. doi: 10.1093/biosci/bix079

Linehan J, Gross M, Finn J (1995) Greenway planning: developing a landscape ecological network approach. Landsc Urban Plan 33:179–193. doi: 10.1016/0169-2046(94)02017-A

Little CE (1990) Greenways for America. The Johns Hopkins University Press, Baltimore

MacArthur RH, Wilson EO (1967) The Theory of Island Biogeography. Princeton University Press, Princeton, NJ

Maco SE, McPherson EG (2003) A Practictal Approach to Assessing Structure, Function, and Value of Street Tree Populations in Small Communities. J Arboric 29:84–97

Margerum RD (2008) A typology of collaboration efforts in environmental management. Environ Manage 41:487–500. doi: 10.1007/s00267-008-9067-9

Martin WH, Boyce SG, Echternacht AC (eds) (1993) Biodiversity of the Southeastern United States: Upland Terrestrial Communities. Wiley, New York, NY

Mason J, Moorman C, Hess G, Sinclair K (2007) Designing suburban greenways to provide habitat for forest-breeding birds. Landsc Urban Plan 80:153–164. doi: 10.1016/j.landurbplan.2006.07.002

McAvoy TJ, Snyder AL, Johnson N, et al (2012) Road survey of the Invasive Tree-of-heaven (Ailanthus altissima) in Virginia. Invasive Plant Sci Manag 5:506–512. doi: 10.1614/IPSM-D-12-00039.1

McCune B, Grace JB (2002) Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR

McCune B, Mefford MJ (2015) PC-ORD. MjM Software, Gleneden Beach, OR

McDonald RI, Urban DL (2006) Edge effects on species composition and exotic species abundance in the North Carolina Piedmont. Biol Invasions 8:1049–1060. doi: 10.1007/s10530-005-5227-5

McKinney ML (2008) Effects of Urbanization on Species Richness: A review of plants and animals. Urban Ecosyst 11:161–176

McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127:247–260. doi: 10.1016/j.biocon.2005.09.005

McKinney ML (2002) Do human activites raise species richness? Contrasting patterns in United States plants and fishes. Glob Ecol Biogeogr 11:343–348

McPherson EG, Simpson JR (2003) Potential energy savings in buildings by an urban tree planting programme in California. Urban For Urban Green 2:73–86

Millennium Ecosystem Assessment Board (2005) Introduction and Conceptual Framework. In: Ecosystems and Human Well-being. Island Press, Washington, DC

Minor ES, Urban DL (2008) A graph-theory framework for evaluating landscape connectivity and conservation planning. Conserv Biol 22:297–307. doi: 10.1111/j.1523-1739.2007.00871.x

Myers DN (2013) Green infrastructure, greenways, and trail planning. In: Fabos JG, Lindhult M, Ryan RL, Jacknin M (eds) Proceedings of Fabos Conference on Landscape and Greenway Planning. Department of Landscape Architecture and Regional Planning, Amherst, MA, pp 145–151

Nagy RC, Lockaby BG, Helms B, et al (2011) Water resources and land use and cover in a humid region: the Southeastern United States. J Environ Qual 40:867–78. doi: 10.2134/jeq2010.0365

National Register of Historic Places (2009) Post-World War II and Modern Architecture in Raleigh, North Carolina, 1945-1965. United States Department of the Interior, National Park Service

Neil K, Wu J (2006) Effects of urbanization on plant flowering phenology: A review. Urban Ecosyst 9:243–257

Newton AC, Echeverria C, Gonzales-Espinosa M, et al (2007) Testing Forest Biodiversity Indicators by Assessing Anthropogenic Impacts Along Disturbance Gradients. In: Newton AC (ed) Biodiversity Loss and Conservation in Fragmented Forest Landscapes: The Forests of Montane Mexico and Temperate South America. CAB International, Cambridge, MA, pp 276–290

Niemelä J (2014) Ecology of urban green spaces: The way forward in answering major research questions. Landsc Urban Plan 125:298–303. doi: 10.1016/j.landurbplan.2013.07.014

Niemelä J, Saarela S-RR, Söderman T, et al (2010) Using the ecosystem services approach for better planning and conservation of urban green spaces: A Finland case study. Biodivers Conserv 19:3225–3243. doi: 10.1007/s10531-010-9888-8

Nitoslawski SA, Duinker PN, Bush PG (2016) A review of drivers of tree diversity in suburban areas: Research needs for North American cities. Environ Rev 24:471–483. doi: 10.1139/er-2016-0027

North Carolina Department of Environment and Natural Resources (2013) The North Carolina Conservation Planning Tool. Raleigh, NC

North Carolina Geodedic Survey (2016) North Carolina State and County Boundary with Shoreline. North Carolina Geodedic Survey, Raleigh, NC

Noss RF (1987) Corridors in Real Landscapes: A Reply to Simberloff and Cox. Conserv Biol 1:159–164

O'Driscoll M, Clinton S, Jefferson A, et al (2010) Urbanization Effects on Watershed Hydrology and In-Stream Processes in the Southern United States. Water 2:605–648. doi: 10.3390/w2030605

Oke TR (1982) The energetic basis of the urban heat island. Q J R Meteorol Soc 108:1–24

Olden JD (2008) Biotic Homogenization. Encycl Life Sci 1–5. doi: 10.1002/9780470015902.a0020471

Opdam P (2002) Assessing the Conservation Potential of Habitat Networks. In: Gutzwiller K (ed) Applying Landscape Ecology in Biological Conservation. Springer-Verlag, New York, pp 381–404

Opdam P, Wascher D (2004) Climate change meets habitat fragmentation: Linking landscape and biogeographical scale levels in research and conservation. Biol Conserv 117:285–297. doi: 10.1016/j.biocon.2003.12.008

Ordonez JC, Luedeling E, Kindt R, et al (2014) Constraints and opportunities for tree diversity management along the forest transition curve to achieve multifunctional agriculture. Curr Opin Environ Sustain 6:54–60. doi: 10.1016/j.cosust.2013.10.009

Orland B, Murtha T (2013) Here Comes the Boom: shale gas, landscapes and an ecological planning imperative. In: Fabos JG, Lindhult MS, Jacknin M (eds) Proceedings of Fábos Conference on Landscape and Greenway Planning 2013: Pathways to Sustainability. Department of Landscape Architecture and Regional Planning, University of Massachusetts, Amherst, MA, pp 91–99

Peck JE (2016) Multivariate Analysis for Ecologists: Step-by-Step, Second. MjM Software Design, Gleneden Beach, OR

Peters G (2016) userfriendlyscience: Quantitative analysis made accessible. R package version 0.5-2

Pickett STA, Cadenasso ML (2008) Linking ecological and built components of urban mosaics: An open cycle of ecological design. J Ecol 96:8–12. doi: 10.1111/j.1365-2745.2007.01310.x

Pino J, Marull J (2012) Ecological networks: Are they enough for connectivity conservation? A case study in the Barcelona Metropolitan Region (NE Spain). Land use policy 29:684–690. doi: 10.1016/j.landusepol.2011.11.004

Pirnat J (2000) Conservation and management of forest patches and corridors in suburban landscapes. Landsc Urban Plan 52:135–143. doi: 10.1016/S0169-2046(00)00128-6

Pugh TAM, MacKenzie AR, Whyatt JD, Hewitt CN (2012) Effectiveness of Green Infrastructure for Improvement of Air Quality in Urban Street Canyons. Environ Sci Technol 46:7692–7699

R Development Core Team (2008) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Radeloff VC, Hammer RB, Stewart SI, et al (2014) The Wildland-Urban Interface in the United States. Ecol Appl 15:799–805

Rails-to-Trails Conservancy (2016) TrailLink. http://www.traillink.com/. Accessed 2 Jun 2016

Rentch JS, Fortney RH, Stephenson SL, et al (2005) Vegetation-site relationships of roadside plant communities in West Virginia, USA. J Appl Ecol 42:129–138. doi: 10.1111/j.1365-2664.2004.00993.x

Rheinhardt R, Wilder T, Williams H, et al (2013) Variation in Forest Canopy Composition of Riparian Networks from Headwaters to Large River Floodplains in the Southeast Coastal Plain, USA. Wetlands 33:1117–1126. doi: 10.1007/s13157-013-0467-0

Ribeiro L, Barão T (2006) Greenways for recreation and maintenance of landscape quality: five case studies in Portugal. Landsc Urban Plan 76:79–97. doi: 10.1016/j.landurbplan.2004.09.042

Ross HP (1992) Raleigh Comprehensive Architectural Survey Final Report. Raleigh Historic Development Commission, Raleigh, NC

Saunders DA, Hobbs RJ, Margules CR (1991) Biological consequences of ecosystem fragmentation: A review. Biol Conserv 5:18–32. doi: 10.1016/0006-3207(92)90725-3

Sawka M, Millward AA, Mckay J, Sarkovich M (2013) Growing summer energy conservation through residential tree planting. Landsc Urban Plan 113:1–9. doi: 10.1016/j.landurbplan.2013.01.006

Schiappacasse P, Müller B (2015) Planning green infrastructure as a source of urban and regional resilience - towards institutional challenges. Urbani Izziv 26:S13–S24. doi: 10.5379/urbani-izziv-en-2015-26-supplement-001

Schmid JA (1975) Urban Vegetation: A review and Chicago case study. Chicago, IL

Schueler T (1995) The Architecture of Stream Buffers. Watershed Prot Tech 1:155–163

Searns RM (1995) The evolution of greenways as an adaptive urban landscape form. Landsc Urban Plan 33:65–80. doi: 10.1016/0169-2046(94)02014-7

Semlitsch RD, Bodie JR (2003) Biological Criteria for Buffer Zones around Wetlands and Riparian Habitats for Amphibians and Reptiles. Conserv Biol 17:1219–1228. doi: 10.1046/j.1523-1739.2003.02177.x

Shwartz A, Turbé A, Julliard R, et al (2014) Outstanding challenges for urban conservation research and action. Glob Environ Chang 28:39–49. doi: 10.1016/j.gloenvcha.2014.06.002

Siderhurst L a., Griscom HP, Kyger C, et al (2012) Tree Species Composition and Diversity and the Abundance of Exotics in Forest Fragments of the Shenandoah Valley, Virginia. Castanea 77:348–363. doi: 10.2179/11-021

Skultety D, Matthews JW (2017) Urbanization and roads drive non-native plant invasion in the Chicago Metropolitan region. Biol Invasions 19:1–14. doi: 10.1007/s10530-017-1464-7

Smart SM, Thompson K, Marrs RH, et al (2006) Biotic homogenization and changes in species diversity across human-modified ecosystems. Proc R Soc 273:2659–2665. doi: 10.1098/rspb.2006.3630

Soares AL, Rego FC, McPherson EG, et al (2011) Urban Forestry & Urban Greening Benefits and costs of street trees in Lisbon , Portugal. Urban For Urban Green 10:69–78. doi: 10.1016/j.ufug.2010.12.001

Southside Richmond Rail-Trail Project Team, James River Branch Rail-Trail Citizens Advisory Committee (2010) James River Branch Rail-Trail Concept Plan. Richmond, VA

Stankey GH, Clark RN, Bormann BT (2005) Adaptive management of natural resources: theory, concepts, and management institutions. Gen. Tech. Rep. PNW-GTR-654. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR

Teng M, Wu C, Zhou Z, et al (2011) Multipurpose greenway planning for changing cities: A framework integrating priorities and a least-cost path model. Landsc Urban Plan 103:1–14. doi: 10.1016/j.landurbplan.2011.05.007

Terando AJ, Costanza J, Belyea C, et al (2014) The southern megalopolis: Using the past to predict the future of urban sprawl in the Southeast U.S. PLoS One 9:. doi: 10.1371/journal.pone.0102261

Theobald DM, Crooks KR, Norman JB (2011) Assessing effects of land use on landscape connectivity: Loss and fragmentation of western U.S. forests. Ecol Appl 21:2445–2458. doi: 10.1890/10-1701.1

Thomas G (2014) Improving restoration practice by deriving appropriate techniques from analysing the spatial organization of river networks. Limnologica 45:50–60. doi: 10.1016/j.limno.2013.10.003

Tillmann JE (2005) Habitat fragmentation and ecological networks in Europe. Gaia 14:119–123. doi: 10.14512/gaia.14.2.11

Trammell TLE, Schneid BP, Carreiro MM (2011) Forest soils adjacent to urban interstates : Soil physical and chemical properties , heavy metals , disturbance legacies , and relationships with woody vegetation. Urban Ecosyst 14:525–552. doi: 10.1007/s11252-011-0194-3

Troy AR, Grove JM, O'Neil-Dunne JPM, et al (2007) Predicting opportunities for greening and patterns of vegetation on private urban lands. Environ Manage 40:394–412. doi: 10.1007/s00267-006-0112-2

U.S. Census Bureau (2015) 2015 TIGER/Line Shapefiles. https://www.census.gov/geo/maps-data/data/tiger-geodatabases.html. Accessed 10 Apr 2017

U.S. Geological Survey (2017) USGS Blue Line Streams. In: NCDENR Water Resour. http://www.wakegov.com/gis/services/Pages/default.aspx. Accessed 12 Apr 2017

United Nations Population Division (2018) World Urbanization Prospects: The 2018 Revision. United Nations Population Division, New York, NY

USDA NRCS (2017) The PLANTS Database. http://plants.usda.gov. Accessed 19 Sep 2017

Valtanen M, Sillanpää N, Setälä H (2014) The effects of urbanization on runoff pollutant concentrations, loadings and their seasonal patterns under cold climate. Water Air Soil Pollut 225:. doi: 10.1007/s11270-014-1977-y

van Kamp I, Leidelmeijer K, Marsman G, de Hollander A (2003) Urban environmental quality and human well-being. Landsc Urban Plan 65:5–18. doi: 10.1016/S0169-2046(02)00232-3

Viles RL, Rosier DJ (2001) How to use roads in the creation of greenways: Case studies in three New Zealand landscapes. Landsc Urban Plan 55:15–27. doi: 10.1016/S0169-2046(00)00144-4

Wake County GIS (2017) Geographic Information Map Services. http://www.wakegov.com/gis/services/Pages/default.aspx. Accessed 1 Sep 2017

Walsh CJ, Roy AH, Feminella JW, et al (2005) The urban stream syndrome: current knowledge and the search for a cure. J North Am Benthol Soc 24:706–723. doi: 10.1899/0887-3593(2005)024\[0706:TUSSCK\]2.0.CO;2

White SS, Ellis C (2007) Sustainability, the Environment, and New Urbanism: An Assessment and Agenda for Research. J Archit Plann Res 24:125–142

Wiken E, Nava FJ, Griffith G (2011) North American Terrestrial Ecoregions—Level III. Commission for Environmental Cooperation, Montreal, Canada

Woodruff SC, BenDor TK (2016) Ecosystem services in urban planning: Comparative paradigms and guidelines for high quality plans. Landsc Urban Plan 152:90–100. doi: 10.1016/j.landurbplan.2016.04.003

Wu J (2014) Urban ecology and sustainability: The state-of-the-science and future directions. Landsc Urban Plan 125:209–221. doi: 10.1016/j.landurbplan.2014.01.018

Wu J (2008) Making the Case for Landscape Ecology. Landsc J 27:41–50. doi: 10.3368/lj.27.1.41

Xian G, Homer C, Dewitz J, et al (2011) The change of impervious surface area between 2001 and 2006 in the conterminous United States. Photogramm Eng Remote Sensing 77:754–762

Yang J, McBride J, Zhou J, Sun Z (2005) The urban forest in Beijing and its role in air pollution reduction. Urban For Urban Green 3:65–78

APPENDIX A: LIST OF 23 CENSUS URBAN AREAS REPRESENTED IN THIS STUDY

A total of 29 greenway planning documents from six states were coded. Planning scales of documents ranged from city, county, and regional levels.

Plan Location	Plan Title	Published
Washington, DC	Priorities 2000 Metropolitan Washington Greenways	2000
Athens-Clarke County, GA	Greenway Network Plan	2003
Atlanta, GA	Atlanta Beltline 2030 Strategic Implementation Plan	2013
Chattahoochee Wildlife Management Area, GA	Chattahoochee River Greenway Planning and Implementation Handbook	2000
Charles County, MD	Charles County Bicycle & Pedestrian Master Plan	2012
Alamance County, NC	Alamance County Trails Plan	2014
Union County, NC	Carolina Thread Trail Master Plan for Union County and Participating Municipalities	2011

Mecklenburg County, NC	Greenway Plan Update 2008	2008
Iredell County, NC	Carolina Thread Trail Master Plan for Iredell County Communities	2011
Rowan County, NC	Carolina Thread Trail Master Plan for Rowan County Communities	2015
Cabarrus County, NC	Carolina Thread Trail Master Plan for Cabarrus County Communities	2009
Durham, NC	Durham Trails and Greenways Master Plan	2011
Gaston County, NC	Carolina Thread Trail Master Plan for Gaston County Communities	2009
Greensboro, NC	Greensboro Urban Area Bicycle, Pedestrian and Greenway Master Plan	2006
Catawba County, NC	Carolina Thread Trail Master Plan for Catawba County Communities	2010
Hickory, NC	Sidewalk, Bikeway, Greenway, and Trail Master Plan	2005
High Point, NC	High Point Pedestrian Bikeway, Greenway, and Trails Master Plan	2010
Raleigh, NC	Capital Area Greenway Planning and Design Guide	2014
Winston-Salem and Forsyth County, NC	Greenway Plan	2015
Anderson, SC	Downtown Bicycle and Pedestrian Connectivity Plan	2014
Columbia, SC	Rocky Branch Greenway Master Plan	2016
Greenville County, SC	Comprehensive Greenway Plan	2010
Rock Hill, SC	Trails and Greenways Master Plan Update	2008

York County, SC	Carolina Thread Trail Master Plan for York County Communities	2009
Spartanburg, SC	Spartanburg Trails and Greenways Plan	2013
Fredericksburg, VA	Fredericksburg Pathways, A Bicycle and Pedestrian Master Plan	2006
City of Roanoke, Roanoke County, City of Salem, and Town of Vinton, VA	2007 Update to the Roanoke Valley Conceptual Greenway Plan	2007
Amherst, Appomattox, Bedford & Campbell Counties, Bedford and Lynchburg, VA	Region 2000 Greenways and Blueways Plan	2003
Richmond, VA	James River Branch River-Trail Concept Plan, A Vision for Southside Richmond	2010

Appendix B: Original Assessment Rubric of Major Greenway Functions Used to Code Plans

The following is the data dictionary of functions used in the rubric. Functions were scored using the following criteria: absence of discussion (0 points), general suggestion or broad overview of the function (1 point), or in-depth discussion or specific guidance provided to achieve the greenway function (2 points). Guidelines provided represented criteria needed for a full rubric score of 2 points out of 2.

Greenway Function	Guidelines for full score
Biodiversity (Ecological)	
Conserve open space	Greenway space will be conserved and remain undeveloped
Habitat conservation / management	Natural habitats for plants and/or animals protected or enhanced
Invasive species	Invasive plants and/or animals will be removed or efforts made to minimize dispersal
Manage for biodiversity	Design or management to maintain or increase plant and animal diversity

	Multiple habitat types	At least two different types of environments along the greenway
	Native plant conservation	Existing native plant communities are managed, or native species will be planted along the greenway
	Reduce habitat fragmentation	Connections between plant/animal habitats are maintained or increased
	Sensitive / significant environments	Protected habitats (e.g. wetlands, floodplains) or other ecologically significant habitats will be conserved or managed
	Species monitoring	Plant and/or animal populations along the greenway will be inventoried or monitored over time
	Vegetated buffers	Vegetation (e.g. trees or shrubs) is used as a boundary between the greenway and adjacent roads or streams, or is used to manage runoff
	Wildlife conservation	Animal species living or migrating along the greenway are protected
	Wildlife corridors	Specific designs features aiding movement or migration of wildlife
Regulating Services (Environmental)		
	Air quality	Improves air quality, reduces particulates or other pollutants
	Carbon sequestration	Carbon dioxide is captured and stored by greenway vegetation
	Flood / erosion control	Physical structure or policy used to manage flooding or erosion
	Minimize construction impacts	Physical structure or policy minimizing impacts during construction

	Minimize disturbance	Policy or procedure minimizing disturbances to habitats, includes visitor management policies and trail maintenance programs
	Non-structural BMP	Policy or procedure designed to reduce water pollution
	Reduce carbon emissions	Greenway facilitates practices to reduce carbon emissions (e.g. encourages non-motorized transportation)
	Stormwater management	Use of an engineered system to manage or treat runoff & stormwater, not including vegetated structures
	Vegetated BMP	Integration of vegetation in physical structures to manage runoff or stormwater (e.g. retention ponds, bioswales, Best Management Practices (BMPs))
	Water quality	Non-specific statement on improving water quality/reducing pollutants, not related to BMPs or other engineering approach
Community Development (Societal)		
	Beauty/scenery	Provides aesthetic value to the area
	Cultural heritage	Preservation of significant historic or cultural sites
	Economic development	Local community benefits economically from the presence or construction of greenway

Environmental education	Used for environmental or cultural education, including use of interpretive signage or outdoor classrooms
Improve mental health	Beneficial for user’s mental health (e.g. reduction in stress)
Improve physical health	Beneficial for user’s physical health (e.g. opportunity for exercise)
Property value	Property values surrounding greenway increase
Recreational opportunities	Provides a space for outdoor recreation and sports
Safe user environment	Policies/procedures used to maintain user's physical safety
Sense of place	Provides opportunity for social interaction or community events
Tourism	Serves as a thoroughfare for tourists or tourist attraction

Appendix C: Full List of Species Observed in the Capital Area Greenway

A '*' indicates the species is not native to the contiguous US. Relative density is calculated as the number of occurrences of species X divided by the total number of individuals; relative dominance is the total basal area of species X divided by the total basal area of all individuals. Values are expressed as a percentage and range from 0-100.

Scientific Name with Author	**USDA Species Code**	**Relative Density**	**Relative Dominance**
Acer negundo L.	ACNE2	1.40	0.46
Acer nigrum Michx. f.	ACNI5	4.55	3.50
Acer rubrum L.	ACRU	1.49	1.36
Acer saccharum Marshall	ACSA3	6.72	4.02
Aesculus pavia L.	AEPA	0.17	0.01
Ailanthus altissima (Mill.) Swingle*	AIAL	0.89	0.22
Albizia julibrissin Durazz.*	ALJU	0.51	0.11
Aralia spinosa L.	ARSP2	0.04	0.00
Arundinaria gigantea (Walter) Muhl.	ARGI	1.28	0.12
Asimina triloba (L.) Dunal	ASTR	0.38	0.07
Baccharis halimifolia L.	BAHA	2.85	4.18
Betula nigra L.	BENI	0.38	0.05

Broussonetia papyrifera (L.) L'Hér. ex Vent.*	BRPA4	0.21	0.07
Camellia japonica L.*	CAJA9	3.66	1.23
Carpinus caroliniana Walter	CACA18	0.26	0.20
Carya cordiformis (Wangenh.) K. Koch	CACO15	0.77	0.19
Carya glabra (Mill.) Sweet	CAGL8	0.09	0.04
Carya pallida (Ashe) Engl. & Graebn.	CATO24	3.44	2.89
Carya tomentosa (Lam.) Nutt.	CATO6	4.34	9.33
Celtis laevigata Willd.	CELA	1.23	0.18
Cercis canadensis L.	CECA4	0.72	0.05
Chamaecyparis thyoides (L.) Britton, Sterns & Poggenb.	CHTH2	1.66	0.17
Chionanthus virginicus L.	CHVI3	0.26	0.03
Cornus florida L.	COFL2	0.13	0.01
Crataegus phaenopyrum (L. f.) Medik.	CRPH	0.55	0.10
Diospyros virginiana L.	DIVI5	2.98	1.36
Elaeagnus umbellata Thunb.*	ELUM	2.98	6.47
Fagus grandifolia Ehrh.	FAGR	0.09	0.01
Fraxinus pennsylvanica Marshall	FRPE	0.13	0.00
Fraxinus profunda (Bush) Bush	FRPR	0.21	0.01
Halesia Ellis ex L.	HALES	0.04	0.00
Hamamelis virginiana L.	HAVI4	0.09	0.23
Ilex decidua Walter	ILDE	2.00	0.09
Ilex glabra (L.) A. Gray	ILGL	1.70	1.06

Ilex montana Torr. & A. Gray ex A. Gray	ILMO	1.36	0.80
Ilex opaca Aiton	ILOP	0.43	0.04
Juglans nigra L.	JUNI	4.51	0.50
Juniperus virginiana L.	JUVI	7.70	9.96
Lagerstroemia indica L.*	LAIN	5.14	7.55
Ligustrum sinense Lour.*	LISI	0.51	0.09
Liquidambar styraciflua L.	LIST2	0.21	0.01
Liriodendron tulipifera L.	LITU	0.34	0.06
Magnolia acuminata (L.) L.	MAAC	0.17	0.02
Magnolia grandiflora L.	MAGR4	0.30	0.14
Magnolia L.	MAGNO	0.26	0.09
Magnolia umbrella Desr.	MATR	0.04	0.00
Magnolia virginiana L.	MAVI2	0.30	0.11
Melia azedarach L.*	MEAZ	4.68	3.40
Morella caroliniensis (Mill.) Small	MOCA7	0.09	0.01
Morus rubra L.	MORU2	0.17	0.03
Nerium oleander L.*	NEOL	0.09	0.13
Nyssa sylvatica Marshall	NYSY	0.85	1.28
Ostrya virginiana (Mill.) K. Koch	OSVI	0.43	1.01
Oxydendrum arboreum (L.) DC.	OXAR	10.54	13.05
Paulownia tomentosa (Thunb.) Siebold & Zucc. ex Steud.*	PATO2	0.09	0.22
Persea borbonia (L.) Spreng.	PEBO	2.64	5.00
Pinus echinata Mill.	PIEC2	0.04	0.00
Pinus palustris Mill.	PIPA2	0.04	0.00

Pinus taeda L.	PITA	0.85	0.15
Platanus ×hispanica Mill. ex Münchh. [occidentalis × orientalis]*	PLHI	0.04	0.00
Platanus occidentalis L.	PLOC	0.21	0.01
Prunus angustifolia Marshall	PRAN3	0.85	1.25
Prunus caroliniana Aiton	PRCA	0.13	1.09
Prunus cerasus L.*	PRCE	0.04	0.00
Prunus serotina Ehrh.	PRSE2	0.13	0.05
Pyrus calleryana Decne.*	PYCA80	0.26	0.17
Pyrus communis L.*	PYCO	1.32	3.41
Quercus alba L.	QUAL	0.89	2.30
Quercus falcata Michx.	QUFA	0.85	5.27
Quercus laurifolia Michx.	QULA3	0.09	1.41
Quercus marilandica Münchh.	QUMA3	0.04	0.02
Quercus michauxii Nutt.	QUMI	0.04	0.00
Quercus nigra L.	QUNI	0.98	0.18
Quercus phellos L.	QUPH	0.34	0.07
Quercus rubra L.	QURU	0.09	0.00
Quercus stellata Wangenh.	QUST	0.17	0.01
Quercus virginiana Mill.	QUVI	0.04	0.00
Rhus copallinum L.	RHCO	0.34	0.01
Robinia pseudoacacia L.	ROPS	0.26	0.07
Salix nigra Marshall	SANI	0.21	0.02
Salvia greggii A. Gray	SAGR4	1.15	2.47
Sambucus nigra L.	SANI4	0.04	0.00
Sassafras albidum (Nutt.) Nees	SAAL5	0.26	0.01

Sideroxylon tenax L.	SITE2	0.51	0.62
Staphylea trifolia L.	STTR	0.04	0.00
Styrax grandifolius Aiton	STGR4	0.26	0.04
Taxodium distichum (L.) Rich.	TADI2	0.09	0.02
Tilia americana L. var. caroliniana (Mill.) Castigl.	TIAMC	0.04	0.01
Toxicodendron radicans (L.) Kuntze	TORA2	0.38	0.02
Ulmus alata Michx.	ULAL	1.40	0.46
Ulmus americana L.	ULAM	4.55	3.50
Ulmus rubra Muhl.	ULRU	1.49	1.36
Viburnum nudum L.	VINU	6.72	4.02
Viburnum prunifolium L.	VIPR	0.17	0.01
Viburnum rufidulum Raf.	VIRU	0.89	0.22
Vitis vulpina L.	VIVU	0.51	0.11

Appendix D: Letter of Permission to Conduct Research in the Capital Area Greenway

City Of Raleigh

NORTH CAROLINA

May 6, 2016

Erika Chin
South Carolina Applied Landscape Ecology Lab
Department of Geography
University of South Carolina

Dear Ms. Chin,

Thank you for your request to conduct a vegetation study along the Capital Area Greenway network.

On behalf of the Parks, Recreation and Cultural Resources Department (PRCR), I am pleased to confirm a favorable approval for the research on the basis described in the request and supporting documentation.

As understood, the study will take place along the Crabtree Cree, House Creek, Neuse River, Rocky Branch and Walnut Creek trails from now through October 2016. The objectives are to conduct a vegetation survey of tree and shrub species and model ecosystem services provided by these urban greenspaces using data collected from the field and secondary land use and climate data.

The approval is given provided that you comply with the conditions set out below.

- Submit a schedule that includes what will be occurring and when;
- Carry and provide contact information for you and your advisor while in the field should any greenway patrons wish to contact you;
- No items may be attached to trees along the greenway system;
- Vegetation may not be damaged and the greenway trail must not be impeded;
- Any tags and signage placed in the research field must be removed immediately upon completion of the study or by the end of October 2016;
- Provide PRCR a report of the completed work;
- Provide results presentation to Park Planning Committee;

- Proposed changes to approved project must be submitted for review and approval before any changes are implemented;

The Parks Recreation and Cultural Resources staff is looking forward to working with you on this project. Please contact me at (919) 996-6688 if you have any questions or concerns.

Sincerely,

Kathryn Hertel
Strategic Initiatives Manger
City of Raleigh Parks, Recreation and Cultural Resources Department

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Raleigh, North Carolina 27601

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