An Exploration of the Impact of Greenway Trail Development on Riparian Habitat

By

John F. McFadden, Ph.D. Candidate

A Dissertation Submitted to
the Faculty of the Graduate School at
Middle Tennessee State University
in Partial Fulfillment
of the Requirements for the Degree
Doctorate of Philosophy

Murfreesboro, TN
May 2009

APPROVAL PAGE

AN EXPLORATION OF THE IMPACT OF GREENWAY TRAIL DEVELOPMENT ON RIPARIAN HABITAT

March 20, 2009
Date of Final Defense

Tara L Perry
Dr. Tara Perry, Committee Chair

Dr. Mark Ivy, Committee Member

Paul Whitworth
Dr. Paul Whitworth, Committee Member

Frank C. Bailey
Dr. Frank Bailey, Committee Member

Dianne A. Bartley
Dr. Dianne A. Bartley, Health and Human Performance Department Chair

Michael D. Allen
Dr. Michael D. Allen, Dean of Graduate Studies

DEDICATION

I dedicate this project to the memory of my father, who taught me that I could do anything I set my mind to, and in honor of my mother, who, through her life of service, taught me that to gain much, one must give it all away. Finally, for my son, Elijah, that he and his generation might have a green and healthy future.

ACKNOWLEDGMENTS

Any project of this size and magnitude is never done alone and thus I wish to acknowledge the contributions of the following individuals. As well, I would suggest that it is not often that a PhD candidate has three committee chairs, but in my case that was what happened. And thankfully the third was the charm! She is first and foremost, Dr. Tara Perry, a recreation therapist who took on a project that apparently no one else could handle. She was a steady force through the thick of it all and kept me from quitting on numerous occasions and moving forward to the end. Her sense of humor was also of great advantage throughout the project. Without it, I am not sure what we would have done. Dr. Paul Whitworth's commitment to the project was greatly appreciated. His thorough, timely, consistent review and editing of the text were invaluable. His attention to detail, knowledge of the literature, and APA writing style was much appreciated. Dr. Mark Ivy's early direction and continued involvement throughout the project was very much valued, along with his willingness to discuss concepts while in line skating on the greenway. Dr. Frank Bailey's help with the tree species diversity sampling methods and review of the data spread sheets was also much needed and appreciated.

I would also like to thank Dr. Toto Sutarso for his help on designing the data analysis plan and Dr. Jennifer Caputo for her review of references and motivational emails. Thanks, also, to Joe Schibig, who consulted with me on several occasions as to how I might go about comparing the greenway's tree data to the data he had collected at Radnor Lake. Tiago Barreira is acknowledged for his help in data analysis and interpretation. Finally, Kami Bruner is acknowledged for her help in the field. Without the help of the aforementioned people, the project would not have happened.

ABSTRACT

McFadden, John F. Ph.D. An Exploration of the Impact of Greenway Trail Development on Riparian Habitat
Directed by Dr. Tara Perry

Greenways are linear parks generally designed and managed to support recreation and conservation. Ahern's (2004) greenway theory includes three hypotheses: co-occurrence of resources, inherent benefits of connectivity, and the compatibility of uses. The compatibility of recreation and conservation uses was the foundation for the current study. The primary purpose of this study was to investigate the effects of greenway development through an examination of trail footprint width (at 8, 10 and 12 ft widths plus their respective mowed areas), trail age, and surface type on percent canopy cover and surface temperature; the secondary purpose was to explore biodiversity through a comparison of tree species diversity for the greenway and a pristine natural area. Two greenways in Middle Tennessee were utilized to achieve the study purposes. Study findings revealed that eight foot asphalt trails do not effect percent canopy cover, while ten and 12 ft trails do effect percent canopy cover ($p = .000$) as compared to on and off-site controls. As well, trail center surface temperatures were significantly different from on-site control surface temperatures ($p = .000$). The main effects model resulting from multivariate analysis of variance revealed that footprint width effects on percent canopy cover and surface temperature were significant; however, further analysis using Tukey's HSD post hoc analysis indicated that there were no significant effects, and the model lacked predictability and explained little variance ($r^2 = .04$). Study findings indicated that trail age had no effect on percent canopy cover. There was a significant, but weak correlation between on-site control canopy cover and surface temperature, yet not between the trail percent canopy cover and surface temperature. T-tests results indicated no significant difference between concrete and asphalt surface temperatures. Finally, descriptive analysis found tree species diversity lower on the greenway when compared to a pristine area. Study results may help planners and designers better integrate conservation of natural resources and recreation infrastructure in riparian greenways. Furthermore, study results may be helpful to greenway managers interested in understanding how vegetation management around hard surfaced trails may impact tree canopy cover. Finally, results from this exploratory study indicate future research directions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Recreation ecology is the study of the impacts of outdoor recreation on natural environments, typically parks and other protected natural areas (Leung & Marion, 2000; Liddle, 1997). Traditionally, recreation ecology studies have focused on direct human impacts to ecological resources, such as the impacts associated with hiking and camping on vegetation (Cole, 1989a, 2004; Cole & Bayfield, 1993; Marion, 1991). For example, Cole and Bayfield (1993) developed standard methods to assess hiking or trampling impacts on trail vegetation cover. Cole (1989a) developed a methodological approach to assess vegetation and soil impacts associated with campsite use, and Marion (1991) developed a natural resource inventory associated with camping impacts. In almost all cases, recreation ecology studies focus specifically on the ecological impacts to vegetation and soil occurring in natural areas as a result of recreational activity (Cole, 2004; Cole & Bayfield, 1993; Cole & Spildie, 2007; Marion, 1991). Importantly, the results of recreation ecology studies may be used to help guide park management decisions (Leung & Marion, 2000; Marion & Leung, 2001). The basis for this current study was on a particular type of park, the greenway. Greenways are linear parks located along natural features such as rivers or ridgelines, which may include recreational uses (Little, 1990). Focusing specifically on greenway characteristics and ecological variables, this research explored the impacts of greenway trail development and management on riparian habitat. Results of the current study may provide greenway planners and managers with empirical information to facilitate effective decision-making in greenway design and management.

Greenways have become increasingly popular across America, potentially due to providing a myriad of environmental and social benefits for individuals and communities (Ahern, 2004; Labaree, 1992; Little, 1990). Due in part to their linear structure, greenways have been suggested to represent a key planning tool for developing sustainable urban landscapes (Ahern, 2004; Lindsey, 2003). Sustainable development includes conservation of natural resources, economic development, and equitable distribution of resources (World Commission on Environment and Development, 1987). Greenways provide increased opportunities for individual (i.e., recreational activities) and social (i.e., community cohesiveness) activities (Gobster, 1995; Godbey, Caldwell, Floyd, & Payne 2005; Henderson, 2005; Kuo & Sullivan, 2001; Sullivan, Kuo, & dePooter, 2004), economic benefits such as increased property values (Crompton, 2000; Nicholls & Crompton, 2005; Shafer, Scott & Mixon, 2000), and support conservation of natural and cultural resources (Ahern, 2004; Baschak & Brown, 1995; Hoctor, Carr, Zwick & Maehr, 2004; Wornell, 1994). Greenway benefits, as evidenced in the literature, may be an important part of sustainable development (Ahern, 2004).

Conservation of natural resources has been a goal associated with the greenway movement and of specific greenways (e.g., Ahern, 1995; Fabos, 2004; Governor's Council on Greenways and Trails, 2001; Murfreesboro, Tennessee, 1993; Lindsey, 2003; Metropolitan Board of Parks & Recreation 2002; National Park Service, 1993). For example, Ahern (1995) identified biodiversity (i.e., the number of different species in a given area) as a primary goal for greenways, while Lindsey (2003) documented conserving "habitat, open space, forests, and wetland areas" (p. 167) as a goal for Indianapolis' greenway system. The National Park Service (1993), in a case study of six greenway systems, found that all six greenway systems studied had conservation of natural resources as a high priority for the greenway.

Greenway conservation goals and benefits are important components of recreation and land use planning and may be key to gaining public and decision maker support. Elected officials and recreation and land use planners need quality information from recreation ecologists and practitioners on greenway conservation benefits to support greenway planning, conservation, and sustainable development. Development of greenways and recreational lands are an important part of planning for developing areas (e.g., Ahern, 2004; Fogg, 2005; Labaree, 1992).

Recreation ecologists are interested in the impacts of outdoor recreation on the natural environment (Hammit & Cole, 1998; Liddle, 1997). Greenways commonly feature recreational trails, and recreation ecology studies have documented and/or suggested that trails and trail footprints negatively impact vegetative habitat (e.g., Ahern, 2004; Cole, 1993, 1995; Hall & Kuss, 1989; Labaree, 1992; Mason, Moorman, Hess, & Sinclair, 2007; Sinclair, Hess, Moorman, & Mason, 2005; Smith & Hellmund, 1993; Tonnesen & Ebersole, 1997). Trails and mowed areas provide poor natural habitat in greenway corridors (Baschak & Brown, 1995; Mason et al. 2007; Schiller & Horn, 1997) and have been associated with lower levels of biodiversity (Mason et al. 2007; Naeem et al. 1999; Schiller & Horn, 1997). Mason et al. (2007) and Schiller and Horn (1997) found that the level of management intensity (i.e., mowed areas and hard surfaced trails) was inversely related to biodiversity, and Baschak and Brown (1995) suggested that mowing decreased natural habitat in greenways. Ahern (2004) recognized that greenway trails had specific areas of impact and suggested that researchers seek to better understand trail impacts on habitat and biodiversity. For example, generally greenway trails are typically hard surfaced (asphalt or concrete) and include an intensely managed area, where little or no natural vegetation exist (Cole, 1993; Fogg, 2005).

Riparian greenways in developing areas have been recognized as a critical component of sustainable development, due to their linear form, location, and potential functions as described in Ahern's (2004) greenway theory. Ahern's greenway theory is predicated on three hypotheses. Ahern suggested in the hypothesis of co-occurrence of resources that ecological, cultural, and historical resources occur at higher rates per unit area of land in riparian areas as compared to upland areas. In his second hypothesis, Ahern suggested that riparian corridor greenways provide benefits associated with connectivity of landscapes and promote natural resource processes and functions. His third hypothesis suggested the compatibility of uses in and along riparian greenways. For example, greenways might be utilized for recreational purposes in addition to conserving habitat and biodiversity as suggested by Labaree (1992). Others (e.g., Ahern, 1995; Hoctor et al. 2004; Jongman & Pungetti, 2004; Little, 1990; Smith & Hellmund, 1993) indicated that greenways maintain and increase biodiversity and conservation of natural resources if utilized in planning for greenspace in developing communities. Biodiversity includes all of the members of the biotic community and has been positively related to habitat (i.e., the area a plant or animal resides, including food, shelter and water) diversity (Naeem et al. 1999). For example, vegetation diversity creates habitat diversity which provides food, shelter and water for organisms (Gregory, Swanson, McKee, & Cummins, 1991). However, many greenways are located in developed or developing areas where natural resources, in particular, riparian vegetation, are degraded in part as a result of historic land use and land development (Tennessee Department of Environment and Conservation, 2006, 2007).

The presence of vegetation, specifically tree species diversity, is an important component of habitat. Trees serve as avian, mammal, insect, and fish (i.e., via stream bank roots, etc.) habitat (Mason et al. 2007; National Research Council, 2002; Wenger, 1999) and effect microclimate (Chen, 1991, 1993; Nowak, Rowntree, McPherson, Sisinni, Kerkman, & Stevens, 1996; Thorne, 1993). Thorne (1993) and Nowak et al. (1996) suggested that forests provide recreational opportunities, wildlife habitat, and moderate temperatures, such that forest temperatures are cooler than developed areas. Finally trees provide improved air quality, decreased storm water runoff, decreased soil erosion, increased water quality, and create urban habitat (Urban Forestry South Expo, 2006).

Tree species diversity, as a measure of biodiversity, is an important component of the biotic community and is related to the stability of the forest and forest habitat. In addition, Lindsey (2003) identified a lack of direct measures of biodiversity as a limitation to his study on Indianapolis, Indiana's greenway system. Dwyer, Nowak, Noble, Heather, and Sisinni (2000) found that inventorying urban forests provided background data that supported understanding of and potentially better management for forest benefits. Moreover, the USDA Forest Service was directed by the National Forest Management Act of 1976 to maintain tree species diversity following timber harvests (Brashears, Fajvan, & Schuler, 2004). Tree species diversity helps maintain the stability of the forest, as more tree species represent a forest condition whereby the forest is less susceptible to a specific disease (Naeem et al. 1999). In some cases specific wildlife or plant life require the habitat of a particular tree species, thus tree species diversity may represent different levels of habitat (Nadkarni et al. 2001; National Arbor Day Foundation, n.d.; University of Tennessee, n.d.). Thus, tree species diversity, a measure of biodiversity, is an important part of forest ecosystems, particularly within recreational greenways.

Ahern (2004) suggested in his hypothesis of use compatibility that greenways can support recreation and biodiversity. However, no studies are known to exist that support the idea that greenways support biodiversity, including tree species diversity. In contrast researchers have found that conservation of natural resources is limited in riparian greenways. Greenways studied by Mason et al. (2007), Schiller and Horn (1997), and Sinclair et al. (2005) were located in developed areas, along forested river corridors, and Lindsey (2003) studied riparian greenways that included some forested areas. These researchers found that riparian greenways provide limited natural resource functions for promoting native bird populations (Mason et al. 2007), supporting fox and deer populations (Schiller & Horn, 1997), controlling mammalian nest predation (Sinclair et al. 2005), and maintaining habitat quality (Lindsey, 2003). Thus, it appears from these studies that recreational greenways, in part due to the presence of trails and managed areas, may not provide the desired level of conservation benefits.

Once constructed and managed, trails typically exist in a trail footprint (Fogg, 2005). The trail footprint consists of the trail width, shoulder widths on each side of the trail, and, in some cases, adjacent mowed areas, each of which may be important variables for study as related to habitat quality. For example, the trail footprint has been associated with various ecological impacts (e.g., Cole, 1993; Cole & Bayfield, 1993; Dale & Weaver, 1974; Hammit & Cole, 1998; Marion & Olive, 2006). Generally, as trail footprint increases in width, a greater amount of natural habitat, including tree canopy may be removed and/or destroyed (Cole, 1993; Mason et al. 2007). Canopy openings allow greater light penetration, change microclimate conditions such as temperature and moisture, and may favor exotic species (Chen, 1991; Chen et al. 1999; Cole, 1993; Labaree, 1992; Ledwith, 1996).

Greenway designers and managers make choices about how wide a trail and trail footprint might be. Typically, trails and trail footprints vary based on the management philosophy of the agency and the purpose for which the trail was designed. As an example, Labaree (1992) argues in his guidelines for greenways prepared for the National Park Service's River and Trails program, against the presence of trails, or only for minimal trails, to promote conservation benefits. Others such as Fogg (2005) and Flink and Searns, (1993) provide guidelines for trail development based on intended trail use(s). For example, Fogg suggests a minimum trail width of 0.3 m (1 ft) wide for hiking, 0.9 m (3 ft) for ADA accessibility, 1.8 - 2.4 m (6 - 8 ft) wide for pleasure walking, and 2.4 - 3.0 m (8 - 10 ft) wide for exercise and service vehicles, all with 0.3 m (1 ft) minimum clearance on each side of the trail and at least 2.1 m (7 ft) of vertical clearance above the trail. An understanding of the effects of trail footprint width on habitat may help recreation planners and managers make more informed decisions that balance human and environmental considerations. While the presence of trails is a reality in greenway development, increased trail footprints and hard surfaces are likely associated with greater ecological impacts to microhabitat and microclimate (Cole, 1993).

The type of tread surface on the trail may have substantial impacts to microclimate and environmental conditions. Earthen tread hiking trails have been associated with soil compaction, decreased infiltration, and increased stormwater runoff, while pervious surfaces such as pervious asphalt or concrete, rocks, and woodchips (e.g., Hammit & Cole, 1998), may allow water to infiltrate, reducing stormwater runoff. Impervious surfaces such as asphalt may increase runoff (Wenger, 1999), create barriers to water movement, and are typically associated with as much as seven degree Celsius higher surface temperatures as compared to natural surface types (Jo, Lee, Jun, Kwan, & Jo, 2001). An understanding of the effects of trail surface and width on surrounding temperature could enhance recreation planners' and managers' ability to reduce environmental impacts associated with trail development. As an example, wider asphalt surfaces likely generate greater effects on surrounding forest floor surface temperatures, and pervious surfaces of natural materials may be cooler than asphalt and concrete. For example, Asaeda, Thanh, and Wake (1996) found that surface temperature, heat storage and heat emission was significantly greater for asphalt versus concrete or bare soil.

While the presence of trails is a reality in greenway development, increased trail footprint widths and hard surfaces are likely associated with greater ecological impacts to microhabitat and microclimate (Cole, 1993; Mason et al. 2007). In addition to trail footprint and surface, greenway age may affect percent canopy cover. For example, the older a greenway is, the more time the canopy would potentially have to recover and overhang the trail, resulting in greater percent canopy cover.

Trail footprint, surface type, and greenway age may affect vegetative cover and overstory. Overstory is related to surface and air temperature and is often measured based on estimates of percent canopy cover. Percent canopy cover has typically been used to describe forest structure, size, and composition (Nowak et al. 1996), and location of urban trees and has been used as an indicator of the urban forest's ecological contribution (e.g., hydrologic, air quality enhancement) (Whitford, Ennos, & Handley, 2001). Canopy cover influences physical and biological habitat components within forest ecosystems (Brower & Zar, 1984; Nowak et al. 1996) and is thought to be one of the most dominant factors affecting urban ecosystem processes (Whitford et al. 2001). Finally, Speight (1973) and Cole (1995) reported that surface and understory leaf area may decrease in response to recreational trampling, likely due to soil compaction. Thus greenway trail sub surface preparation with heavy equipment may effect leaf area.

Forests help moderate air and surface temperatures (e.g., Chen, 1991; Jo et al. 2001; Nowak et al. 1996; Thorne, 1993). Air and surface temperatures have been shown to be affected by forest canopy shading and have a significant influence on other physical and biological habitat parameters (e.g., Brower & Zar, 1984; Chen, 1991; Jo et al. 2001; Ledwith, 1996; McPherson & Rowntree, 1993). For example, McPherson and Rowntree (1993) found that trees reduced summer cooling costs by shading structures, and Ledwith (1996) found that decreases in forest canopy width increased air temperature. Thus, air and surface temperature appear sensitive to changes in canopy cover, and wider trails may be associated with decreased canopy cover and increased surface temperature. Researcher findings associated with these relationships imply that surface temperatures are likely highest in the center of an asphalt trail where one would expect little canopy cover, and are lower at the trail footprint edge (e.g., beginning of forest vegetation), and decrease as one moves into the forest interior (Chen, 1991; Jo et al. 2001; Nowak et al. 1996; Thorne, 1993). Thus, the location of temperature readings (i.e., trail center, forest edge, and interior forest sites) may be an important variable for study.

Trail development and mowing are under the control of the greenway planner, designer and/or manager. Research on the effects of trail footprint may provide practical implications for greenway designers, planners, and managers to promote natural resource conservation in planning, designing, and managing recreational greenways. Baschak and Brown (1995) suggested "greenway planners, designers, and managers need clear guidelines, based on scientific evidence, if ecological concepts are to be applied" (p. 223). Schiller and Horn (1997) suggested that greenway planners and designers should balance "greenway infrastructure with preservation (or restoration) of wild vegetation" (p. 114) in urban greenways. Mason et al. (2007) suggested that "twice as many development-sensitive birds" (p. 159) might be present in greenways with "little or no managed area" (p. 159) as compared to greenways with 6.5 - 13 ft (1.9 - 3.9 m) wide trail footprints. Finally, Mason et al. (2007) recommended trail footprint widths should be narrow to ensure that tree canopy cover remains intact.

In summary, existing research findings imply that as trail footprint increases, canopy cover decreases, and surface temperature increases. Additionally, as surface type changes from vegetation to a hardened surface such as asphalt or concrete, surface temperature increases, and the highest temperature will be found at the center of a paved trail, with lower temperatures at the trail footprint / forest edge and the forest interior respectively. In addition, as the trail ages following the removal of vegetation and trail development, vegetative cover and overstory may improve over time. While the research in other contexts imply canopy cover and surface temperature relationships, no studies are known to exist for greenway trails that examine the effects of trail footprint width, greenway trail age, and surface type on percent canopy cover and surface temperature.

Significance of the Study

Outdoor recreation trail impacts on vegetative cover have been documented in wilderness areas and other protected natural areas (Cole, 1995; Marion & Olive, 2006), yet no studies have investigated the effects of greenway trail width on vegetative cover or habitat, and only a few researchers investigated relationships between greenways and biodiversity (e.g., Mason et al. 2007; Schiller & Horn, 1997). Therefore, the current study may help researchers understand how greenway trail footprint width impacts percent canopy cover and surface temperature. Secondly, the study may help greenway planners, designers, and managers better understand how trail footprints can be modified to balance greenway infrastructure with natural resource conservation goals as suggested by Schiller and Horn (1997). Finally, the current study, by assessing trail foot print width effects to canopy cover, will begin to assess Ahern's (2004) third hypothesis: compatibility of greenway uses.

Purpose of the Study

The primary purpose of this study was to examine the effect of greenway trail footprint width, trail age, and surface type on percent canopy cover and surface temperature in forested riparian greenway corridors. To accomplish this purpose, three treatment groups were established for greenway trail footprint widths: eight ft (2.4 m) trail width plus mowed area, ten ft (3.0 m) trail width plus mowed area, and 12 ft (3.6 m) trail width plus mowed area. Within group comparisons were made to an adjacent on-site interior forest control and an off-site ecoregional reference control. An examination of differences among treatment groups was also an integral component of the study to determine the effects of greenway trail footprint width on habitat as measured specifically by percent canopy cover and surface temperature. Secondarily, the study investigated biodiversity, as measured by tree species diversity, of the greenway as compared to a pristine forested area.

Hypotheses

Based on the paucity of research examining the impact of greenway trail variables on habitat and microclimate conditions, five of the following six hypotheses for this study were stated in null form.

HO_1. No significant differences will exist between the trail footprint width (8 ft [2.4 m] plus mowing, 10 ft [3.0 m] plus mowing and 12 ft [3.6 m] plus mowing) and its respective control sites on percent canopy cover.

HO_2: No significant differences will exist between trail footprint width (8 ft [2.4 m] plus mowing, 10 ft [3.0 m] plus mowing and 12 ft [3.6 m] plus mowing) and surface temperatures (trail center, forest edge, and interior control).

HO_3: No significant differences will exist among the three greenway trail footprint widths on percent canopy cover and surface temperature.

HO_4: No significant differences will exist for the effects of greenway trail age on percent canopy cover.

HO_5: A significant relationship will exist between percent canopy cover and surface temperature (based on Chen, 1991; Chen et al. 1999; Jo et al. 2001; Ledwith, 1996).

HO_6: No significant differences will exist for the effect of trail surface type (asphalt or concrete) on surface temperature.

The secondary purpose or research question, investigating greenway tree species diversity, was accomplished utilizing descriptive statistics, and thus no hypothesis was included.

Definitions

1. Albedo is a surface's reflectivity of the sun's radiation and generally is expressed as a percentage (Marsh, 2005). Lighter surfaces have a higher reflectivity (approaching 100%) and darker surfaces have a lower reflectivity (approaching 0%) (Akbari, Pomerantz, & Taha, H. (2001).
2. Biodiversity is defined as all the components of a biotic community including but not limited to plants and animals (Naeem et al. 1999).
3. Community type is a broad categorization of major habitats such as deciduous or coniferous forest, bog, and grassland (Brower & Zar, 1984).
4. Control sites were utilized for comparisons for percent canopy cover and tree species diversity. There were two control sites used for comparisons of percent canopy cover. These included 1) on-site forested interior control areas located near the respective trail sampling points, and 2) off-site controls located in areas without a greenway trail and expected to have high levels of forest canopy. The control site for tree species diversity was the pristine site located at Radnor Lake.
5. Dominance represents the species that is most in control of the ecosystem and may be measured based on diameter at breast height (Brower & Zar, 1984).

6. Forest age is generally reported in years; however, in the current study diameter at breast height (size) was used to estimate an individual tree's age (Brower & Zar, 1984).
7. Frequency is the number of times a particular event occurs, for example the number of times a particular species shows up in a sample (Brower & Zar, 1984).
8. Greenways are defined as linear parks often with multiple functions such as providing areas to support recreation and conservation (Little, 1990). The definition for a given greenway may have many variables, thus making one standard definition difficult. For the purpose of this study, greenways are defined as linear riparian corridors utilized for recreation and conservation and include functional elements of movement for humans, wildlife, and water.
9. Greenway master plan is a planning document that outlines a community's vision for, and primary goals associated with, a greenway (Flink & Searns, 1993). It may include the location and route of the greenway; land, water, and heritage conservation mechanisms; access and facility locations; management information; estimated costs; and development strategies.
10. Greenway trail is a non-motorized transportation route within a greenway corridor and may be designed for single or multiple uses (Flink & Searns, 1993).
11. Greenway trail footprint is the area in which the trail is located, including surfaced trail width, trail shoulders, and managed / mowed vegetation width and/or including the trail shoulder. The greenway trail footprint has been

identified as a high recreational use and high impact zone (Cole, 1993). For example the placement of an asphalt trail in the greenway footprint and intense vegetation management limit habitat and biodiversity (Baschak & Brown, 1995; Lindsey, 2003).

12. Habitat is defined as an area where an organism or group of organisms live and is described by biotic, chemical, physical, and geographic parameters, including an organism's food sources, and microclimate. Habitat diversity is directly related to biodiversity (Brower & Zar, 1984; Labaree, 1992).

13. Importance value represents the sum of relative frequency, relative density, and relative dominance of a particular tree species divided by three (Brower and Zar, 1984; Schibig, 1996). It is a measure of a particular species' influence on the forest ecosystem. Species with higher importance values tend to be the dominant species in the ecosystem (Brower & Zar, 1984, Schibig, 1996).

14. Percent canopy cover is the percentage of surface area shaded by overhanging leaves or foliage (Brower & Zar, 1984; Daubenmire, 1959).

15. Recreation ecology is the study of the impacts of outdoor recreation on natural environments, typically parks and other protected natural areas (Liddle, 1997). Recreation ecology studies may be used to help guide park management decisions (Leung & Marion, 2000).

16. Riparian area refers to the area directly adjacent to a river, stream, wetland, or other water body, and supports natural resource functions such as hydrology, biodiversity, and connectivity (National Research Council, 2002).

17. Shannon Weiner Diversity Index accounts for species richness (number) and the distribution (evenness) of the individual species with in the sample. The Index is a relative number and is used for comparing populations (Brower & Zar, 1984).

18. Species diversity is the number of different species in a given area and is representative of biodiversity (Brower & Zar, 1984).

19. Surface type is the specific material utilized for the greenway trail and may include asphalt, concrete, and/or gravel (Fogg, 2005).

20. Sustainable development is "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" and includes economic, equity, and environmental considerations (World Commission on Environment and Development, 1987, p. 8).

21. Temperature is a measure of heat of an environment, substance or surface as related to its molecular movement and surface temperature is "the radiating temperature of the ground surface including grass, bare soil, roads, sidewalks, buildings, and trees" (GLOBE, 2005, p. 3). For the purpose of this study, surface temperatures were taken in three locations: at the center of the asphalt trail, at the edge of the greenway trail footprint and forest edge and in the forested interior (control) area.

22. Trail age is the actual age (from construction date to present date) of the asphalt trail in the greenway.

23. Tree density refers to the number of individuals per unit of area, for example, the number of Maple trees per acre (Brower & Zar, 1984).

24. Vegetative cover is the amount of area covered by a perpendicular projection of plant material (Brower & Zar, 1984) and has been expressed as a percent in recreation ecology studies (e.g., Cole, 1995; Marion & Leung, 2001; Schiller & Horn, 1997).

25. Vegetation structure is the spatial layout of the vegetation community, including horizontal and vertical planes (Pauchard, Ugarte & Millan, 2000). Vegetation stratification is the vertical layering of the forest habitat. Vertical forest habitat may be broken down into ground, herb, shrub, understory, and overstory canopy layers and is related to habitat and biological diversity (Brower & Zar, 1984).

Delimitations

1. This study investigated forested riparian greenway trail corridors with at least 50 ft wide forested corridors.

2. The study investigated only greenways with hard surfaced trails used for non-motorized recreation.

3. With regard to mowed areas adjacent to trails, the study investigated trail areas with 2 - 6 ft (0.6 - 1.8 m) wide mowed zones. The widths were chosen based on common mower cutting widths (D. Bunt, personal communication, June 16, 2008) and personal observation.

4. This study assessed only two, of the many potential, measures of habitat: percent canopy cover and surface temperature. As well, this study examined one variable of biodiversity, tree species diversity.
5. This study assessed greenways located in Middle Tennessee.

Limitations

1. The small number and geographic location of greenways sampled may limit the generalizability of the study findings.
2. The greenway systems investigated are located in Middle Tennessee and may vary in resource allocation, vegetative types and structure, and other characteristics, potentially limiting applicability of findings to greenway systems with different age, resource allocation or other characteristics.
3. Tree canopy cover and surface temperature represent characteristics of the ecosystem; therefore a comprehensive measurement of natural resource function is not gained.
4. Greenways and study sections were selected based on purposive sampling for riparian corridor, trail width, etc. A random start point was selected in the first 60 ft (18 m) of the trail and a standard 60 ft (18 m) sampling interval was then used to select data collection points. Transects were then established and included points at the center of the trail, trail footprint edge/forest edge, and interior forest control site. These sampling methods may limit findings to those locations and may not represent the greenway or greenways as a whole.

Assumptions

1. The indicators chosen for data collection are likely sensitive to the placement of greenway trails, trail width, and trail surface.
2. Canopy cover is representative of one level of ecosystem structure and influences ecosystem process, habitat diversity, and thus is related to vegetation and animal diversity.
3. Surface temperature is one component of microhabitat, that when changed may impact plant or animal diversity.
4. Prior to trail construction, canopy cover along the trail corridor was assumed to be similar to canopy cover in adjacent control areas.

CHAPTER II

LITERATURE REVIEW

Greenways are, for a myriad of reasons, being planned and developed across America. Searns (1995) referenced over 500 active greenway projects, and Moore and Shafer (2001) suggested greenway trails were a growing and significant component in providing recreation opportunities in communities. In addition to recreation, most greenways are thought to conserve natural resources, due in part to being located along rivers and streams (Ahern, 2004; Fabos, 2004; Walmsley, 1995). Streamside or riparian greenways may offer great potential for conservation of natural resources relative to the land area they occupy (Ahern, 1995, 2004; Fabos, 2004; National Research Council, 2002; Wenger, 1999) and may be the most promising sustainable development landscape-planning tool available (Ahern, 2004). Ahern's greenway theory (2004) suggested greenways were part of sustainable landscapes because they offered opportunities for conservation of biodiversity, connectivity, and natural hydrology, and allow for additional uses, potentially engaging numerous additional user groups. The following section includes an overview of greenway definitions, benefits, and history.

Greenway Definitions and Benefits

The focal recreational setting in this study is the greenway trail footprint and will require some understanding of the term "greenway" and its purported benefits. The term greenway originated in the late 1800s and was derived from the terms greenbelt and parkway (Fabos, 2004). According to Little (1990), William Wythe coined the term greenway in 1959 in a discussion of work designed to protect ecologically-sensitive resources. Greenway definitions by several authors (e.g., Ahern, 1995; Fabos, 1995; Little, 1990; President's Commission on Americans and the Outdoors, 1987; Shafer, Scott, & Mixon, 2000) have consistently stated that greenways are linear in form and have multiple functions.

The President's Commission on Americans and the Outdoors (1987) proposed a vision for greenways that incorporated linear form and functional elements of recreation and conservation. Many authors (e.g., Ahern, 1995; Fabos, 1995, 2004; Flink & Searns, 1993; Forman, 1983; Lindsey, 2003; Little, 1990; McGuckin & Brown, 1995; Moore & Shafer, 2001; Shafer et al. 2000) have included these same elements in greenway definitions. For example, Little (1990) defined greenways as natural protected corridors that increase environmental quality and provide recreational opportunities.

Fabos (1995) defined greenways as networks of corridors, preexistent to development, which included recreation, conservation, and historic preservation as greenway purposes. Fabos' (1995) definition was similar to Little's (1990) in capturing the purposes, yet also recognized preexistent, presumably pristine natural resource functions, including biodiversity and hydrology. Flink and Searns (1993) recognized greenway networks, yet added greenways as linear areas that provide connections to support wildlife movement between habitat areas and enhance urban riparian areas by protecting natural biodiversity sinks. Finally, Ahern's (1995) greenway definition was similar to those provided by the President's Commission on Americans and the Outdoors (1987), Little (1990), and Flink and Searns (1993), yet suggested that greenways were a key part of sustainable land use. For the purpose of this study, greenways are defined as riparian corridors utilized for recreation and conservation of natural resources and include elements of connectivity for humans, wildlife, and water.

Greenways provide community benefits including opportunities to enhance human well-being, quality of life, social cohesiveness, economics, and conservation of natural resources. Physical activity levels appear to be increased when greenways are located closer to an individual's home (Giles-Corti et al. 2005; Gobster, 1995; Henderson, 2005; King, Brach, Belle, Killingworth, Fenton, & Kriska, 2005; Orsega-Smith, Mowen, Payne, & Godbey, 2004). Exposure to nature through greenway use and recreation can enhance quality of life, psychological well-being, and community cohesiveness (Coley, Kuo, & Sullivan, 1997; Driver, 1990, 1999; Hartig, Mang & Evans, 1991; Kaplan, 1995; Kuo & Sullivan, 2001; Orsega-Smith, et al. 2004; Purcell & Lamb, 1998; Smith & Hellmund, 1993; Sullivan, Kuo & dePooter, 2004) and may be related to the quality of the natural features in the greenway (Frauman & Cunningham, 2001; Gobster, 1995). Greenways benefit the economy by increasing property values and increasing user spending (Driver, 1990; Espey & Owusu-Edusei, 2001; Lutzenhiser & Netusil, 2001; Nicholls & Crompton, 2005). Finally, Ahern (1995, 2004) and others (e.g., Fabos, 2004; Labaree, 1992; Little, 1990; Smith & Hellmund, 1993) have suggested greenways benefit communities by conserving natural resources including habitat, biodiversity, connectivity, and natural hydrology. Literature on the conservation benefits of greenways is provided later in this chapter.

History of Greenways

Fabos (2004) identified five phases of greenway history. Phase I, from 1867 to 1900, was during the time of Fredrick Law Olmstead, while Phase II, from 1900 to 1940, focused on greenway planning. Phase III was based primarily on the environmental movement and occurred from the early 1960s through mid-1980s. Phase IV was referred to by Little (1990) as the naming of greenways, and Phase V represented the greenway movement abroad (Fabos, 2004).

Olmstead was considered the father of greenways and contributed to the development of greenways in the U.S. and designed the first linear, networked riparian parks in California in 1887 (Fabos, 1995, 2004; Little, 1990; Walmsley, 1995). In addition, Olmstead proposed Boston's Emerald Necklace, a network of riverside greenways (Little, 1990; Walmsley, 1995). By 1902, the Emerald Necklace was the largest greenway park system in the United States and considered by Fabos (2004) to be a precursor to the current greenway planning approach. During the latter part of Phase I, greenway parks were planned and developed in Minneapolis and Kansas City. Kansas City's plan protected natural resources located along the Kansas and Missouri Rivers (Walmsley, 1995).

Phase II of the greenway movement was most well known for greenway planning by landscape architects. For example, in 1903 the Olmstead Brothers designed a 40-mile long linear park system for Portland, Oregon, while others utilized natural corridors in the park planning process (Fabos, 2004). Benton MacKaye, originator of the idea for the Appalachian Trail, promoted natural corridors for recreational uses and supported creating barriers to stop urbanization (Little, 1990; MacKaye, 1921; Yahner, Korostoff, Johnson, Battaglia, & Jones, 1995). In the 1920s, greenbelts were designed to buffer urban areas and keep inhabitants connected to nature (Walmsley, 1995). However, greenbelts were not as large or pristine as communities had originally envisioned and unfortunately were lost to rampant suburban development (Walmsley, 1995).

In 1928, Massachusetts' open space plan was developed and included natural hubs in a network of corridors. From 1929 to 1931, a linked park system was developed for Radburn, New Jersey (Fabos, 2004). Finally, the Blue Ridge Parkway was proposed at the end of Phase II and included 500 miles extending from Cherokee, North Carolina, to Shenandoah National Park in Virginia (Moore & Shafer, 2001; National Park Service, 2006).

Phase III occurred from 1960 to 1980 and was heavily influenced by the environmental movement (Fabos, 2004). In 1966, *Trails for America* was published, and in 1968, the National Trails System Act was passed and designated the Appalachian and Pacific Crest Trails as national trails (Yahner et al. 1995). In 1964, Lewis, in developing the Wisconsin Heritage Trail, a statewide greenway trail plan, identified 220 cultural and natural resource values that needed to be conserved, finding over 90% fell along natural corridors such as river valleys (Fabos, 2004; Lewis, 1964). According to Fabos (2004), the greenway movement began to recognize the valuable relationship between nature conservation and greenways. In 1969, Ian McHarg wrote the seminal work, *Design with Nature*. McHarg (1969) proposed a residential development where over half of the land was included in a greenway network designed to protect natural resources. The greenway network was identified prior to locating the human structural components of the development (Fabos, 2004).

Phase IV of the greenway movement included two major events: the publication of the report from the President's Commission on Americans and the Outdoors (1987) and Little's (1990) *Greenways for America* (Fabos, 2004). Additionally, the U.S. Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, Transportation Equity Act (TEA) of 1998, Transportation Equity Act for the 21st Century (TEA-21), and Safe Accountable Flexible Efficient Transportation Equity Act: A legacy for Users (SAFETEA-LU) began to refocus transportation policy, providing local funding for greenway trail initiatives (Moore & Shafer, 2001; United States Department of Transportation, n.d.). For example, SAFETEA-LU, enacted in 2005, provided for a pilot program designed to promote the construction of a network of non-motorized transportation routes in an effort to assess the feasibility of increasing walking and bicycling as major components of locomotion/transportation in certain areas (United States Department of Transportation, n.d.).

The inclusion of a greenway vision by the President's Commission on Americans and the Outdoors in 1987 was taken as an endorsement of greenways as a viable land use planning tool (Fabos, 2004). ISTEA, TEA-21 and SAFETEA-LU were instrumental in helping fund and establish greenways as a component of urban environments and promoting greenway trails for walking and bicycling as a mechanism of alternative locomotion/transportation (Moore & Shafer, 2001; United States Department of Transportation, n.d.).

Phase V of the greenway movement was international in scale as evidenced by the numerous greenway projects occurring globally (Fabos, 2004). Phase V included greenways as one of the most utilized urban planning and design tools for development that conserves natural resources for future generations, as it promoted more livable communities (Salazar, 2005). History suggests that greenways have consistently been tied to conservation of natural resources along natural corridors. For example, the first greenways were planned and developed along rivers and streams (Fabos, 2004), and Lewis (1964) documented that 90% of natural and cultural resources fall along natural corridors. Lewis' Wisconsin Heritage Trail was designed around conserving natural and historic resources along these natural linear corridors.

Ahern's Theory of Greenways

Ahern (1995) stated that the use of greenways are a key planning strategy developing communities might use to accomplish sustainable land use and conservation goals if the greenways were designed and constructed to maintain biodiversity, habitat, and connectivity, while also serving a variety of human uses. Ahern (2004) suggested in his theory that 1) Greenways include significant cultural, historic, and natural resources; 2) there are inherent benefits associated with the connectivity greenways provide; and 3) there is assumed compatibility of greenway uses. Ahern's first suggestion, that greenways include significant resources, became known as the "hypothesis of co-occurrence of greenway resources" (p. 36). Ahern advanced that "greenways are a linked, or spatially integrated network of lands that are owned or managed for public uses including biodiversity, scenic quality, recreation, and agriculture" as these purposes co-occur within an area (p. 36). Others have suggested or found that riparian greenways include high levels of natural resources per unit of land area as compared to their upland counterparts (e.g., Hawes & Smith, 2005; Lewis, 1964; National Research Council, 2002; Wenger, 1999). For example, the National Research Council (2002) reported that riparian areas carry out significant hydrological, biogeochemical, and habitat functions.

Ahern (2004) recognized in his second hypothesis within the greenway theory that greenways create “a presumed advantage, or synergy, resulting from spatial connectivity and linkage” (p. 36). Connectivity represented a landscape’s functional associations and ability to interact with other landscapes through time. Connectivity included functional linkages that promoted ecologic and human functions such as movement. The ecological functions of connectivity of habitat not only support wildlife movement, but also the movement of water, nutrients and/or pollutants. Ahern suggested that a greenway’s ability to serve as a wildlife corridor is a function of its design, in that designers must consider and include individual species’ habitat requirements for those species to utilize the greenway as a mechanism to connect to other larger natural areas. For example, if the species’ habitat does not exist, it is unlikely that the respective species can move through an area to connect to another area (Ahern, 2004).

Ahern’s (2004) third hypothesis, the compatibility of multiple uses, stated that greenways are “viable because they provide multiple functions within a specific and often limited spatial area, and that these uses can be planned, designed and managed to exist compatibly or synergistically” (p. 45). Ahern and others (e.g., Cole, 1993; Hammit & Cole, 1998; Swinnerton, 1989) have concluded that recreational facilities and uses, including trails and hiking, impact natural resources. Additionally, Ahern (2004) suggested that trail impacts could be minimized and made compatible with conservation goals if greenway planners and managers better understood trail impacts on natural resources, and Ahern advanced that further research was needed to assess trail impacts on ecosystem functions in greenways.

This current doctoral study addressed Ahern's (2004) third hypothesis. It has been well documented that hiking trails affect natural resources (Cole, 1993; Hammit & Cole, 1998; Liddle, 1997; Mason et al. 2007); however, little research has been conducted to understand the effects of greenway trails on natural resources. Findings from the few existing greenway and natural resource conservation studies (e.g., Mason et al. 2007; Schiller & Horn, 1997) suggest that greenway designers, planners, and managers are not following basic guidance on maintaining the compatibility of recreation and conservation uses. In contrast, there does appear to be a wealth of information on greenways and ecology (e.g., Ahern, 1991, 1995, 2004; Baschak & Brown, 1995; Cole, 1993; Flink & Searns, 1993; Jongman & Pungetti, 2004; Labaree, 1992; Smith & Hellmund, 1993). However, there is a paucity of empirical studies on greenway ecology, particularly related to trail effects on riparian forests, available to planners, designers, and managers. Thus, the primary purpose of this study was to assess the hypothesis of compatibility of multiple uses (e.g., recreation, conservation, and habitat) by investigating the effects of trail footprint (trail width, trail shoulder, and associated mowed area), trail surface, and trail age on habitat and microclimate via measures of percent canopy cover and surface temperature. A second purpose was to examine biodiversity through a comparison of greenway tree species diversity to a pristine site's tree species diversity. Importantly, consistent with Ahern's concepts, study findings may suggest ways to reduce environmental impacts of trail development to enhance the compatibility of conservation and recreation purposes.

Greenways and Conservation

The literature on greenways and conservation is broken down into two broad categories. One category describes the development of greenways as a planning strategy to attain conservation goals. The second category involves greenway-specific studies designed to evaluate conservation of biodiversity, habitat, and connectivity. The greenway planning literature focuses primarily on maintaining and enhancing biodiversity and connectivity, while the studies designed to evaluate site-specific natural resource conditions focus on sustainability, biodiversity, and habitat in riparian greenways. Several authors (e.g., Ahern 1995; Baschak & Brown, 1995; Fabos, 1995; Flink & Searns, 1993; Jongman & Pungetti, 2004; Labaree, 1992; Linehem, Gross, & Finn, 1995; Shafer et al. 2000; Smith & Hellmund, 1993; Walmsley, 1995; Wornell, 1994) have suggested that the uses of greenways are a component of a planning framework for attaining conservation goals. Other authors have investigated the relationship of greenways to sustainable development (e.g., Ahern, 1995; Lindsey, 2003), and biodiversity and habitat (e.g., Mason et al. 2007; Schiller & Horn, 1997; Sinclair, et al. 2005).

Fabos (2004) and Walmsley (1995) found that most greenways they studied were located in natural resource rich riparian zones, thereby presenting opportunities to conserve and/or enhance biodiversity, habitat, connectivity, and natural hydrology (Ahern, 2004; Hoctor et al. 2004; Labaree, 1992; Smith & Hellmund, 1993). Ahern (1995, 2004), Smith and Hellmund (1993), Labaree (1992), Little (1990) and others (e.g., Lanarc, 1995; Linehem, Gross, & Finn, 1995; Ryan, 1993; Ryder, 1995; Searns, 1995; Shafer, Scott et al. 2000; Walmsley, 1995; Wornell, 1994) have suggested greenways are a core component of enhancing and maintaining ecosystem functions such as biodiversity. Conversely, other researchers studying greenway site-specific ecological functions (e.g., Lindsey, 2003; Mason et al. 2007; Schiller & Horn, 1997; Sinclair et al. 2005) raised questions about the value of recreational riparian greenways in natural resource conservation.

Greenways and conservation planning. McHarg (1969), Bauer (1980), Toccolini, Fumagalli and Senes (2006) and Yu, Li, and Li (2006) identified a lack of conservation planning associated with greenway goals and promoted setting priorities for development based on natural resource functions. Several authors (e.g., Ahern, 1991, 1995, 2004; Arendt, 2004; Fabos, 1995; Riberio & Baraco, 2006; Ryder, 1995) recommended the development of greenways using a multi-jurisdictional planning approach to bring diverse interests together. Similarly, regional and national greenway plans were proposed by Fabos (2004) and Ryan, Fabos, and Allan (2006), all suggesting ecological and recreational goals might be accomplished through a comprehensive greenway planning approach.

Labaree (1992) identified six potential ecological functions provided by greenway corridors, while Smith and Hellmund (1993) suggested greenways might increase landscape connectivity. Shafer, Scott, et al. (2000) recommended that greenway functions should, in part, be determined based on adjacent levels of development, while biodiversity and connectivity were the focus of Linehan, et al.'s (1995) study. Benedict and McMahon (2002) posited that greenway planning could help address water quality and connectivity issues associated with habitat fragmentation, while Baschak and Brown

(1995) proposed an ecological assessment framework for riparian greenways, in an effort to increase capacity of greenways as networks.

Labaree (1992) recognized six ecologic functions associated with greenway corridors and focused on developing guidelines for designing and maintaining riparian functions related to wildlife and water resources. The six functions identified included source, sink, filter, barrier, habitat, and conduit. Source refers to a landscape's ability to produce seed or animals capable of migration (connectivity and biodiversity), while sink refers to an area's hydrologic ability to trap sediment, nutrients, and/or pollutants. Filter implies that some substances or organisms may pass through, while limiting other organisms or substances. Barriers, such as a river imply no passage, while conduit implies a path for movement or connectivity. Labaree and others (Shafer, Scott et al. 2000) noted that not all greenways may be capable of supporting all ecological functions and that recreation might impair natural functions.

Labaree's (1992) guidelines for designing greenways included various tasks that an agency should pursue, including conducting a resource inventory, identifying specific habitats, and acquiring as much flood plain and riparian zone as possible. Guidelines for maintenance of riparian functions included acquiring land areas on both sides of rivers, intermittent streams, and wetlands within the riparian corridor. In addition, Labaree recommended investigating flow, sediment, and nutrient dynamics, while maintaining natural vegetation along rivers or streams, specifically by not mowing along riverbanks. According to Labaree, (1992), greenway facilities and trails should be located away from sensitive habitat, including rivers, and wet and/or shallow soils; be constructed of permeable materials; and developed such that trail width is minimized.

Smith and Hellmund (1993) suggested that naturally vegetated riparian greenways reconnect fragmented habitats and promote natural hydrology by filtering stormwater and floodwaters. Forested riparian zones increase groundwater recharge, thus potentially increasing groundwater discharge during low flow periods (Smith & Hellmund, 1993).

Smith and Hellmund (1993) also proposed a flexible design method for developing ecological greenways. The method assumes that conserving water resources, biodiversity, and recreation are greenway goals. The method includes four stages but fails to give specific guidance on ecological greenway characteristics; however, parts indicate directions that may benefit investigating natural resource function in greenways (Smith & Hellmund, 1993). Stage 1, Understanding the regional context, revolves around stepping back from the project and looking at the greater landscape to make sure that one takes in to account the regional significant natural resources and how the greenway might best fit. Stage 2 asks designers to identify project goals and a specific landscape, including larger conservation areas (nodes) in potential greenway corridors. Thus, one might presume that nodes have some value to ecological greenways for habitat and connectivity, which would be indicative of an ecologically- healthy greenway. Stage 3 brings the greenway planner and designer to identifying the specific boundaries of the proposed greenway, while Stage 4 involves creation and implementation of site designs and management plans. As a part of the process, adjacent urban land uses are identified as a source of ecological problems for greenways. This is due in part to edge greenway habitat, which might allow exotic species, pets, and humans to intrude into the greenway, with potentially deleterious effects on biodiversity. Accordingly, greater greenway forested widths may be indicative of a healthier riparian greenway ecosystem (Smith & Hellmund, 1993).

Shafer, Scott, et al. (2000), in proposing a classification system for greenways, suggested different greenway purposes based on adjacent land use. For example, a greenway's primary function in a developed area would include recreation, flood control, transportation, economic development, and aesthetic quality, with secondary functions related to natural resource conservation. This work suggested adjacent land use was a determining factor in conservation of natural resources in greenways. The classification method proposes a dense developed land use around riparian greenways, which, based on the research findings of Lindsey (2003) and Mason, et al. (2007), might limit natural resources conservation.

Linehan et al. (1995) presented a greenway planning approach to conserve biodiversity and connectivity while providing for open space and economic development. The authors found biodiversity to be more sensitive to functional linkage than cultural or recreational uses associated with networks, and found network analysis to be effective in promoting connectivity. Linehan et al. used land cover, wildlife and habitat assessment, and node and connectivity analyses to generate functional greenway networks that would promote biodiversity. Their work suggested that greenway networks are likely to have greater biodiversity as compared to stand alone greenways.

Benedict and McMahon (2002) posited that the development of greenways represent a strategic planning approach to address environmental challenges associated with urbanization and concluded that investing in green infrastructure (i.e., riparian conservation) was more cost effective than traditional engineering approaches (i.e., increasing filtration equipment). Benedict and McMahon (2002) cited New York City's savings of $4 - 6 billion on water treatment by conserving $1.5 billion of riparian infrastructure in the Catskill Mountains. Similar to other approaches (i.e., Hoctor et al. 2004), Benedict and McMahon (2002) proposed a hub and linkage system of green infrastructure with larger parks and greenway corridors.

Fabos (1995) suggested a planning approach where single-purpose projects can be integrated into multipurpose projects through including additional purposes such as water quality protection and recreation. For example, the author suggested that riparian greenways produce high quality water by filtering pollutants from stormwater and conserving biodiversity while also providing opportunities for recreation. The author estimated that most of the landscape needed in the U.S. to maintain biodiversity was in riparian areas and suggested maintaining biodiversity through greenway planning and development.

McGuckin and Brown's (1995) planning approach promoted the use of stormwater structures, such as retention ponds, in a network of greenways to promote biodiversity. The authors suggested that integrating stormwater structures into greenways could increase wildlife habitat and non-consumptive wildlife recreation. McGuckin and Brown's approach implied that greenways with water features have greater hydrologic functions and biodiversity, as well as increased user satisfaction of recreationists, than those greenways that lack such water structures.

Jongman and Pungetti (2004) compared ecological networks to greenways, defining ecological networks as the components necessary to provide for ecosystem and species population needs in an anthropogenic landscape, including natural areas, corridors, and riparian buffers. According to the authors, ecological networks and greenways are thought to provide a source of landscape connectivity and diversity through their linear form. The comparison of greenways and ecological networks suggests that greenways may provide some of the same natural resource functions as ecological networks.

Hoctor et al. (2004) suggested that greenway planning could be utilized as a mechanism to determine the most functional conservation corridors on a regional basis. Hoctor et al. included a four-step process for planning ecologically functional greenways, including identification of ecological areas, ecological hubs, linkages, and creation of networks. Hoctor et al. concluded that their greenway planning process was a powerful planning approach for prioritizing and acquiring conservation hubs and greenway links in Florida, yet cautioned that on the ground confirmation of natural resource function was necessary as a part of the planning and acquisition process.

Baschak and Brown (1995) proposed a planning, design, and management framework and applied it in a case study. The framework was based on an ecological approach for riparian greenways, including an integrated assessment designed to increase the effective size and functional capacity of greenway corridors and networks. While noting the impractical nature of setting aside large tracts of urban land, Baschak and Brown suggested that local governments could increase the effective size of habitat in a greenway by limiting management actions such as mowing, and suggested that communities initiate assessments in an effort to conserve and enhance natural resource functions within greenways.

Baschak and Brown's (1995) assessment framework included six criteria, scored on a three-point scale and summed to give an overall ecological value. The instrument was designed to assess an entire site's natural resource conditions and thus was not suitable to determine impacts associated with specific features such as recreational trails in the greenway. However, plant community structure, including percent canopy cover, could be utilized to assess trail impacts on habitat; this approach has been used in other studies as well. For example, Cole and Bayfield (1993) developed experimental methods to examine the effects of recreational trampling on vegetation.

It is apparent from the planning literature that greenways may provide many functions (Shafer, Scott et al. 2000), and may and/or should be located in natural resource rich riparian zones if conserving biodiversity is a priority (Fabos, 1995; McGuckin & Brown, 1995). Greenway planners advance the idea that planning can be utilized to establish ecological greenway corridors and networks (Hoctor et al. 2004; Linehan et al. 1995). McGuckin and Brown (1995) and Shafer, Scott, et al. (2000) indicated that recreation continued to be a core goal in greenway planning and development, while others (e.g., Labaree, 1992; Smith & Hellmund, 1993) made specific recommendations on methods that may be used to minimize the effects of recreation structures on natural resources. The current study, by assessing the effects of trail footprint width, trail age, and surface type on percent canopy cover and surface temperature, may help designers and planners understand the effects of greenway trails on natural resources and how to reduce those effects.

Greenway conservation goals. Recreational greenway goals include direct or implied restoration and conservation of natural resources including habitat, biodiversity, connectivity, and hydrology (Ahern, 1995, 2004; Baschak & Brown, 1995; Murfreesboro, Tennessee, 1993; Hoctor et al. 2004; Lindsey, 2003; Little, 1990; Metropolitan Board of Parks & Recreation, 2002; National Park Service, 1993). The National Recreation and Park Association suggested that greenways promote connections to larger parks, enhance ecology, and provide outdoor recreation (Mertes & Hall, 1995), and Shafer, Scott et al. (2000) argued that greenways serve to balance human needs and natural resource protection. Similarly, Searns (1995) suggested that "land and resource stewardship" (p. 72) includes conservation of wildlife, habitat, flood control, and water quality, in addition to urban beautification and recreation, as greenway goals.

Ahern (1995) suggested that biodiversity should be the primary goal if greenways were to be a part of sustainable development. Relatedly, Baschak and Brown (1995) suggested that their greenway planning framework's goal was to maintain biodiversity and ecological processes. In greenway plans for Florida and New England, Hoctor et al. (2004) and Fabos (2004), respectively, included maintenance of ecological functions as a key greenway goal. For example, Hoctor et al. (2004) utilized a regional landscape methodology to develop an "ecologically functional . . . greenway system" (p. 223) designed to restore and protect Florida's natural resources, including biodiversity, or the numbers of plants and/or animals.

The National Park Service (1993), in a case study of six greenway systems, found all to have stewardship of natural resources as a high priority. Tennessee's Governor's Council on Greenways and Trails (2001) included conservation of greenway corridors as a goal for supporting wildlife migration, flood control, and pollution filtration. McGuckin and Brown (1995) sought to include stormwater structures in greenways in an effort to enhance water quality, connectivity, and greenway networks. Similarly, Jongman and Pungetti (2004) suggested that nature conservation was the key greenway goal, and Fabos (1995) recommended maintaining hydrological functions as a greenway goal, suggesting greenways could be utilized to enhance water quality.

Conservation goals are often stated in greenway master plans. For example, Lindsey (2003) identified Indianapolis, Indiana's Greenway Master Plan (GMP) goals as including conserving habitat, open space, forests, and wetlands. Nashville, (Metropolitan Board of Parks & Recreation, 2002) and Murfreesboro, Tennessee's (Murfreesboro, Tennessee, 1993) greenway goals include biodiversity, connectivity, and hydrologic functions. For example, Nashville's GMP goals suggested conserving corridors of naturally vegetated lands, riparian areas, and animals and plants. Secondly, Murfreesboro's GMP goals were more specific and included promoting a land ethic, environmental restoration, improvement of water quality, and habitat conservation (Murfreesboro, Tennessee, 1993).

The City of Brentwood Tennessee's Parks, Trails, and Recreation Plan (REM Design Group, 2002) goals include conservation and preservation of natural open space, and creating a network of recreational trails and green space that connect parks and natural resources. Specifically, Brentwood's Goal Two seeks to "Preserve non-agricultural open spaces, hillside and farm land viewsheds and natural resources in Brentwood's Planning Area as part of the amenities of the developing green space network . . . ." (p. 55). Brentwood's plan objectives and policies suggest that natural edges or linear parks should be used as buffers to enhance viewsheds and as ecological resources, and that the city should increase its capacity to effectively manage habitat and wildlife (REM Design Group, 2002).

Community greenway goals often include the stewardship of natural resources and maintaining habitat, biodiversity, connectivity, and hydrology (Ahern, 2004; Baschak & Brown, 1995; Fabos, 2004; Murfreesboro, Tennessee, 1993; Hoctor et al. 2004; Lindsey, 2003; Mertes & Hall, 1995; Metropolitan Board of Parks & Recreation, 2002; National Park Service, 1993; Governor's Council on Greenways & Trails, 2001). Greenway goals may also focus agencies on balancing human needs with natural resource conservation (Shafer, Scott, et al. 2000). Finally, some communities' greenway goals included conserving habitat, open space, forests, and wetlands (Lindsey, 2003), while others identified water quality enhancement as a greenway goal (Murfreesboro, Tennessee, 1993). A common recreational greenway goal identified in the literature focuses on conservation of natural resources, including maintaining and restoring habitat and biodiversity (Ahern, 1995; Lindsey, 2003).

While conservation of natural resources is presumed to be a goal of most greenways, it continues to be important to assess the extent to which these goals are being met by specific greenways. This assessment is important to provide decision makers and greenway managers empirical evidence regarding whether or not local greenway design, development, and management are attaining the desired conservation goals and ecosystem functions.

Ecological Functions

Properly functioning ecological conditions have three distinct benefits vital to the well-being of the human population. The benefits include production of ecological goods, such as medicines and food, production of non-market values such as aesthetics, and finally, ecosystem services such as oxygen production, carbon sequestration, and nutrient and water cycling (Naeem et al. 1999). Particular groups of species carry out specific functions within ecosystems, and some species' functions may be disproportionately greater than others in influencing ecological processes and habitat, giving them a higher importance in the ecosystem. Finally, high levels of biodiversity have been recognized as a key indicator of high levels of ecosystem functioning (Naeem et al. 1999).

Biodiversity. Hay (1991), Ahern (1995) and Fabos (2004) stated that greenways play an important role in biodiversity conservation, and Naeem et al. (1999) concluded that biodiversity has significant benefits to society. Naeem et al. defined biodiversity as components of the biotic community, including plants, animals, and microorganisms, and the authors asserted that the biotic community was responsible for controlling ecosystem processes and functions.

Habitat has been linked to biodiversity in natural areas, and specifically in riparian zones (Brower & Zar, 1984; Forsey & Baggs, 2001; Hawes & Smith, 2005; National Research Council, 2002; Pauchard, Ugarte & Millan, 2000; Wenger, 1999). Additionally, riparian greenway ecology studies have linked poor habitat to intensive greenway vegetation management practices such as larger mowing area and increased trail widths. For example, increased mowing and trail widths have been associated with low numbers of development sensitive mammals (Schiller & Horn, 1997) and lower avian diversity (Mason et al. 2007). Finally, Baschak and Brown (1995) suggested that greenway mowing decreased the effective area of natural habitat, and thus biodiversity.

Riparian ecological functions. Riparian zones have been documented as some of the most biologically diverse environments in the American landscape, consequently representing highly functional ecosystems (e.g., Hawes & Smith, 2005; Hay, 1991; National Research Council, 2002; Wenger, 1999). Wenger (1999) defined riparian zones as areas along streams with higher biodiversity than adjacent areas. Riparian zones (Bodie, 2001; Broadmeadow & Nisbet, 2004; Cockle & Richardson, 2003; Hawes & Smith, 2005; National Research Council, 2002; Peterjohn & Correll, 1984; Rodewald & Bakermans, 2006; Rottenborn, 1999; Stauffer & Best, 1980; Wenger, 1999) include water, soil, vegetation, and wildlife and provide three primary ecosystem functions: connectivity, hydrology, and biodiversity.

Riparian vegetation provides a number of important ecological functions, such as maintaining biodiversity and habitat (Forsey & Baggs, 2001; Gregory, Swanson, McKee, & Cummins, 1991; Hammit & Cole, 1998; Mason et al. 2007; Nadkarni, Merwin, & Nieder, 2001), and supporting natural hydrology (Ahern, 2004; Ettema, Lowrance, & Coleman 1999; Labaree, 1992; National Research Council, 2002; Smith & Hellmund, 1993; Wenger, 1999). For example, riparian vegetation demonstrates a form of biological diversity in that each plant layer (e.g., ground, herb, shrub, understory and canopy) represents a variety of different species (Brower & Zar, 1984; Nadkarni et al. 2001). In addition, vegetation is responsible for providing food and habitat for all animals (Gregory et al. 1991). Riparian trees are responsible for avian and mammal habitat (Mason et al. 2007; Wenger, 1999), plant habitat (Nadkarni et al. 2001) stream bank stability, water infiltration, nutrient uptake and cycling, and fish, and insect habitat, and importantly, maintaining cooler air, water, and surface temperatures (Chen, 1991; Chen et al. 1993, 1995, 1999; Hawes & Smith, 2005; Jo et al. 2001; Ledwith, 1996; National Research Council, 2002; Wenger, 1999).

Riparian forests provide wildlife habitat (Forsey & Baggs, 2001; Hawes & Smith, 2005; Mason et al. 2007; Meyer et al. 2003; Sinclair et al. 2005). As examples, Meyer et al. (2003) noted that riparian zones provided valuable habitat and enhanced wildlife connectivity while Smith and Hellmund (1993) suggested that greenways provide ecological goods and services by conserving habitat and wildlife connectivity. In addition, Forsey and Baggs (2001) studied the impacts of tree harvesting in riparian areas and found that sensitive mammals were negatively impacted by small disturbances in riparian forest habitat.

Mason et al. (2007) found that the percent of managed area (i.e., trail, mowed or otherwise manicured percent of total area) with no or few trees the most consistent predictor of a lack of avian diversity ($p < .001$) within the riparian greenway. Several of the avian guild habitats were specific to vegetation stratification, including tree cavity nesting (which implies the need for mature trees with canopy), and understory, shrub, and ground nesting habitats. This demonstrates that vegetation layering should be present if greenways are to support biodiversity. Mason et al. suggested that minimizing managed areas (e.g., mowing) in greenways could maximize avian habitat, potentially allowing for twice the number of development sensitive avian species as compared to greenways with trails 6 - 8 ft (1.8 - 2.4 m) wide and adjacent mowed areas. Thus, riparian vegetation, specifically trees and tree canopy, are important to avian diversity (Mason et al. 2007), mammal diversity (Brower & Zar, 1984; Forsey & Baggs, 2001; Gregory et al. 1991; Hammit & Cole, 1998; Mason et al. 2007; National Research Council, 2002; Wenger, 1999), plant diversity (Nadkarni et al. 2001), hydrology (National Research Council, 2002; Smith & Hellmund, 1993; Wenger, 1999), and habitat connectivity (Meyer et al. 2003; Smith & Hellmund, 1993).

Recreational impacts on ecological functions. Recreation ecology is the study of recreational impacts on the natural environment, generally in wilderness and natural areas (Leung & Marion, 2000; Liddle, 1997). For example, researchers have explored the effects of recreational activities on vegetation (Cole, 1989a, 2004; Cole & Bayfield, 1993; Marion, 1991). In most cases, researchers are exploring direct impacts associated with a particular recreation activity such as hiking (Cole, 2004; Cole & Bayfield, 1993; Cole & Spildie, 2007; Marion, 1991). Recreational activity effects water and soil (Gregory et al. 1991; Hammit & Cole, 1998; Liddle, 1997), vegetation (Cole, 1995; Cole & Bayfield, 1993; Dale & Weaver, 1974; Hall & Kuss, 1989; Tonnesen & Ebersole, 1997; Tyser & Christopher, 1992), and wildlife (Bennett & Zuelke, 1999; Knight & Cole, 1991; Miller, Knight & Miller, 1998). For example, the effects of trampling soil and vegetation on water include increased pollutant (i.e., nutrient and sediment) loading and are typically associated with loss of vegetation, soil compaction, soil erosion, and increased runoff (Gregory et al. 1991). Increased nutrient and sedimentation loading may also lead to loss of both habitat and biological diversity (National Research Council, 2002; Walsh et al. 2005; Wenger, 1999).

Trail construction or use via trampling during hiking can destroy vegetation (Cole, 1995; Cole & Bayfield, 1993; Kuss & Hall, 1991; Hammit & Cole, 1998; Leung & Marion, 2000; Marion & Olive, 2006), or altering vegetation height and growth (Kuss & Hall, 1991; Tonnesen & Ebersole, 1997), changing species composition by selecting for resistant species (Cole, 1995; Kuss & Hall, 1991), and/or by the introduction of exotic species (Cole, 1993; Leung & Marion, 2000; Tyser & Christopher, 1992). For example, Tonnessen and Ebersole (1997) found that herbaceous and some woody species, such as shrub and tree seedlings, along trails decreased in number as a result of human trampling.

Recreational hiking affects wildlife by destroying habitat and creating disturbances resulting in physiological and psychological stress, which affects wildlife behavior (Bennett & Zuelke, 1999; Boyle & Samson, 1985; Cassirer, Freddy, & Ables, 1992; Cole, 1993; Knight & Cole, 1991; Miller, Knight & Miller, 1998). As examples, Bennett and Zuelke (1999) found that recreational disturbances in forested habitat had at least temporary effects on avian movement and behavior, and others (i.e., Cassirer, Freddy & Ables 1992) found that elk flee when approached by cross-country skiers. Finally, Knight and Cole (1991) found that disturbances could displace wildlife from necessary habitat and disrupt reproductive success.

In summary, hiking impacts the soil, vegetation, water, and wildlife of an area (Cole, 1993, 1995; Dale & Weaver, 1974; Dawson, Huinz & Gordon, 1974; Hall & Kuss, 1989; Hammit & Cole, 1998; Knight & Cole, 1991; Leung & Marion, 2000; Liddle, 1997; Miller et al. 1998; Tonnesen & Ebersole, 1997; Tyser & Christopher, 1992). Soils become compacted, increasing runoff and pollutant loads (Gregory et al. 1991; National Research Council, 2001; Walsh et al. 2005; Wenger, 1999), while vegetation is destroyed or its growth is stunted (Tonnesen & Ebersole, 1997). Finally, wildlife can be affected by the noise and disturbances of recreational use (Bennett & Zuelke, 1999). Interestingly, almost all recreation ecology studies have been conducted in wilderness and natural areas, with only a few being conducted in developed areas including greenways. The current study addresses a gap in the recreation ecology literature by assessing greenway trail footprint width, and trail age effects on percent canopy cover and surface temperature.

Studies designed to evaluate greenways' site-specific ecological functions. Several studies have examined natural resource conditions of greenways utilizing case studies and systems approaches. Lindsey (2003) utilized ad hoc ecology studies in an effort to relate greenways to sustainable development. Mason et al. (2007) and Schiller and Horn (1997) investigated biodiversity, while Sinclair et al. (2005) and Miller and Hobbs (2000) investigated nest predation.

Baschak and Brown's (1995) case study revealed that no greenway landscape element investigated had high ecological value, and only three of seventeen landscape elements had moderate scores for ecological value. Similar to Baschak and Brown's findings, other studies (e.g., Mason et al. 2007; Schiller & Horn 1997; Sinclair et al. 2005; Whitford et al. 2001) have documented degraded natural resource conditions in riparian greenways, despite stated greenway conservation goals.

Lindsey (2003) analyzed natural resource conditions in six Indianapolis, Indiana, recreational riparian greenways utilizing a case study approach. He identified ecological indicators, such as canopy cover, species frequency, dominance, and habitat quality, as variables that planners could study to determine if greenways were sustainable (Lindsey, 2003). Study results indicated that five of six greenways assessed were rated poor or fair for habitat quality; forest cover was low (11%) compared to the historic county coverage (98%) and residential area coverage (13%). Furthermore, forest vegetation was dominated by non-native species. While informative, the study failed to relate greenway trail impacts to natural resource conditions and lacked direct measures of biodiversity, connectivity, and habitat quality. Finally, Lindsey suggested that habitat quality would change over time due, in part, to greenway management decisions such as mowing extent and frequency.

Schiller and Horn (1997) questioned the wildlife conservation value of greenways located in the Mid-Southeastern United States. The intent of the study was to examine the relationships between habitat quality and presence of selected disturbance-sensitive mammals (i.e., deer and fox). Study methods included utilizing scent stations (scent attractant surrounded by sand in which tracks can be identified) to determine the presence of deer and fox. Independent variables included vegetation management, corridor width, land use, and connectivity. Observations and reviews of greenway master plans, maps, and/or other written materials were conducted and interviews utilized to obtain the independent variable data. Vegetation management was classified into four attributes: 1) city park (lawn with few mature trees), 2) lawn with small forest (less than one half forest), 3) one half to three fourths forest with the rest lawn, and 4) primarily forest (greater than three fourths forest). Greenway width was categorized into narrow (less than 100 ft [30.4 m]), medium (most of greenway greater than 100 ft [30.4 m] but some less than 100 ft [30.4 m]), and wide (greater than 100 ft [30.4 m]). Principle land use was divided into categories based on land use densities and included large forests, exurban (rural with patchy forest), suburban residential, suburban mixed use (which included commercial), urban residential (urban or high residential densities), and urban mixed use. Connectivity was determined based on greenway connections to larger areas (small-scale 10 - 100 hectares and large-scale greater than 100 hectares).

The study found that less than 50% of greenway segments contained fox or deer, and the authors concluded that adjacent land use, vegetation management, and greenway width were key factors related to the presence or absence of fox or deer. For example, the presence of fox and deer was strongly correlated to greenway vegetation management (fox, $p < .003$, deer, $p < .0023$); no greenway managed as a city park had both species. Additionally, the presence of fox was positively related to greenway corridor width ($p < .0004$), and finally, 13 of 19 greenways managed as mostly forest had fox only. Apparently, there is an inverse relationship, as suggested by Baschak and Brown (1995) and documented by Schiller and Horn (1997), between vegetation management and biodiversity. However, fox and deer data associated with primarily forested greenways suggest other factors, such as land use, may play a role in animal presence and diversity (Schiller & Horn, 1997).

Schiller and Horn (1997) found that adjacent land use was correlated with fox and deer presence. For example, fox and deer were most likely found in greenways surrounded with the least amount of urban development. The study implied that greenways in developed areas might never host high levels of animal biodiversity as few greenways have the required forested width or adjacent forested land to support such populations. However, because of the association of species present and vegetation management practiced, it would appear that natural vegetation management (i.e., less mowing and more forested area) might help increase biodiversity by increasing natural habitat in the greenway as suggested by Baschak and Brown (1995).

Mason et al. (2007) investigated the effects of forested riparian corridor width, adjacent land use, land cover (e.g., managed areas, paved surface, grass, etc.) and vegetative structure on avian diversity. The researchers sought to recommend how greenway planners and managers could increase habitat for avian species. Birds were sampled in 50 m circular plots along 34 forested riparian greenway segments (300 square m each) in Raleigh and Cary, North Carolina. Forested corridor widths were determined utilizing aerial photography and varied from 106 to 4,265 ft (32.5 - 1300 m) (Mason et al. 2007).

Adjacent land use was similar on both sides of the corridor and determined based on zoning which included low-density residential (less than 7.5 lots per hectare), high density residential (greater than 7.5 lots per hectare), and office/institutional land uses. Land cover was evaluated by analyzing aerial photographs and examining the surface areas of tree canopy, pavement, lawn, water, agriculture, and bare earth. These data were used to calculate percent cover class adjacent to each sampling location. Greenway composition and vegetation stratification were determined by estimating percentages of mature forest (less than six m vegetative height), young forest (greater than 6 m vegetative height), managed area, and stream area. Managed areas included roads, mowed and maintained surfaces, trails, and ball fields within each 50 m avian sampling plot; mature forest was the dominant cover class, although each plot was further defined based on percent canopy cover and canopy height. Percent canopy cover was determined utilizing a densitometer, while percent pine, hardwood, vine, shrub, and ground cover were visually estimated based on the following categories (0 = none, 1 = 0 - 20%, 2 = 21 - 40%, 3 = 41 - 60 %, 4 = 61 - 80%, 5 = 81 - 100%).

Study results suggested that forested greenways greater than 50 m in width, with less managed area, and lower levels of adjacent land use density maximized native bird diversity. For example, no interior forest avian species were recorded in greenways less than 50 m wide, and researchers found an inverse relationship between development-sensitive native bird diversity and percent coverage of managed areas such as trails and mowed areas ($p < .003$). Finally, total species abundance in greenways decreased as adjacent pavement and bare earth increased. The study, similar to those conducted by Schiller and Horn (1997) and Baschak and Brown (1995), implied that greenway planners and managers seeking to increase avian diversity should limit vegetation management, increase greenway width to greater than 50 m, and develop greenways in areas with low levels of surrounding development (Mason et al. 2007).

Miller and Hobbs (2000) examined the effects of recreational trails and human activity on nest predation in riparian areas. The investigators placed artificial nests along three transects: one close to a trail; one parallel to the trail and across the river; and another reference transect in an undisturbed natural area. Predation was highest in the reference transect and lowest along the transect closest to the recreational trail. Birds were the primary predator around the recreational trail, while mammals tended to stay away from the recreational trails. The species preying on the nests next to trails included blue jays, magpies and grackles, and are known to inhabit human-dominated landscapes. This study implied that increased recreational use and human activity decrease the likelihood of mammalian nest predation along trails but may increase avian nest predation by non-development sensitive species.

Similarly, Sinclair et al. (2005) studied the effects of forest corridor width, adjacent land use, and habitat structure on mammalian nest predators in greenway corridors. The study utilized greenways that were mainly riparian mixed hardwood and pine forests in Raleigh and Cary, North Carolina. Mammalian nest predation was examined using scent stations that were sampled five times over 24-hour periods. Forested corridor width, adjacent land use, and habitat structure were determined in a fashion similar to that used by Mason et al. (2007) and included utilizing aerial photographs and analyzing 300 square m plots. Sinclair et al. (2005) identified land cover, which included buildings, pavement, lawn, water, agriculture, and bare earth. Habitat structure was determined in a 20 m radius around scent stations and included data on trail type, trail width, managed area, and scent station distance to water, and forest type and structure.

Sinclair et al. (2005) found nine species of potential nest predators including raccoons, mice and rats, striped skunks, domestic cats, opossums, red and gray fox, and gray squirrels. The number of nest predators was found to increase as forested corridor width decreased, and decreased as adjacent buildings increased. Additionally, the authors found that mammalian nest predation increased as trail width and mature forest increased. Results of this study implied that in order to minimize mammalian nest predation, greenways needed less mature forest and more development (buildings) as adjacent land use. However, Sinclair et al.'s implication is contrary to the habitat needs of many avian species (Mason et al. 2007) and thus the authors suggested there should be some balance in controlling nest predation and avian needs (Sinclair et al. 2005).

In summary, the previously described studies, in exploring greenway ecology, have utilized measures of vegetation amount and condition (i.e., mowed area) in an effort to assess greenway ecosystem functions. Similarly, vegetation characteristics in recreation ecology studies included vegetation amount, composition, and condition.

According to Hammit and Cole (1998), vegetation amount has been the most often used impact parameter for measuring recreational effects on natural resources. Percent canopy cover is an indirect measure of the upper canopy layer of vegetation and a representative measure of vegetative cover, defined as a percentage of a plant's vertical projections above the ground (Brower & Zar, 1984; Hammit & Cole, 1998). Marion and Leung (2001), Hall and Kuss (1989), Marion and Cole (1996), and Mason et al. (2007) all used a measure of percent vegetative cover to describe recreational trail and/or campsite impacts, and Mason et al. (2007) identified several avian species in greenways requiring mature trees and canopy habitat. Importantly, Leonard and Whitney (1977) suggested that trails and trail areas receive more light than other areas, implying that trails reduce canopy cover thereby increasing light exposure and surface temperature. Finally, Mason et al. (2007) suggested that allowing tree canopy cover over greenway trails to remain intact could minimize negative recreational trail effects by allowing canopy avian habitat to remain intact. Thus, it appears that studies of percent canopy cover and surface temperature may be appropriate for measuring ecosystem function in greenways.

Measuring Ecological Functions

Ecology studies designed to describe ecosystem functions may utilize detailed species surveys and/or habitat measures as indicators of ecosystem functions (Brower & Zar, 1984; Mason et al. 2007). According to Brower and Zar (1984), there are three generally accepted methods used to conduct these assessments. The first is to carry out a detailed inventory of the plant community, identifying all species present (Brower & Zar, 1984; Hammit & Cole, 1998). While this method has merit in describing detailed floristic characteristics of an area, it is limited by the need for a highly trained plant taxonomist and may not be cost- or time-effective (Brower & Zar, 1984; Marion, Leung, & Nepal, 2006). However, as an alternative approach, one may sample a component of the plant community, such as tree species diversity.

Secondly, one can characterize the community types utilizing dominant species categorization, such as oak-hickory forest, meadow or wetland. This method includes general information on one level of community type and some information on microhabitat (Brower & Zar, 1984). This method is limited in application to this study in that it lacks detail to allow for site comparisons to determine trail footprint effects on natural resource conditions. The third technique is a physiognomic assessment and allows one to assess the elements of vegetation form, appearance, and habitat. Brower and Zar (1984) posited that physiognomic assessment techniques are descriptions of vegetation broad enough to be used by non-specialists, yet result in data on the basic organization, general appearance, and specific forms of vegetation. Physiognomic assessment has the advantage of being non-technical, detailed, non-quantifiably overwhelming, accurate, and flexible, but organized (Brower & Zar, 1984).

Physiognomic assessment lends itself to the current study because its flexibility allows assessment of the effects of greenway trail footprint, trail age, and surface type on vegetation form and microhabitat, specifically percent tree canopy cover (percent canopy cover) and surface temperature. Percent canopy cover and surface temperature are measures of physical habitat components and may be related to one another (Chen, 1991; Chen et al. 1993, 1995; Jo et al. 2001; Ledwith, 1996; Nelson, Macedo, & Valentine, 2007).

Percent canopy cover as a measure of ecological function. Percent canopy cover represents the quantity and allocation of leaf area (Maco & McPherson, 2002) and "is the driving force behind the urban forest's ability to produce benefits for the community" (p. 270). Percent canopy cover is an indirect measure of habitat density in the upper level of the forest ecosystem (Brower & Zar, 1984; Mason et al. 2007) and is responsible, in part, for controlling physical and chemical functions associated with temperature, moisture, and light availability (Brower & Zar, 1984; Chen, 1991; Chen et al. 1993, 1995; Ledwith, 1996; Maco & McPherson, 2002).

Importantly, percent canopy cover has been recognized as a factor dominating ecosystem processes and functions in developed environments (Maco & McPherson, 2002; Whitford et al. 2001) and suggested as being related to air, surface, and water temperature through shading (Carlson & Groot, 1997; Chen, 1991; Chen et al. 1993, 1995; Wenger, 1999). For example, Carlson and Groot (1997) found that as canopy openings increased, surface temperatures increased. Average and extreme soil temperatures were greatest in areas with the largest canopy openings. Carlson and Groot (1997) may have bearing on this study, as canopy openings along the greenway trails may be proportional to trail footprint width and similarly affect surface temperature.

Surface temperature as a measure of ecological function. Increased air, surface, and water temperatures have been associated with decreases in forest canopy cover (Carlson & Groot, 1997; Chen, 1991; Chen et al. 1993, 1995; Jo et al. 2001; Ledwith, 1996; McCullough, 1999; Wenger, 1999), and air and surface temperature have been related to different surface types (Akbari, Resenfeld, & Taha, 1995; Aseada, Thanh, & Wake, 1996). As examples, Ledwith (1996) found that air temperature increased as forested buffer width decreased following removal of riparian trees. Chen et al (1993) found that daily averages of air and soil surface temperature were consistently lower in the forest interior as compared to a clear-cut or edge site.

Chen et al. (1993) found that air and soil temperatures decreased along an environmental gradient from the forest edge to the forest interior. Importantly, soil surface temperatures were consistently lower at forest interior sites as compared to edge or clear-cut areas. Interestingly, greater differences were observed for soil surface temperature during partly cloudy days between the forest edge and forest interior as compared to sunny days. Finally, researchers found that the greatest surface temperature variability existed at the forest edge, and was perhaps related to site orientation. For example, a southwestern facing forest edge receives more solar radiation than would a eastern or northern facing forest edge and thus would be exposed to greater solar heat gain (Marsh, 2005). The northern facing forest edge would have a shadow corridor along its northern length. The authors concluded that edge microclimates were not "intermediate" to forest interior or clear-cut sites for temperature (Chen et al. 1993).

Chen et al. (1995) investigated the significance and extent of the impacts of forest edge on microclimate, including soil temperature. Researchers found that edge effects typically extended greater than 30 m into forest interiors, yet found that soil temperature change did not extend as far into the forest interior as did air temperature changes. For example, air differences were seen as much as 180 m (590.5 ft) into the forest interior where soil temperature differences were seen up to 60 - 120 m (196.8 - 393.7 ft) into the forest. Moreover, gradient soil surface temperatures were greatest along southwestern facing edges, again suggesting edge orientation plays a significant role in soil surface temperatures, as this would effect the amount of solar radiation exposure.

Jo et al. (2001) concluded that surface temperature was related to land cover type and that surface temperature measurements may be a significant indicator of sustainability. The study investigated different land covers and their relationship to surface temperature. Surface temperature and land cover data were taken from satellite imagery. The authors measured 5 - 7°C (9 - 13°F) differences between forested areas and residential areas. As developed areas increased in density (i.e., from residential to commercial), surface temperature differences ranged from 7 - 9°C (13 - 16°F) greater in the developed areas as compared to the forested areas.

Asaeda et al. (1996) investigating heat storage in various surface types found that heat storage, emissivity, and surface temperature was significantly greater for asphalt when compared to concrete and bare soil. Similarly, Akbari et al. (1995) and Akbari, Pomerantz, Taha (2001) suggested that dark surfaces including asphalt effect climate and energy use in cities by increasing air temperature. Akbari et al. (2001) reported that developed areas with darker surfaces and less vegetation were heated by the sun during the daylight hours, resulting in increased air temperatures of 1 - 5°C (2 - 9°F) warmer than surrounding areas with fewer darker surfaces and more vegetation (i.e., rural areas) (Akbari et al. 2001; Heat Island Group, 2005). Akbari et al. (2001) suggested that pavement and structure surface temperatures increase dramatically to the point of increasing ambient air temperature. McPherson (1994) concluded that the thermal mass associated with urban areas including pavement (i.e., roads and parking areas) and air temperature variability was in part related to how the structures (e.g., roads, houses, etc.) absorb heat from the sun.

Wenger (1999) suggested that riparian vegetation shaded and helped maintain cooler groundwater and stream temperatures, while Jo et al. (2001) found that surface temperatures were 5 - 7°C (9 - 12°F) cooler in forested areas as compared to road surfaces. Finally, changes in temperature appear to be related to the shading provided by riparian forest trees and increase with tree canopy removal (Carlson & Groot, 1997; Chen, 1991; Chen et al. 1993, 1999; Jo et al. 2001; Ledwith, 1996; McPherson, 1994).

Measuring surface temperatures at the trail center, forest edge, and at associated forested interior control sites may yield an understanding of the greenway trail's contribution to a potentially altered microclimate (McPherson, 1994). Finally, measuring percent canopy cover and surface temperature at multiple locations on greenway trails appears to be cost- and time-effective.

Tree species diversity as a measure of ecological function. Tree species diversity is an important component of the forest ecosystem. Diversity of trees, wildlife, landscapes, and other landforms has been suggested as one of the most distinguishing aspects of an urban forest, and Dwyer, Nowak, Noble, Heather, and Sisinni (2000) concluded that urban forest inventories and monitoring will provide necessary background information for understanding and management of the benefits of urban forests. Moreover, the National Forest Management Act of 1976 recognized the importance of tree species diversity (Brashears, Fajvan, & Schuler, 2004), and directed the USDA Forest Service to maintain forest tree species diversity as it harvested trees for market (University of New Mexico, n.d.). In the current study, collecting data on tree species diversity in a greenway will provide a direct measure of biodiversity and address one limitation identified by Lindsey (2003) in his assessment of recreational greenways in Indianapolis, Indiana.

Forests are typically divided into different types based on the dominant tree species. In Tennessee, the major forest types are oak-hickory (73%), oak-pine (13%), pine (10%), and bottomland hardwood (5%) with over 200 different tree species across the state (Hopper, Applegate, Dale, & Winslow, 1995). Hedman and Van (1995) explored riparian forest succession in the Southern Appalachian Mountains and found species composition changed over time. For example, dominant species in younger forest communities tended to be Yellow Popular, Birch, Basswood, and Black Cherry, while Hemlock, Pine, and Oak tended to dominate older forest communities (Hedman & Van, 1995). Brashears et al. (2004) found 25 tree species prior to clearcutting, with Sugar Maple, Yellow Popular, and Basswood with the highest importance for canopy trees. Following clearcutting, four species (i.e. Yellow Popular, Sugar Maple, Black Birch, and Striped Maple) represented 70% of the species regenerating on the sites. In Middle Tennessee, Schibig (1996) differentiated the Radnor Lake forest community by habitat types and noted oak-hickory forests dominated the majority of the forest community. However, Silver Maple, Sugarberry, Elm, Green Ash, and Box Elder dominated the Radnor Lake riparian community (Schibig, 1996).

Trees species diversity, like biodiversity, is important from an ecological perspective as higher levels of diversity demonstrate the long-term stability of the forest ecosystem (Naeem et al. 1999; Urban Forest, n.d.). A lack of diversity increases the forest's susceptibility to pests and/or disease (Urban Forestry, n.d.). For example, it might take only one pest or disease to destroy a majority of trees in a forest with low diversity (i.e., many individuals, few species). However, if tree species diversity is high (i.e., many species, fewer individuals), no one pest or disease has the capacity to impact many individuals. Thus the stability of the forest is enhanced by higher tree species diversity (Naeem et al. 1999; Urban Forest, n.d.).

Furthermore, tree species diversity is important as different species help to create the variety of habitat and structure in the forest environment (Nadkarni et al. 2001; National Arbor Day Foundation, n.d.), and a particular tree may include specific habitat (e.g., food, shelter) for a specific plant (Nadkarni et al. 2001) or wildlife species (University of Tennessee, n.d.). For example, evergreens, such as Red Cedar and Douglas Fir, create year round shelter for wildlife, as well as provide windbreaks. Deciduous trees, such as Hackberry, lose their leaves in winter, yet still have a high value to wildlife, specifically small mammals and birds (National Arbor Day Foundation, n.d.). In addition, tree species that reach larger diameters become hollow providing den cavities for wildlife (University of Tennessee, n.d.). Tree species diversity enhances the stability of the forest (Naeem et al. 1999; Urban Forest, n.d.), increases plant and animal habitat in the forest ecosystem (Nadkarni et al. 2001; University of Tennessee, n.d.), and represents a direct measure of biological diversity within the forest, thus addressing one of the limitations of historic greenway studies (Lindsey, 2003).

Collecting tree species data has generally been carried out utilizing two basic methodologies, linear transect sampling and plot sampling (Brower & Zar, 1984). In some cases, sampling plots are established along linear transects as was done by Schibig (1996). Transect sampling requires that a line be established, and then trees that intersect the line, or that are in some way close to the line are sampled. Plot sampling involves selecting an area of a specific size and generally sampling all of a specific type of vegetation, such as trees, in the plot. Cotham and Curtis (1956), and Brower and Zar (1984) suggested transect sampling for tree species diversity. Cotham and Curtis compared five different transect methods; closest individual, nearest neighbor, random pairs, point centered quarter (PCQM), and quadrat methods and concluded that PCQM provided the most reliable results with the least effort. PCQM requires that quarters be established around randomly selected points along the transect, from which the closest tree meeting study criteria, such as diameter, may be sampled (Cotham & Curtis, 1956). In contrast, the Carolina Vegetation Survey (Peet, Wentworth, Duncan, & White, 1997) method allows the investigator to flexibility regarding plot location, size, shape, and specific data collected. For example, one could place plots along a common transect, or randomly locate plots in a forest ecosystem. The Carolina Vegetation Survey generally requires that plots be subdivided and randomly sample every plant in 10% of sub plots that meet study criteria (i.e. trees of certain size) (Peet et al. 1997). The PCQM as described by Cotham and Curtis (1956) was used in the current study.

Measuring Trail Impacts on Ecological Functions. Experimental studies that have examined the effects trails have on natural resources have focused almost exclusively on wilderness environments (e.g., Leung & Marion 2000; Miller et al. 1998; Tonnesen & Ebersole, 1997). These traditional wilderness recreation ecology studies have begun to focus on ecological indicators, partly in response to management frameworks such as Stankey's (1985) Limits of Acceptable Change (LAC) planning system (Leung & Marion, 2000) and to address time and cost constraints. LAC focuses on limiting impacts associated with recreational activities and has been adopted and used as a management framework by several resource management agencies (Jackson & Burton, 1999).

Recreation ecology research designs have fallen into four broad categories including descriptive surveys, comparison studies of test sites and adjacent control sites (or paired sampling approach), before and after natural experiments, and before and after simulated experiments (Leung & Marion, 2000). Sampling approaches are generally in two broad categories consisting of sampling-based and census-based approaches. Sampling-based approaches include systematic point sampling and transect use. Systematic point sampling is characterized by sampling at selected intervals, with the start point randomly chosen, and collecting data on variables such as vegetation condition or recreational use levels (Leung & Marion, 2000). Cole (1983) suggested that point sampling methods, as compared to census-based methods, allowed investigators to develop more accurate detail on environmental characteristics and trail impact indicators. Marion and Leung (2001) compared the systematic point sampling and problem census (i.e., identifying all cases of a particular problem) trail impact sampling methods along a 15-mile section of the Appalachian Trail in Great Smoky Mountains National Park. The study's purpose was in part "to compare the procedures, data type, and utility of two common assessment methods . . . ." (p. 18). The researchers found that the systematic point sampling method provided better accuracy and reliability, when compared to census methods while measuring user impacts with continuous data, such as percent canopy cover.

Transects have been used extensively to assess trail and other impacts on natural environments (Brower & Zar, 1984; Leonard & Whitney, 1977; Marion & Cole, 1996;

Marion & Olive, 2006). Transect use in this study was similar to methods used by Marion and Olive (2006), Marion and Cole (1996), Leonard and Whitney (1977), and as suggested by Brower and Zar (1984), as a standard method for assessing trail and other impacts on vegetation. For example, Leonard and Whitney (1977) used transects set perpendicular to recreational trails to document trail impacts on soil loss and vegetation, while Marion and Olive (2006) used transects to assess trail conditions, primarily soil erosion, in the Big South Fork National Recreation Area. In the latter study, trail transect end points were delineated based on vegetation change (Marion & Olive, 2006).

Census-based sampling includes assessment of sections of trail or assessments of specific problems along trails. Sectional assessment involves dividing the trail into segments and assessing each segment for degradation, while problem assessment seeks to assess every occurrence of a selected problem (Leung & Marion, 2000). Other more time consuming methods have been developed for assessing soil erosion (i.e., Leonard & Whitney, 1977) and vegetation monitoring (e.g., Cole & Bayfield, 1993; Hall & Kuss, 1989).

Trail vegetation trampling studies in recreation ecology typically focus on amount of use and intensity, and may be natural or simulated (Leung & Marion, 2000). While this study sought to assess the effects of the trail footprint on the ecology of greenways, trampling research methods were not appropriate as the greenway trail footprint is considered a high impact zone (Cole, 1993), and the trails most often consist of hard surface materials (asphalt or concrete). The use of hard surfaced trails in greenways allows for multiple user types such as walkers, inline skaters, and bikers, as well as two directions of traffic flow (Flink & Searns, 1993; Fogg, 2005). Cole (1993) suggested hard surfaced greenway trails limit negative environmental impacts outside the trail footprint by focusing the recreation impact in the trail footprint.

Greenway Trails

Greenway trails vary in surface type, width, and surrounding amount of managed area (Flink & Searns, 1993; Fogg, 2005; Labaree, 1992; Tennessee Department of Environment and Conservation, 2007). For example, in Middle Tennessee, surfaced trails are mostly constructed of asphalt (87%) with very few trails constructed of concrete (8.2%) (Tennessee Department of Environment and Conservation, 2007). Flink and Searns (1993) listed several surface materials including concrete and asphalt. Flink and Searns suggested two broad categories of surface materials, "hard and soft" (p. 213) with the major difference between the two being that soft surfaces absorb water, and hard surfaces cause water to runoff. Since Middle Tennessee greenway trails are primarily asphalt with few being concrete, and since it appears that darker surfaces (i.e., asphalt) absorb more heat energy and have less albedo (Akbari, 2005) than lighter surfaces (i.e., concrete), literature suggests that surface type warrants evaluation as related to surface temperature.

In Middle Tennessee, trail widths vary from 4 - 12 ft (1.2 - 3.6 m) with the majority of hard surfaced trails being 8 ft (2.4 m) or 10 ft (3.0 m) (82%) (Tennessee Department of Environment and Conservation, 2007). These widths are consistent with guidelines by Fogg (2005) and Flink and Searns (1993) who have recommended varying trail widths for different recreational uses. For example, Flink and Searns (1993) suggested 10 ft (3.0 m) wide trails for pedestrian and bicycling use with a total vegetation clearing and grubbing width of 17 ft (5 m). Such widths are likely common to support service vehicles as noted by Fogg (2005) but run counter to recommendations by Labaree (1992) who advocated that trails should not be present in greenways, or only minimal in size, to minimize ecological impacts. Literature as described in the previous sections of this chapter (e.g., Baschak & Brown, 1995; Mason et al. 2007; Schiller & Horn, 1997) suggests that narrower trails and trail footprints will likely have less ecological impacts than wider trails and trail footprints.

Summary

In summary, ecosystem functions have primarily been evaluated by collecting data on species composition and habitat (e.g., Hall & Kuss, 1989; Marion & Leung, 2001; Marion & Olive, 2006). Brower and Zar (1984) included three general methodologies to assess ecosystem functions: Detailed species studies, community descriptions, and the physiognomic approach. The latter method provides flexibility and quantifiable results and has been used to describe the form and structure of vegetation in natural areas. Percent canopy cover, surface temperature, and tree species diversity measures are similar to variables traditional recreation ecology studies have used to assess recreation impact.

Recreation ecologists have documented four categories of negative impacts to natural areas from recreational use, which include impacts to soil, vegetation, water, and wildlife (e.g., Cole, 1993; Hammit & Cole, 1998; Liddle, 1997). Recreational impact studies have almost exclusively been carried out in wilderness areas and have recently begun to focus on ecological indicators including measures of vegetative cover (i.e., percent canopy cover) and microclimate (i.e., surface temperature) (Lindsey, 2003; Marion & Leung, 2000). Leonard and Whitney (1977) suggested that trails impact tree canopy cover, and others have found increases in air and surface temperatures to be related to decreases in forest canopy (Carlson & Groot, 1997; Jo et al. 2001). For the purpose of this study, measuring percent canopy cover and surface temperature appear most appropriate due to the apparent relationships between trail footprint impacts and vegetative cover (Hall & Kuss, 1989; Hammit & Cole, 1998; Marion and Cole 1996).

CHAPTER III

METHODOLOGY

The primary purpose of this study was to examine the effects of trail footprint width, trail age, and surface type on percent canopy cover and surface temperature, in forested riparian greenway areas. A second purpose was to explore the biodiversity, as measured by tree species diversity, of a greenway compared to a natural pristine site. This chapter details the methods utilized in the study and includes project background, sampling, data collection, and data analysis.

Project Background

Greenway goals often include stewardship of natural resources, in particular conserving and maintaining habitat and biodiversity (Ahern, 1995, 2004; Fabos, 2004; Murfreesboro, Tennessee, 1993; National Park Service, 1993); however, many questions exist as to whether these goals are being attained, and few empirical studies exist that document relationships between greenways and habitat or biodiversity. In this study, a quasi-experimental approach was used to examine the effects of greenway trail footprint (i.e., greenway trail width and adjacent mowed area width), trail age, and surface type on percent canopy cover and surface temperature. Secondly, the study compared tree species diversity within greenways to a pristine area.

Habitat has been linked to biodiversity in natural areas, and specifically in riparian zones (Brower & Zar, 1984; Forsey & Baggs, 2001; Hawes & Smith, 2005; National Research Council, 2002; Pauchard et al. 2000; Wenger, 1999). Riparian greenway ecology studies have linked poor habitat to intensive greenway management (e.g., mowing and the amount of hard surfaced trails). These studies have shown that as the area of mowed land and hard surfaced trail area increases, the amount of habitat is reduced and is associated with decreased numbers of development sensitive mammals (Schiller & Horn, 1997) and avian diversity (Mason et al. 2007). Finally, Baschak and Brown (1995) have suggested that greenway mowing decreased the effective area of natural habitat, and Cole (1993) suggested that greenway trail corridors were high impact zones due to the placement of hard surfaced trails and intense vegetation management. Thus, it is important to assess the trail footprint's effect on habitat versus only assessing the effect of the trail.

Recreation ecologists have documented four categories of impacts to natural areas including impacts to soil, water, vegetation, and wildlife (Hammit & Cole, 1998). For the purpose of this study, measuring vegetation conditions was most appropriate for examining the impacts of greenway trails due to its relationship with biodiversity, as several authors claim greenways conserve biodiversity (Ahern, 2004; Fabos, 2004; Labaree, 1992; National Park Service, 1993; Smith & Hellmund, 1993). Secondly, several studies (e.g., Cole, 1995; Cole & Bayfield 1993; Dale & Weaver, 1974) have documented vegetation impacts associated with the presence and use of trails, and these authors report that data on vegetation can be reliably and cost effectively collected (Brower & Zar, 1984; Hammit & Cole, 1998).

Generally, vegetation characteristics include the amount, composition, and condition of flora species present at the study site (Hammit & Cole, 1998). Percent canopy cover is a measure of the upper canopy layer or overstory of vegetative cover

(Brower & Zar, 1984). Vegetative cover is often studied in research on impacts of recreational use. As examples, Marion and Leung (2001), Hall and Kuss (1989), Marion and Cole (1996) and Mason et al. (2007) all used a measure of percent vegetative cover to describe recreational trail and/or campsite impacts, and hiking has been shown to decrease some herbaceous and woody species (Tonnessen & Ebersole, 1997). Importantly, Leonard and Whitney (1977) suggested that trail areas receive more light than forested areas, implying that trails reduce overstory canopy cover, thereby increasing light exposure and temperature.

Forested corridor widths of at least 50 ft (15 m) have been suggested as effective to reduce stream temperatures (Broadmeadow & Nisbet, 2004; Wenger, 1999), and moderate and reduce air and surface temperature (Ledwith, 1996; Meleason & Quinn, 2004). In contrast, Chen (1991) found 100 ft (30 m) forested buffer widths sufficient to maintain water and air temperatures when compared to clear-cut areas. Others found that 50 ft (15 m) buffers provided pollutant removal (Broadmeadow & Nisbet, 2004; Fischer & Fischnich, 2000; Hawes & Smith, 2005; Wenger, 1999), provided aquatic and terrestrial habitat (Broadmeadow & Nisbet, 2004), and facilitated stream bank stabilization (Wenger, 1999). For example, Fisher and Fischnich (2000) suggested that while buffers as small as 20 ft (7 m) filter pollutants and promote water infiltration, 30 - 60 ft (9 - 18 m) buffers with trees and shrubs provide food and habitat for aquatic and terrestrial wildlife. Finally, Lee, Smyth, and Boutin (2004) documented 50 - 95 ft (15 - 29 m) wide municipal buffer requirements in the United States, suggesting that wider buffers may not be realistic in municipal jurisdictions (Lee, Smyth, & Boutin, 2004). Thus, the current study was conducted along forested greenway corridor sections greater than 50 ft (15 m) in width.

Increases in microclimate surface temperature have been found to be related to decreases in volume of riparian forest canopy (Chen, 1991; Ledwith, 1996; McCullough, 1999; Wenger, 1999), and Wenger (1999) suggested that riparian vegetation helped maintain cooler stream temperatures. Consistently, Ledwith (1996) found that mean air temperature increased as forested buffer width decreased, and Chen (1991) found that air temperature decreased along an environmental gradient from the forest edge to the forest interior. Finally, Jo et al. (2001) found forest surface temperatures 5 - 7°C cooler than asphalt road surface temperatures. Thus, it appears that temperature changes are related to the shading provided by riparian forests and that temperatures are sensitive to tree canopy removal (Chen, 1991; Jo et al. 2001; Ledwith, 1996). The aforementioned studies suggest that temperature likely decreases from the trail center, to the footprint edge/forest edge, to the forest interior areas in that order. Surface temperature data was collected at three points (trail center, trail footprint edge, and interior forest control site) to assess the effects of the trail footprint on microclimate.

Site Selection

Sites for this study included the following: Two purposively selected greenway trails, an off-site ecoregional control location for percent canopy cover, and a pristine site for comparison of tree species diversity. Middle Tennessee communities have numerous greenways in developed areas, and many of these are located along river corridors (Tennessee Department of Environment and Conservation, 2007). The Tennessee Department of Environment and Conservation's Greenway and Trail Database includes

52 greenway corridors with 80.9 mi (131 km) of constructed trails and 34 mi (54 km) of proposed trails in the Middle Tennessee Region (Figure 1) (Tennessee Department of Environment and Conservation, 2007). The asphalt trails vary in length from 0.2 - 5.0 mi (0.32 to 8 km) and range in width from 4 - 12 ft (1.2 - 3.6 m). The TDEC database lists 5.6 mi (9 km) of 4 ft (1.2 m) wide trails (7%), 2 mi (3.2 km) of 6 ft (1.8 m) wide trails (2.4%), 39.6 mi (64 km) of 8 ft (2.4 m) wide trails (49%), 26.5 mi (43 km) of 10 ft (3 m) wide trails (33%), and 1.5 mi (2.4 km) of 12 ft (3.6 m) wide trails (2%). Four trails are listed without specifying surface widths, thus the above percentages do not equal 100%. Trail surface materials include gravel (3.7 mi or 5.9 km, 4.5%), concrete (6.7 mi, or 10.7 km, or 8.2%), and paved surfaces (presumably asphalt, 70.5 mi, 113 km or 87%).

Forested Middle Tennessee greenways were purposively selected based on trail widths and the presence of greater than 50 ft (15 m) wide forested segments, and a random starting point with a fixed sampling interval was used to choose sampling locations. Google Earth's aerial imagery was utilized to determine forested widths (Google Earth, n.d.). Google Earth's measuring tool allowed one to mark one location on the aerial photograph and then draw a line to another point for distance measurement. Once the points were marked, the width was read and recorded. Once the initial width was measured, the length of the trail segment was determined and recorded, and forested corridor width field measured at the beginning, middle, and end point of each trail treatment group.

Figure 1. Middle Tennessee Counties include Davidson, Franklin, Grundy, Hickman, Houston, Humphreys, Lawrence, Marshall, Maury, McNairy (not shown), Montgomery, Putnam, Robertson, Rutherford, Smith, Sumner, Wilson and Williamson counties.

The greenway studied included a total of 5.9 miles (9.5 km) of trails of which 1.4 miles (2.2 km) met study criteria (i.e. forested width, footprint width, and located adjacent to a stream). A total of 29 individual sampling points for one treatment condition (8 ft [2.4 m]) and 30 sampling points for two treatment conditions (10 ft [3 m] and 12 ft [3.6 m]) were utilized for data collection. All trails were constructed with asphalt, with the exception of some access and tunnel areas (concrete) and bridges (steel structure with wood). The greenway studied was chosen because there was at least 1/3 mile each of 8, 10, and 12 ft (2.4, 3.0 and 3.6 m) wide trails located in a forested riparian corridor. Additionally, having all treatment groups located in the same greenway controlled for variability in park management practices and in site conditions (i.e., soils), weather patterns, and historic vegetation type. One additional greenway was chosen because it had an 8 ft wide concrete trail. This site was used as a comparison with asphalt trails to examine the effect of surface type on surface temperature.

In the current study, for each sample point along the trail, corresponding control sites were selected in the adjacent forested interior in an area beyond a visually identifiable change in vegetation (Marion & Olive, 2006), such as a change from a grassed area to a forested area. Control sites were located as much as possible in naturally forested areas adjacent to the greenway trail. The objective was to determine visually obvious boundaries associated with greenway vegetation management, such as borders between mowed areas or trail edge and naturally vegetated area adjacent to the trail footprint. In some cases (along the 8 ft [2.4 m] trail), vegetation management was occurring in the forested control area albeit there was still a visually discernable line between intensive vegetation management and the forested zone beyond the trail footprint. Marion and Olive (2006) and Marion and Cole (1996) both utilized this technique in studies designed to assess recreational hiking impacts in defining trail boundaries and included representative photographs to ensure consistency in determination of vegetation-defined points (Figure 2).

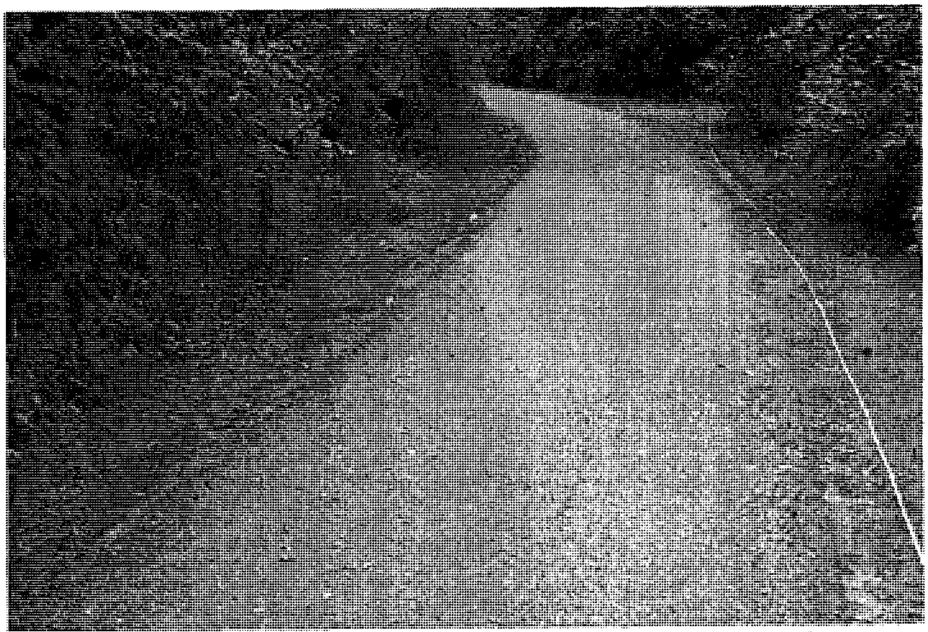

Figure 2. Visually obvious boundary between mowed area and forested area along greenway trail.

Cole (1989b) suggested locating control sites as close to test sites as possible in undisturbed locations when assessing campsite vegetation impacts. In the current study, the control sites were located adjacent to sample sites along a transect, and every effort was made to locate the control sites on the stream side of the trail at 21 ft (6.4 m) or one half the distance to the stream off the trail footprint edge. These sites, having no trail, were used to measure percent canopy cover as control data for comparison with percent canopy cover over the greenway trail sample points.

Two study variables, percent canopy cover and tree species diversity required off site control locations. The greenway trailed sampled for percent canopy cover was in ecoregion 71i (Arwine, Broach, Cartwright, & Denton, 2000). In order to achieve an effective off site control comparison for percent canopy cover, a natural area was chosen in the same ecoregion. Ecoregional reference sites have similar environmental characteristics and tend to have high quality riparian zones (Arwine et al. 2000). A site along Carson Fork was selected as the ecoregional reference because it is located in the same ecoregion as the greenway site and is adjacent to an ecoregional reference stream (Arwine et al. 2000). Unfortunately, because of recreational activities (i.e., off road vehicle use) and the location of a farm road, the investigator was only able to acquire 20 sampling points from this off-site control. A second off-site control was identified in Cedars of Lebanon State Forest along Hurricane Creek from which 10 sampling points were selected. Both off-site controls had similar forest vegetation to each other and to the treatment sites and lacked the presence of a greenway trail.

To establish the control site for the tree species diversity, a pristine natural area was chosen. The pristine forested area at Radnor Lake was chosen based on the presence of an older forest community as documented by Schibig (1996). According to Schibig, this forested area was last harvested in the early 1950s and was harvested using a selective cut method leaving numerous mature trees (Schibig, 1996). Greenway tree species diversity data were compared to data from the pristine site.

Sample Point Selection

Once forested greenway trail segments were identified, they were divided into sections based on the shortest lengths meeting study criteria and sampled using the point sampling method as suggested by Cole and Bayfield (1993), and utilized by Marion and Olive (2006). Point sampling utilizes points located at standard intervals to assess trail conditions. In the current study, the first sampling point was randomly selected along the first 60 ft (18 m) of a specific trail segment, with each additional point being selected based on a standard sampling interval of 60 ft (18 m). The 60 ft (18 m) interval was determined based on acquisition of a minimum of 30 sampling points per treatment group (8, 10, 12 ft [2.4, 3.0, 3.6 m]). The number of sampling points (30/treatment group) was based on the estimated minimum number of sample points necessary to conduct appropriate data analyses.

Point sampling approaches are limited based on the acquisition of a representative sample that accurately characterizes the trail condition (Leung & Marion, 1999). Hammit and Cole (1998) reported that sampling intervals varied from 164 to 1641 ft (50 - 500 m), and that at least 100 observations were needed to have a representative trail sample. In contrast, Leung and Marion (1999) assessed sampling intervals from 98 to 1,990 ft (30 - 606 m), finding sampling intervals of 328 ft (100 m) yielded accurate results for four types of trail impacts assessed such as exposed roots. Finally, Leonard and Whitney (1977) suggested sampling intervals of 328 ft (100 m) or less was sufficient to characterize trail width, soil loss, and vegetation.

For the current study, the systematic point sampling method, with a fixed sampling interval of approximately 60 ft (18 m) was used in an effort to acquire at least 30 sampling points per treatment group. In instances where the sampling point did not meet study criteria the interval was increased or decreased (no more than 15 ft [4.5 m]) to find a point where study criteria were met. Such instances may have included the existence of a recreational facility (i.e. Frisbee golf course, park bench), parking lot, sewer line, or other structures that changed the forested characteristics of the trail. Use of this increase or decrease of sampling interval was limited given the purposive nature of the trail footprint selection. Once a sampling point was located on the greenway trail, a transect was established between the greenway trail sampling point and the stream. In the current study, transects were established utilizing the following method:

1) Sampling points were located and marked on the trail with chalk or other non-permanent but obvious markers (i.e., note pad, etc.).
2) Standing at the sampling point, right angles from the trail tread were determined (visually or with a compass). In some cases, transects were not at right angles to the trail tread as the tread was not parallel to the stream. Due to trail sinuosity, if transects had been at a right angle it may have resulted in control points in the same or overlapping positions for two different trail sampling points.
3) The adjacent control site for a respective sampling point was located 21 ft (6.4 m) from the trail footprint edge into the forested interior, unless the distance to the stream was less than 42 ft (13 m) in which case the control site was located ½ the distance to the stream in the forested interior, in most cases, on the stream side of the trail. Based on Ledwidth (1996) and Chen (1991), surface temperature differences may be measured as little as 15 ft (5 m) into the forest interior; thus in most cases, surface temperatures were measured at 21 ft (6.4 m) from the forest edge to ensure differences were detected if present. In some cases, due primarily to limited distance from the trail to the stream, the distance was halved, limiting the effect of the stream. Finally, every attempt was made to keep control points on the stream side of the trail; however, in some cases, this was not possible due to inadequate distance (i.e., less than 10 ft [3 m]) between the trail footprint edge and the stream and/or the presence of recreational facilities (i.e., Frisbee golf course).

4) Surveyor's tape was used to mark each sampling point transect.
5) Data at the control site was collected once a transect was established.

Research Variables and Data Collection

Data were collected on general greenway characteristics, trail conditions, habitat conditions, and tree species diversity. Trail data were collected at each sampling point and included trail and mowed widths, surface type, and trail age. Forest age and tree species data were collected at every third control point along the greenway trail. Habitat data included vegetation stratification, percent canopy cover, and surface temperature.

Descriptive greenway characteristics. Descriptive greenway characteristics collected included greenway goals, corridor length, greenway corridor width, and vegetation stratification. The specific park Greenway Master Plan (GMP) for the greenway studied was reviewed to identify natural resource conservation-related goals (REM Design Group, 2002). This information was used to briefly describe any goals that may promote conserving, maintaining, and/or enhancing habitat and biodiversity.

Greenway corridor length and width data were documented through greenway plans provided to the researcher by the park manager (REM Design Group, 2002) and utilized to calculate total area occupied by the greenway. Several researchers assessing recreational greenway natural resource conditions have collected or suggested collecting data on length and width (e.g., Labaree, 1992; Mason et al. 2007; Schiller & Horn, 1997; Shafer, Scott, et al. 2000; Sinclair et al. 2005; Whitford et al. 2001). Whitford et al. (2001) identified total area of greenspace as a crude indicator of biodiversity, with larger patches of greenspace indicative of higher levels of biodiversity.

Vegetation stratification was recorded based on the presence or absence of five layers (Brower & Zar, 1984). The ground layer is generally described as vegetation that is less than one inch in height, while the herbaceous layer is greater than one inch, but less than eight inches. The shrub layer rises to 8 ft (2.4 m), with the understory rising up to 30 ft (9 m). Finally, canopy trees are generally greater than 30 ft (9 m) in height.

Greenway trail footprint data. Paved (asphalt) greenway trails in Middle Tennessee's forested greenways range in width from 4 - 12 ft (1.2 - 3.6 m) (Tennessee Department of Environment and Conservation, 2007); however, the majority (82%) of the paved trails are 10 - 12 ft (3.0 - 3.6 m) wide. The trail in the selected greenway includes 8, 10, and 12 ft (2.4, 3.0, 3.6 m) wide sections. These three trail widths were used as independent treatment groups. The use of only one greenway system in the current study helped control for effects associated with different management practices such as mowing.

The physiognomic assessment method was utilized to assess trail footprint (trail width, mowed width), trail surface type, and trail age effects on habitat (Brower & Zar, 1984). The greenway trail footprint includes the trail width, shoulder width, and associated mowed width (Figure 3). In addition, trail surface and distance to stream data were collected. Trail width, shoulder width, mowed width, and distance to stream were collected using a 100 ft (30 m) measuring tape. Trail age and forest age were collected as it was thought that these variables might affect percent canopy cover. Trail age was determined via a phone call to park managers.

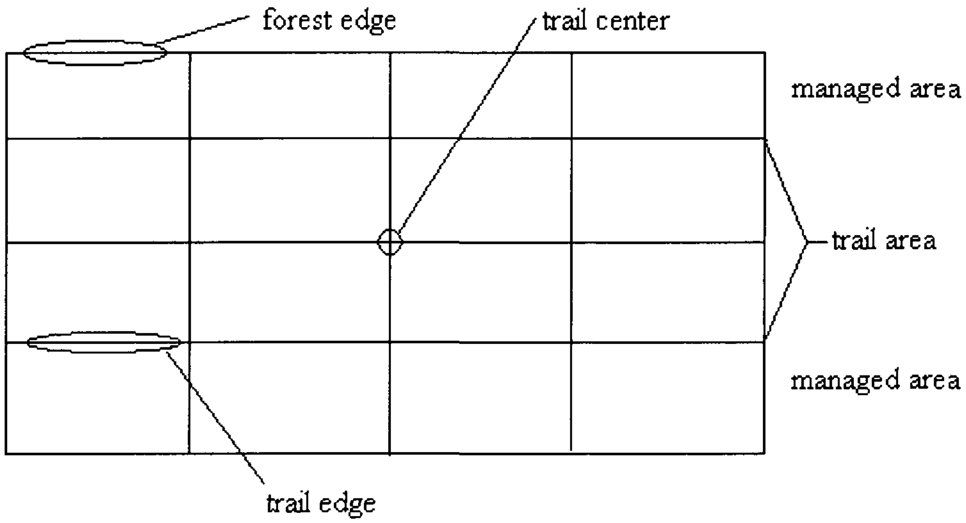

Figure 3. Greenway trail footprint sampling grid. Line intersects represent 25 canopy cover sampling points.

Forest age was estimated based on tree diameter at breast height (DBH) and collected with a tree measuring stick (Leblanc, n.d.). While the tree measuring stick was not as accurate as other, more costly methods, it does provide a cost and time effective measure of DBH. Because forest age was not imperative to the study, the investigator accepted less accuracy in exchange for efficiency. Tree age is difficult to measure unless available from tree ring increment boring, cross sections, or historical accounts; however tree age is in some cases inferred from tree size, specifically DBH. The relationship between tree age and DBH does vary between tree species, management history, and site quality (International Society of Arboriculture, n.d.). The common method used to obtain more accurate measures of tree age is increment boring, which potentially introduces disease and insects into the tree center (International Society of Arboriculture, n.d.). Thus, DBH was used to infer forest age as larger trees represent older trees (International Society of Arboriculture, n.d.).

Natural resource data. For the purpose of this study, data on percent canopy cover, surface temperature and tree species diversity were collected. Percent canopy cover is a measure of vegetative cover, is related to habitat, and influences elements of microclimate such as surface temperature (Brower & Zar, 1984). Percent canopy cover is important as it influences air and surface temperatures, soil moisture, light intensity, and is a measure of canopy habitat (Brower & Zar, 1984; Mason et al. 2007; Whitford et al. 2001). Additionally, Whitford et al. (2001) concluded that percent canopy cover was one of the dominant factors impacting ecosystem processes in developed areas. Finally, Cole and Bayfield (1993) suggested visually estimating canopy coverage of vascular plant species at less than 5%, or as close to 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, or 90% as possible to assess trail effects.

The current study utilized a densitometer, also known as a sighting tube, to measure percent canopy cover. A sighting tube is a small three inch long, one and one half inch diameter tube with a crosshair made of wire located at one end (Ganey & Block, 1994; Globe, 2005). In a study examining the validity of the sighting tube, the instrument was compared to a spherical densitometer and found to be more accurate and precise by Ganey and Block (1994). Ganey and Block suggested utilizing one meter interval sampling along linear transects were appropriate to determine percent canopy cover. The sighting tube used (Geographic Resource Solutions, 2008) has two mirrors located at a right angle to each other and two bubble levels (Figure 3). The instrument was held directly in front of the observer while leveling the instrument prior to recording if the crosshairs intersects foliage (Photograph 2). One benefit to the sighting tube method is that it eliminates the potential for overlap as long as one takes readings in a consistent direction (i.e., facing the trail center). In the current study, all trail center readings were taken along the long axis of the trail, and peripheral (trail edge and trail footprint edge) readings were taken facing the trail center. According to GRS, this type of densitometer increases accuracy and repeatability in that the bubble level allows one to look directly overhead as compared to a traditional straight tube densitometer or ocular estimation (Harrington, personal communication, 2009). Percent canopy cover was calculated as the percentage of sample points on the transect containing foliage (Ganey & Block, 1994). For the purpose of this study, percent canopy cover was collected in a five by five point grid with the trail and/or control sampling point at the center of the grid. Every effort was made to maintain a 25 square yard grid for the trail and control site to assess percent canopy measures; however, in some cases the control grid had to be shifted or minimally collapsed due to obstructions (i.e., trees/briars, recreation facility, social trail at control sample point) in order to acquire the data. In all cases, sighting tube orientation was maintained in order to eliminate potential overlap from collapsed grids, and 25 readings were collected in order to maintain less than 10% standard error for percent canopy cover measurements.

Surface temperature data were collected because it is thought to be related to canopy cover and can easily and cost effectively be measured (Chen, 1991; Chen et al. 1993; Ledwith, 1996). As such, it may be possible for greenway managers to assess the effects of canopy cover on trails utilizing an infrared thermometer. Secondly, research has shown differences between road and forest surface temperatures and thus this measure should be sensitive to openings in canopy cover (Chen et al. 1999; Jo et al. 2001; Ledwith, 1996).

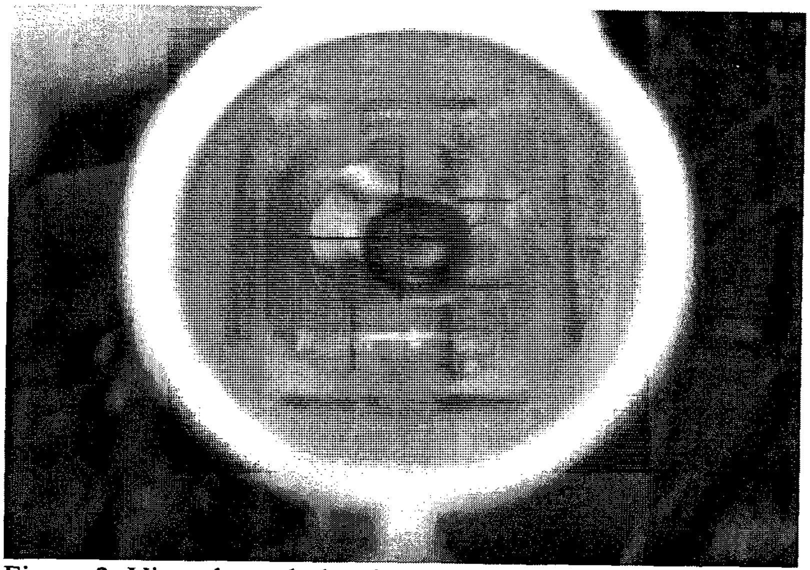

Figure 3. View through densitometer used to measure percent canopy cover. Note one horizontal and one vertical bubble levels and crosshairs.

Surface temperature data were collected with a hand held infrared Raytek, (Model Raynger ST) thermometer with an accuracy of +/- 2°F (+/- 1 °C) (Fluke Corporation, 2004; Globe, 2005). Surface temperature measurements were collected in accordance with manufacturer's recommendations, generally holding the infrared thermometer four ft off of and perpendicular to the ground, activating the instrument by pulling the trigger and then reading the digital display (Fluke Corporation, 2004). The instrument measures energy that is emitted, reflected, and/or transmitted from the surface being measured (Fluke Corporation, 2004). The duff (leaf litter, twigs, etc.) was removed prior to surface temperature measurements at the trail center, forest edge, and forest interior sites due to high variability in duff temperature measurements (i.e., 2 - 6°F) in a small area, and the soil surface measurements under the duff represented a true surface temperature. This method was based on Brosofske, Chen, Naiman, & Franklin (1997) who removed the duff to place probes as close to the soil surface without actually touching the soil.

Surface temperature readings were collected at the center of the paved greenway trail, at the trail footprint boundary, and in forested interior (control) area. Surface temperatures were collected along the three treatment sections in September and October during the afternoon hours (i.e., 12 - 4 p.m.). This was done in an effort to control for the trail and forest surfaces' exposure to the sun, shadow corridor, and ambient air temperatures such as to minimize variation in conditions (Chen et al. 1995; Marsh, 2005). Unfortunately, surface temperature measurements for the 8 ft (2.4 m) concrete and 8 ft (2.4 m) asphalt trail comparisons were collected during December on days greater than 60°F. Because no leaves were on trees during the December data collection, no canopy cover data exists for these measurements. Finally no temperature measurements were collected in the off-site controls.

The Point-Centered Quarter Method (PCQM) as described by Cotham and Curtis (1956), and Brower and Zar (1984) was utilized to collect data on tree species diversity. PCQM has been shown to give the least variability in results of distance from the sampling point to the tree, gives more tree species data per sampling point, and is less susceptible to subjective bias when compared to other methods (Cotham & Curtis, 1956). PCQM requires more time per sampling point, yet requires fewer sampling points. Brower and Zar (1984) suggest the methodology is sensitive to nonrandom distributions of individuals, particularly if only small numbers of individual trees or few points are to be sampled as the method may underestimate tree density. Brower and Zar's criticism was related to randomly sampling only one or two points. PCQM (Cotham & Curtis,

1956) required ten sampling points per treatment group with four data points (i.e., 40 individual trees per treatment group) or 30 sampling points (120 trees across all treatment groups) in the entire greenway. As well, because the data from the pristine site at Radnor Lake was collected in a linear pattern, the PCQM represents a similar, yet more efficient methodology, allowing the two data sets to be generally compared. The PCQM sampling procedure as applied to this study was as follows:

1) Randomly generate a number between one and three to choose the first sampling point out of the first three trail sampling points.

2) Once the trail sampling point is established, locate the adjacent control point and draw an imaginary line through the transect. This sectioning creates the quarters to be sampled.

3) Beginning in the upper left hand quarter, moving clockwise measure the distance to the nearest tree. Each sampling point included the following data:

   a. Quarter number.
   b. Distance from sampling point to the tree center to nearest inch. These data were used to calculate tree density similar to Schibig (1996)
   c. Tree species.
   d. Diameter at breast height (DBH) in inches. Brest height was 51 in. based on its mode in forest and ecology related research as presented by Brokaw and Thompson (2000). DBH was used to estimate forest age.

4) Repeat the process for each sampling point along the transect.

5) Record data in the Field Data Form (Table 1).

Table 1

Tree Species Diversity Field Data Form

Sampling Point	Quarter Number	Species	Distance (ft. in.)	Diameter at Breast Height (in.)
1	1	X	12, 0	3
	2	Y	21, 2	13
	3	Z	42, 0	9
	4	A	27, 11	21

The data collected with the PCQM were utilized to calculate species richness (number of species), and the Shannon-Weiner Diversity Index. In addition, relative density, dominance, and frequency of species was calculated and used to calculate importance values for each species. Diversity indices are used to compare communities within populations, and should include measures of richness (number of species) and evenness (numbers of individuals within a species) (Brower & Zar, 1984). The Shannon-Weiner Diversity Index is used to compare communities (Brower & Zar, 1984) and is calculated with the following formula:

$$H' = \sum p_i \log p_i,$$

where p_i is the proportion of the total number of individuals occurring in a species,

$$p_i = n_i/N_i$$

where n_i is the abundance of a particular species and N_i is the number of individuals. As the species richness becomes more even, the Shannon-Weiner Diversity Index increases (Brower & Zar, 1984).

Relative density was calculated for each tree species by determining the percent of the total number of observations for a particular species. Relative dominance was determined by dividing total basal area into basal area for a particular species and multiplying by 100. Basal area was calculated based on DBH using the following formula: 3.14 x radius^2 where the radius is one half the DBH. Relative frequency or the percentage of sample points at which a tree species occurs was determined by dividing total frequency of all species into absolute frequency and multiplying by 100. Importance value for a species was calculated by summing relative density, relative dominance, and relative frequency and dividing by 3 (Brower & Zar, 1984; Cotham & Curtis, 1954; Schibig, 1996).

Data Analysis

Data analysis is the process of organizing and structuring data in an effort to give the data meaning (Marshall & Rossman, 1999). The purpose of the data analysis was to examine the effects of trail footprint width, surface type, and trail age on percent canopy cover and surface temperature and to explore how the greenway tree species diversity compared to the pristine area's tree species diversity.

Descriptive statistics including mean, median, mode, and standard deviations were calculated to describe the data sets for each treatment and control group. Relative density, dominance, and frequency were calculated for each tree species as was done by Schibig (1996). This data was used to calculate the Shannon-Weiner Diversity Index, and tree species importance values, which allowed descriptive comparison of greenway's tree species data to the pristine site's tree species data (Brower & Zar, 1984; Cotham & Curtis, 1954).

Combinations of multivariate analysis of variance (MANOVA), analysis of variance (ANOVA), t-tests, and correlation analysis were selected to address each of the study hypotheses. MANOVA allows for the comparison of treatment and control groups when there are multiple dependent variables such as percent canopy cover and surface temperature (Shavelson, 1996). ANOVA allows comparisons when investigating differences at multiple sites or among multiple treatment groups (Brower & Zar, 1984; Shavelson, 1996).

ANOVA was utilized to examine whether significant differences existed among groups for hypotheses one, two, and four. Hypothesis one examined the differences in percent canopy cover at the trail, the on-site control, and off-site control for each of the three designated trail footprint widths; hypothesis two examined the differences in surface temperature in each of the three treatment groups, at the three locations: trail center, forest edge, and forest interior. Hypothesis four explored the difference among trail ages and percent canopy cover. Hypothesis three explored the differences among trail footprint widths on both percent canopy cover and surface temperature and was analyzed using MANOVA. In cases where significant differences were found in the ANOVA or MANOVA analyses, Tukey's HSD post hoc analysis was conducted to determine specific differences among groups. Correlation analysis was used to examine the relationship between percent canopy cover and surface temperature in hypothesis five. Lastly, t-tests were conducted for hypothesis six to determine differences between concrete and asphalt surfaces on surface temperature. Tree species diversity was descriptively compared utilizing the Shannon Diversity Index and tree species importance values. For all analyses, statistical significance was set at the .05 level.

CHAPTER IV

RESULTS

The purpose of this study was to examine the effects of trail footprint width, trail age, and surface type on percent canopy cover and surface temperature in forested riparian greenways. A second purpose was to explore the biodiversity, as measured by tree species diversity, of a greenway trail corridor as compared to a natural pristine site. Following is a description of the greenway studied and results from the data analyses conducted for each of the six study hypotheses.

Greenway Description

Descriptive data were collected on greenway characteristics, including trail length and width, age, width of open and forested area, surface type, and vegetation stratification. The greenway studied, located in Middle Tennessee, was 5.9 miles (9.5 km) in length and included trail widths of 8, 10 and 12 ft (2.4, 3.0, and 3.6 m). All treatment conditions and data collected were based on this one greenway as a means to mitigate the effects of regionally dispersed study sites and their associated differences in vegetation type, age class, historic and adjacent land use. A total of approximately 1.3 miles (2.0 km) of this greenway trail (.3 miles [0.5 km] on the 8 ft [2.4 m] trail and 0.5 miles [.8 km] on each of the 10 and 12 ft [3.0 and 3.6 m] wide trails) was sampled in the study. The greenway trail was built in stages over a 16-year period; the 8 ft (2.4 m) wide section was 16 years old, while the 10 and 12 ft (3.0, and 3.6) wide trail segments were

10 and four years old, respectively. The forested corridor width from the stream to the forest edge ranged from 0 to 1195 ft (0 - 364 m). The sampled forested corridor width ranged from 35 - 1195 ft (10.6 - 364.2 m) ($M = 429, SD = 350$). The total parkland area was approximately 296 acres (120 hectares) (based on average length * width), with the total forested land area of the greenway trails sampled (i.e., trails and adjacent forested areas) being approximately 64 acres (25.8 hectares) in size. Finally, greenway vegetation along the trails included ground, herbaceous, shrub, understory, and canopy layers. Greenway sample sites had a range of two to five vegetation layers ($M = 3.8, SD = .63$) all of which were forested and thus had canopy.

Greenway Master Plan and Goals

An initial step in the study methodology was to review the greenway master plan. The greenway master plan (REM Design Group, 2002) was reviewed in an effort to identify and describe conservation related goals and objectives. Specifically, the investigator examined the existence of linkages between the master plan goals and objectives and actual ecosystem functions, such as the extent of biodiversity, habitat, and connectivity. During the initial review of the master plan, goals and objectives, including those related to conservation, were found in Section Six of the document. This section entitled "Goals, Objectives and Policies" was subjected to careful review. Each goal was followed by one objective and several policies designed to meet the objective. Generally, the plan included goals and objectives that aimed to conserve and preserve natural open space, create greenspace and a network of trails, and restore natural resources (REM Design Group, 2002).

Goals One, Two, Five, and Six related to conservation. Goal One seeks to "Provide sufficient lands . . . for parks, trails, recreation facilities and programs, and open space. Create a variety of natural and recreational experiences, atmospheres, and environments . . . . " (REM Design Group, 2002, p. 53). Objective 1.1's under Goal One stated purpose was to "Create a green space network that encompasses an interconnected system of trails, natural open space, and parks throughout the City . . . ." (REM Design Group, 2002, p. 53). This objective states the city's desire to create natural experiences and have natural open space.

Goal Two seeks to "Preserve non-agricultural open spaces, hillside and farm land viewsheds and natural resources . . . as part of the amenities of the developing green space network . . . ." (REM Design Group, 2002, p. 55). Objective 2.1 specifically states that its purpose is to:

> Encourage the establishment of an edge to . . . to act as a buffer . . . . This edge should be in the form of a linear park and/or greenway and serve as a viewshed enhancement, ecological resource . . . . (REM Design Group, 2002, p. 55)

This objective appears to establish the city's desire to have specific forms of greenspace to serve as an ecological resource. As a follow-up to Goal Two and Objective 2.1, Policy 2.1.1 states that the city should include management of open space land for wildlife and habitat specific ecological functions and the policy specifies, "edge" (p. 55) and "buffer" (p. 55) habitats (REM Design Group, 2002).

Goal Five states that the city will "Provide a green space network comprising an interconnected system of park trails . . . natural open space and greenbelts . . . ." (REM

Design Group, 2002, p. 60). This goal implies that the network will provide connected natural corridors, including habitat for wildlife movement.

Finally, Goal Six advances the plan's intent to "Reaffirm the City's strong commitment to education through programs that encourage life-long learning and activities that foster an appreciation of recreation, park and open space resources" (REM Design Group, 2002, p. 63). Objective 6.1 places educational emphasis on learning opportunities for the community, some of which relate to environmental education and restoration. As a means to meet the objective, Policy 6.1.4 states that: "The City will establish . . . Natural Open Space . . . Habitat Conservation program to manage . . . open spaces . . . and promote the restoration of riparian environments of Marsh Creek and others around the community . . . ." (REM Design Group, 2002, p. 63). Policy 6.1.4 appears to establish the city's desire to conserve habitat and maintain and restore riparian zones in the community (REM Design Group, 2002, p. 63). These goals provide a context for understanding planning intentions for conservation in parks and greenways and discussing the study results, providing a framework to examine how greenway development affects measures of habitat and biodiversity as measured by percent canopy cover and surface temperature in addition to tree species diversity.

Hypothesis One

Hypothesis One stated that there would be no significant differences among percent canopy cover at the greenway trail, at the adjacent on-site control, and at the off-site control within each of the three treatment groups (8 ft, 10 ft, and 12 ft [2.4, 3.0, and 3.6 m] trail footprint widths). Results from the one-way ANOVA are presented in Table 2.

Table 2

One-way Analysis of Variance Summary for Trail Effects on Percent Canopy Cover

Source	*df*	*F*
8 Foot		
Between groups	2.00	12.29
Within groups	84 (0.01)	(0.01)
10 Foot		
Between groups	2.00	16.64**
Within groups	87 (0.03)	(0.03)
12 Foot		
Between groups	2.00	9.44**
Within groups	87 (0.01)	(0.01)

Note. The values in parenthesis are mean square error.
** $p < .000$.

If significant differences were present, ANOVA was followed by Tukey's HSD post hoc analysis. Trail percent canopy cover, as measured with the GRS densitometer, ranged from 44 - 100% on the 8 ft trail (2.4 m), and the adjacent on site control percent canopy cover ranged from 56 - 100%. On the 10 ft (3.0 m) trail, percent canopy cover ranged from 4 - 92%, and from 64 - 100% on the adjacent on site control. Percent canopy cover ranged from 36 - 100% on the 12 ft (3.6 m) trail, and 56 - 96% on the adjacent on site control. The off site control percent canopy cover ranged from 56% - 96%. Because the 30 sampling points for the off-site control were located in two different areas (20 from Carson Fork ecoregional reference site and 10 from Cedars of Lebanon State Forest), t-tests were run on the percent canopy cover data to determine if the two sites were significantly different. Results indicated the sites were not significantly different (*t*

$= 1.36, p = .20$), resulting in a combined 30 sample points for the off-site control that could be used for comparison with the two other percent canopy locations. Furthermore, the three (8 ft, [2.4 m], 10 ft [3.0 m], and 12 ft [3.6 m]) on-site controls were not significantly different from the off-site control.

In examining the first trail footprint width, 8 ft (2.4 m), ANOVA results indicated no significant differences between trail percent canopy cover as compared to the on- and off-site controls; however, the comparisons among all three sites were approaching significance ($F [2, 86] = 3.00, p < .055$). The off-site control percent canopy cover was 7% higher than the 8 ft (2.4 m) trail percent canopy cover, while the on site control percent canopy cover was 4% higher than the trail percent canopy cover.

The 10 ft (3.0 m) wide trail percent canopy cover as compared to the on- and off-site controls showed significant differences among groups $F (2, 86) = 16.64, p < .000$. Tukey's HSD post hoc analysis revealed both the on-site and off-site controls had significantly higher percent canopy cover than did the 10 ft (3.0 m) greenway trail canopy cover. The on-site control was 26% higher ($M = 88\%$), and the off-site control was 19% higher ($M = 81\%$) than the trail canopy cover ($M = 62\%$). The 12 ft (3.6 m) trail percent canopy cover as compared to the on- and off-site controls showed significant differences among groups $F (2, 86) = 9.443, p < .000$. Tukey's HSD post hoc analysis revealed both the on-site and off-site controls had significantly higher percent canopy cover than did the greenway trail. The on-site control was 12% higher ($M = 83\%$) and the off-site control was 10% higher ($M = 81\%$) than the trail canopy cover ($M = 71\%$). Hypothesis One was partially supported, due to the fact that there were no significant differences in percent canopy cover at the three locations for the 8 ft (2.4 m) trail;

however for the 10 and 12 ft trails (3.0 and 3.6 m), percent canopy cover at the three locations was significantly different.

Hypothesis Two

Hypothesis Two stated that there would be no significant difference in surface temperature at three locations: Trail center, forest edge, and forest interior (the on-site control). Results are presented in Table 3.

Table 3

One-way Analysis of Variance Summary for Trail Effects on Surface Temperature

Source	*df*	*F*
8 Ft (2.4 m)		
Between groups	2	12.29**
Within groups	84	(15.44)
10 Ft (3.0 m)		
Between groups	2	29.73**
Within groups	87	(34.92)
12 Ft (3.6 m)		
Between groups	2	13.78**
Within groups	87	(39.28)

Note. The values in parenthesis are mean square error.
** *p < .000.*

Ranges in surface temperatures were as follows. For the 8 ft (2.4 m) trail, surface temperatures ranged from 74 - 101° F (23 - 38°C), with a mean of 84°F (29°C) for the trail center, 74 - 92°F (23 -33°C) with a mean of 82°F (28°C) for the forested edge, and 73 - 85°F (23 - 29°C) with a mean of 79°F (26°C) for the forested interior. For the 10 ft (3.0 m) trail, surface temperatures ranged from 72 -102°F (22 -39°C), with a mean of

82˚F (28°C) for the trail center, 69 - 105°F (21 - 41°C), with a mean of 76˚F (24°C) for the forested edge, and 65 - 76°F (18 - 24°C) with a mean of 70˚F (21°C) for the forested interior. For the 12 ft (3.6 m) trail, surface temperatures ranged from 66 - 106°F (19 - 41°C), with a mean of 79˚F (26°C) for the trail center, 63 - 91°F (17 - 33°C), with a mean of 74˚F (23°C) for the forested edge, and 62 - 76°F (17 - 24°C) with a mean of 71˚F (22°C) for the forested interior.

ANOVA revealed significant differences among 8 ft (2.4 m), $F(2, 84) = 12.29, p < .000$, 10 ft (3.0 m), $F(2, 87) = 29.73, p < .000$, and 12 ft (3.6 m), $F(2, 87) = 13.78, p < .000$, groups. Tukey's HSD post hoc analysis revealed significant differences in surface temperatures among 8 ft (2.4 m) trail center and forest interior ($p = .000$) and forest edge and forest interior ($p = .003$). Forest interior temperatures were 5˚F (2.7° C) cooler than 8 ft (2.4 m) trail center surface temperature and 4˚F (2.2° C) cooler than forest edge temperature. Among the 10 ft (3.0 m) trail surface temperatures, Tukey's HSD post hoc analysis revealed significant surface temperature differences among trail center and forest edge ($p = .001$) and forest interior ($p = .000$), and forest edge and forest interior ($p = .001$). The 10 ft (3.0 m) trail center surface temperature was 12˚F (7°C) warmer than the forest interior temperature while the forest interior was 6˚F (3°C) cooler than the forest edge. Among the 12 ft (3.6 m) trail surface temperature measurements, trail center to forest edge ($p = .004$) and forest interior ($p = .000$) were significantly different. The forest interior temperature along the 12 ft (3.6 m) trail was 8˚F (4°C) cooler than the 12 ft (3.6 m) trail center surface temperature, while the forest edge was 5˚F (2.4°C) cooler than the 12 ft (3.6 m) trail center surface temperature. Thus, Hypothesis Two, which stated there would be no significant differences in surface temperatures, was rejected for each of the trail widths.

Hypothesis Three

Hypothesis Three stated that there would be no significant differences in percent canopy cover along the trail center and surface temperature change scores among the three treatment groups: 8 ft (2.4 m) trail, 10 ft (3.0 m) trail, and 12 ft (3.6 m) trail footprint widths. Surface temperature change scores (trail center to forest interior) were used to control for the possibility of variation in edge effects due to mowing and vegetation, and air temperature when comparing the three treatment groups. Results for the MANOVA are presented in Table 4.

Table 4

Means, Standard Deviations, and Multivariate Analysis of Variance for Percent Canopy Cover and Surface Temperature Change Score

	MANOVA		Percent Canopy Cover		Surface Temperature Change (˚F)	
	F (4, 168)	*N*	*M*	*SD*	*M*	*SD*
Trail Width	2.90*					
8 Ft (2.4 m)		29	0.74	0.13	3.55	3.99
10 Ft (3.0 m)		30	0.62	0.27	5.92	7.00
12 Ft (3.6 m)		30	0.71	0.15	3.08	4.15
Total		89	0.70	0.20	4.19	5.34

$^{*}p < .05$

A significant difference was detected among the different trail footprint widths for percent canopy cover and surface temperature change scores in the main effects model, *F*

(4, 168) = 2.90, $p < .05$, observed power = .489). However, Tukey's HSD post hoc analysis revealed that there were no significant differences among the groups for either percent canopy cover or surface temperature. While the main effects model was significant, the model lacks predictive value. Furthermore, the R^2 value was .04, explaining little variance in percent canopy cover and surface temperature due to trail footprint width. Hypothesis Three was partially supported, as the main effects model was significant. However, Tukey's HSD post hoc analysis revealed no clear differences in percent canopy cover and surface temperature related to trail footprint width.

Hypothesis Four

Hypothesis Four stated that there was no significant difference in percent canopy cover among the different trail ages. Prior to exploring trail age effects on percent canopy cover, forest age (tree size) was examined to ensure that the forest age was similar throughout the three trails and thus did not impact trail age. ANOVA was run on tree diameter at breast height, an approximation of forest age, with the result of no significant differences among the three treatment groups for forest age *F (2, 117) = .611, (p = .54)*. The 8 ft (2.4 m) trail was 16 years in age; the 10 ft (3.0 m) trail was 10 years in age, and the 12 ft (3.6 m) trail was 4 years in age. Because trail ages were in three categories that were in essence the same as the trail footprint widths (i.e. the three trail widths, 8, 10, and 12 ft corresponded to the three trail ages 16, 12, and 4 years respectively), the results were the same as results from Hypothesis Three. There were no significant differences in percent canopy cover associated with trail footprint widths, and, thus, their corresponding ages. Therefore, Hypothesis Four was accepted.

Hypothesis Five

Hypothesis Five stated that there would be a positive relationship between percent canopy cover and surface temperature. There was a significant, though weak, correlation between the adjacent on-site control percent canopy cover and the trail surface temperature ($r = .300, p < .01$) and the forest interior (control) temperature ($r = .393, p < .01$); however, trail percent canopy cover was not correlated with surface temperature at either location. These mixed findings resulted in Hypothesis Five being partially supported.

Hypothesis Six

Hypothesis Six stated that there was no significant difference in surface temperature between the two trail surface types, asphalt and concrete. The data were collected on warmer days (greater than 65°F [18°C]) in December. Asphalt surface temperatures were lower ($M = 58$°F [14°C], $SD = 1.01$) than concrete ($M = 61$°F [16°C], $SD = 1.19$). The difference between groups was not significant ($t = 11.58, p < .31$). Thus the hypothesis was supported.

Tree Species Diversity

The second purpose of the study was to examine a measure of biodiversity, tree species diversity, in the greenway. The research sought to descriptively determine if the greenway would have lower tree species diversity as compared to Radnor Lake's tree species diversity. Descriptive comparisons between the greenway and Radnor Lake were made utilizing Importance Values or overall idea of the influence of the species in the community (Brower & Zar, 1984), and the Shannon Weiner Diversity Index. Greenway and Radnor Lake tree importance values are presented in Table 5. A total of 11 taxa were collected on the greenway with the dominant species being Osage Orange, Hackberry, Box Elder, and Sycamore. The taxa with the highest importance values were Box Elder (12.63), Osage Orange (11.41), Black Walnut (10.98), Hackberry (9.64), and Sycamore (5.86). The Shannon-Weiner Diversity Index for the greenway site was 0.86.

Radnor Lake had a total of 14 taxa collected from the riparian community. The dominant species included Sugar Maple, Hackberry, Elm, Ash, and Box Elder. The taxa with the highest importance values in the Radnor Lake community included Sugar Maple (30.3), Hackberry (17.8), Elm (15.7), Ash (9.8), and Box Elder (6.8). The Shannon-Weiner Diversity Index for Radnor Lake's riparian community was 1.124. Importance values indicate that the species in the two communities are different in frequency, density, and dominance in the forest ecosystem. Finally, Shannon-Weiner Diversity Index for the greenway (0.86) as compared to Radnor Lake's Shannon-Weiner Diversity Index (1.124) indicates the greenway has lower tree species diversity.

Table 5

Tree Species Diversity Data

Species	Common Name	Importance Values Greenway	 Radnor Lake
Acer nugundo	Box Elder	12.63	6.8
Acer rubrum	Red Maple	-	1
Acer saccharinum	Silver Maple	-	30.3
Acer saccharum	Sugar Maple	-	0.6
Celtis laevigata	Hackberry	-	17.8
Celtis occiendentalis	Hackberry	9.64	2.1
Diospyros virginiana	Persimmon	-	4.5
Fraxinus pennsylvaniaca	Green Ash	4.59	9.8
Juglans nigra	Black Walnut	10.98	-
Juniperus virginiana	Eastern Red Cedar	2.13	-
Maclura pomifera	Osage Orange	11.41	-
Plantanus occidentalis	Syacamore	5.86	3.7
Populus spp.	Cottonwood	0.30	-
Quercus muhlenbergii	Chinkapin Oak	-	1.4
Quercus spp.	Oak (Shumard)	1.38	2.1
Quercus spp.	Oak (White)	1.38	-
Robinia pseudoacacia	Black Locust	2.75	-
Salix nigra	Black Willow	-	0.9
Ulmus spp.	Elm	3.17	15.7

Note. Cells with (-) indicate species was not present in sample from site.

CHAPTER V

DISCUSSION

Recreational greenways have been suggested by several authors (Ahern, 2004; Hay, 1991; Searns, 1995) to provide conservation benefits, including biodiversity, connectivity, and habitat. Relatedly, Moore and Shafer et al. (2000) implied that recreation activities are occurring more frequently in greenway corridors along constructed hard surfaced trails. Outdoor recreation has been found to impact natural resources, including vegetation, soil, water, and wildlife (Ahern, 2004; Cole, 1989b, 2004; Cole & Bayfield, 1993; Marion, 1991); thus, if one is interested in providing both recreation and conservation benefits in greenways, it is important to assess the effects of outdoor recreation impacts on greenway ecology (Ahern, 2004). The presence of greenway trails in greenway corridors likely disrupts greenway ecology (e.g., Ahern, 2005; Labaree, 1992; Mason et al. 2007). The purpose of this study was to examine the effects of trail footprint width, trail age and trail surface type on percent canopy cover and surface temperature within the greenway corridor. A secondary purpose was to examine tree species diversity, as a measure of biodiversity, of the greenway corridor as compared to Radnor Lake's tree species diversity.

Conservation Related Goals and Objectives

Protecting greenway corridors is often promoted as a means of conserving natural resources in developed landscapes (Ahern, 1995, 2004; Baschak & Brown, 1995; Murfreesboro, Tennessee, 1993; Hoctor et al. 2004; Lindsey, 2003; Little, 1990;

Metropolitan Board of Parks & Recreation, 2002; National Park Service, 1993). However, several studies (e.g., Ahern, 2004; Baschak & Brown, 1995; Lindsey, 2003; Mason et al. 2007; Miller & Hobbs, 2000; Schiller & Horn, 1997; Sinclair et al. 2005) have questioned the conservation value of greenways in developed areas in part due to the presence of recreational trails (Ahern, 2004). The first step in understanding the conservation goals for the greenway examined in this study was to review the greenway master plan. Following is a brief discussion of the goals found in the master plan document.

Goal One of the park and greenway master plan (REM Design Group, 2002) documented the municipality's intention to provide residents with natural experiences in the park and greenway system. Goal Two indicated the city's intent to preserve natural resources at least in part in a linear form, while Goal Five suggested the city is interested in a network of natural corridors. Finally, Goal Six stated the city's desire to conserve habitat and restore riparian environments. Based on the aforementioned goals, it appears that the municipality does intend to conserve natural resources including habitat. Based on the habitat data collected in this study, it appears the municipality is partly meeting these goals. For example, the greenway included different types of habitat, as approximately 6 miles (9.6 km) of greenway trail are located in riparian zones, indicating the potential for significant natural resource conservation (Ahern, 1995; Lewis, 1964; National Research Council, 2001; Wenger, 1999).

The naturally forested riparian greenway sections included on average 4 of 5 ($M = 3.8$) possible vegetation or forest habitat layers (i.e. ground, herb, shrub, understory, canopy). Each of these vegetation layers represents different types of plants, which in turn include different habitat for both plants and animals. For example, different avian species may require tree canopy, while others require ground habitat (Mason et al. 2007). The four vegetation layers consistently present in the forested-greenway corridor represents zones of vegetation and habitat diversity (Brower & Zar, 1984; Forsey & Baggs, 2001; Hawes & Smith, 2005; National Research Council, 2002). The aforementioned habitat data seem to suggest that the greenway is partly meeting the riparian and habitat conservation goals established by the municipality.

The aforementioned data suggest that the greenway is helping to accomplish conservation goals; however, other data suggest that the greenway is only partly meeting these goals. For example, naturally forested riparian environments occupied approximately 64 of 296 (24%) acres (26 of 120 hectares) with the remainder non-forested. This appears to be due to intense vegetation management associated with recreation facilities, such as tables and grills, as well as open areas along the greenway trail. For example along the ten foot trail, some sampling points had to be moved to meet study criteria over 300 feet forward due to a lack of forested area on one or both sides of the trail. However, there were two larger naturally forested areas along the eight-foot and 12 ft trail. These areas may be big enough to serve as stop over habitat in a larger network of greenway corridors as suggested by Smith and Hellmund (1993).

Percent Canopy Cover (Hypothesis One)

Hypothesis One declared that percent canopy cover would not differ among the three locations: greenway trail, adjacent on-site control and off-site control within each of the three treatment groups (8, 10, and 12 ft [2.4, 3.0, and 3.6 m] trail footprint widths plus managed area). ANOVA results indicated that significant differences in percent canopy cover were present among the trail footprint widths and controls. Tukey's HSD post hoc analysis for pair wise comparisons revealed that the 8 ft (2.4 m) trail footprint's percent canopy cover (74%) was not significantly different from the two control areas, and that the 10 (64%) and 12 (71%) foot (3.0 and 3.6 m) trail footprints' percent canopy cover were significantly different from the two control areas. Thus, it appears that the 10 and 12 ft (3.0 and 3.6 m) trail footprint widths, which included the trail and the mowed width (*M = 19 ft [5.8 m]*) did affect percent canopy cover. However, the 8 ft (2.4 m) trail footprint width, which also included the hard surfaced trail and mowed width (*M = 16 ft [4.8 m]*) did not effect percent canopy cover; notedly, though, this difference was approaching significance (*p = .055*).

It seems somewhat reasonable, given the study results and the literature, to conclude that footprint width may affect percent canopy cover, and thus the wider a trail footprint, the greater the effect may be on percent canopy cover. This is somewhat consistent with the literature (e.g., Baschak & Brown, 1995; Mason et al. 2007; Schiller & Horn, 1997) in that several authors suggested that lower levels of managed area, including trails and associated mowed areas, seem to be associated with greater ecological function, which may be associated with canopy cover (Mason et al. 2007; Whitford et al. 2001). Therefore, if recreation and conservation uses are compatible, as presumed by Ahern's (2004) third hypothesis, this data and the literature appear to be suggesting, consistent with Labraee (1992), that recreational greenway trail width should be minimized.

In addition to the aforementioned managed areas, vertical vegetation management along the trail corridor likely affects percent canopy cover. Specifically, Fogg (2005) suggested up to 10 ft (3.0 m) vertical clearing of vegetation during trail construction and maintenance. Based on the literature, vertical vegetation maintenance may explain some variation in percent canopy cover. For example, limbs 10 ft high on the tree trunk, which would normally overhang the trail, likely were removed as a part of trail construction and are removed during trail maintenance. Moreover, trees in the forested control areas had no limb removal, thus vertical vegetation management might explain some of the differences between trail and control percent canopy cover.

The 8 ft (2.4m) trail footprint width percent canopy cover was not significantly different from either control's percent canopy cover. A second, contrasting or alternative explanation for the 8 ft (2.4 m) trail footprint width findings of no significant difference in percent canopy cover is that the on-site control locations may have been impacted. These sites were identified based on a visually identifiable vegetation change along the trail, such as a change from a mowed area to a forested area. This method was similar to the method used by Marion and Olive (2006) and suggested by Leonard and Whitney (1977) and Marion and Cole (1996). All of the aforementioned studies were located in parks and/or non-developed environments, generally along dirt footpaths, while the current study was located in a developed community along an asphalt greenway trail. In addition, the 8 ft (2.4 m) on-site control percent canopy cover was 78%, while the 10 ft

(3.0 m) and 12 ft (3.6 m) on-site control percent canopy covers were 88% and 83% respectively. It may be that the paved trail impacts extend well beyond the visually identifiable mowed vegetation boundary and thus the lack of difference in percent canopy cover on the 8 ft (2.4 m) trail was a result of the on-site control's location being in the trail impact zone. For example, it may be that the construction of the hard surfaced trail, the trail management, and trail's presence affect the surrounding forest canopy cover. The asphalt trail's albedo may create warmer surface and air temperatures that increase evaporation and decrease soil moisture content, potentially impacting canopy cover. This is supported by Cole's (1993) assertion that greenway trails were high impact zones designed for intense recreational activity. Unfortunately, it contrasts with Cole's idea that one can concentrate the recreation use impact to one area while protecting another area.

Surface Temperature (Hypothesis Two)

Hypothesis Two stated there would be no significant differences in surface temperature among the three locations: trail center, forest edge, and forest interior for the three treatment groups. The hypothesis was rejected, as surface temperatures among the three locations for the three treatment groups were significantly different. In all cases, the trail center surface temperature was significantly higher than the forest interior surface temperature. This may be explained primarily by reductions in percent canopy cover and then the asphalt trail's albedo. The trails' mean percent canopy cover was 62% on the 10 ft (3.0 m) trail, 71% on the 12 ft (3.6m) trail, and 74% on the 8 ft (2.4 m) trail. Carlson and Groot (1997) documented that increased canopy openings were associated with increased soil surface temperature in clear-cuts, and along forested edges. Chen et al.

(1995) found temperature gradients extending from the forest edge as much as 240 meters into the forest interior. Jo et al. (2001) found surface temperature 5-7°C (9-13°F) lower in forested areas as compared to residential areas. Similar to Jo et al. (2001), the current study found surface temperature differences 2-6°C (4-12°F) cooler in forested interior (on-site control) areas as compared to asphalt trail center sites. Based on these data and the literature, it is reasonable to suggest that canopy openings are, at least in part, responsible for the surface temperature differences. This suggestion is also partially supported by the positive correlation of percent canopy cover and surface temperature in the forested on-site control, albeit the relationship was not present between trail surface temperature and trail percent canopy cover, likely due to the asphalt trail's albedo or solar energy reflectivity.

The asphalt trail's albedo, as suggested by Marsh (2005), Aseada et al. (1996), and Akbari et al. (1995) may have affected trail surface temperature. Asphalt has a lower albedo (5-10% reflective capacity) than soil (25-30%), and thus more incoming solar radiation would be absorbed by the asphalt trail, increasing the surface temperature of the trail (Marsh, 2005). As well, asphalt has been shown to store more heat and have higher surface temperature as compared to bare soil (Asaeda et al. 1996). It seems reasonable to suggest, based on the current study's data and the literature, that differences in surface temperature are explained by decreased canopy cover and the asphalt trail's low albedo.

In contrast to Chen et al. (1993, 1995), all forest edge surface temperature means were intermediate to the trail center and forest interior surface temperatures. The most likely explanation for the difference in this data and Chen et al. appears to be that the current study canopy openings were much smaller than in Chen et al. (1993, 1995). Chen et al. (1993, 1995) collected forest edge surface temperatures on the margin of larger deforested areas where canopy openings were larger and presumably exposed the soil to greater solar radiation than those associated with an 8, 10, or 12 ft (2.4, 3.0, or 3.6 m) wide greenway trail. In support of this explanation, 82% of the forest edge surface temperature measurements were collected in the shadow corridor of the forest canopy. This data seems to suggest that the greenway trail canopy openings investigated do not allow as much solar radiation, thereby keeping edge temperatures intermediate to trail center and forest interior surface temperatures. For example, the entry of solar radiation or sun window is reduced and shade corridor increased along the greenway corridor as compared to open clear-cuts as studied by others (i.e. Chen et al. 1995). This is likely due to the narrower clearing associated with the trail corridor as compared to the clear-cuts, leaving trees and canopy partially intact on both sides of the trail.

Percent Canopy Cover and Surface Temperature Change Scores (Hypothesis Three)

Hypothesis Three stated that there would be no significant differences in percent canopy cover and surface temperature change scores among the three treatment groups: 8, 10, and 12 ft (2.4, 3.0, and 3.6 m) trail footprint widths. Temperature change scores were measured as the difference between the trail center and forest interior control site temperature to control for variability in air temperature across locations and time. Initially, statistical analysis comparing the three trail widths' percent canopy cover and surface temperature change scores showed significant differences. However, Tukey's HSD post hoc analysis for multiple pair wise comparisons revealed no significant differences in percent canopy cover or surface temperature among the three treatment groups.

The tests of between subject effects were approaching significance for percent canopy cover ($p = .07$) and surface temperature change scores ($p = .08$). This would seem to indicate that trail footprint width was close to having an effect on percent canopy cover and/or surface temperature change scores. Percent canopy cover for the 10 ft (3.0 m) wide trail was 64% while the 8 and 12 ft (2.4 and 3.6 m) wide trails had 74 and 71% canopy cover respectively. The differences in percent canopy cover among the treatment groups may then explain the 2.5-3°F (1.4-1.7°C) difference in temperature change scores among the 10 ft (3.0 m) trail footprint and the 8 and 12 ft (2.4 and 3.6 m) trail footprints.

The aforementioned data are somewhat consistent with the literature, as several researchers have found increased soil surface temperature associated with wider canopy openings or no canopy cover (Carlson & Groot, 1997; Chen et al. 1993, 1995; Cunningham, Schaefer, Cebek, & Murray, 2008). However, the data fail to explain the relationship between trail footprint width and canopy cover as the 10 and 12 ft (3.0 and 3.6 m) trail plus mowing have similar footprint widths (19 ft [5.8m]) yet a percent canopy cover mean difference of 8%, while the 8 ft (2.4 m) trail plus mowing has a footprint width of 16 ft (4.8 m) and a mean percent canopy cover of 74%, 10% greater than the 10 ft (3.0 m) trail.

In reviewing the data for the 10 ft (3.0 m) trail it was noted that the first 10 sampling points had an average percent canopy cover of 39% with a range of 4-72%, as compared to a mean of 76% with a range of 36-92% for sites 10-11 to 10-20 and a mean of 72% for sites 10-21 to 10-30. The footprint width averaged 17 ft (5.2m) for the first 10 sampling points as compared to 19 and 21 ft (5.7 and 6.4 m) for the next two groupings of 10 sampling points (10-11 to 10-20 and 10-21 to 10-30). Upon reviewing the data sheets it had been noted that there was a split rail fence located along the first ten sampling points on the eastern portion of the 10 ft (3.0 m) trail. This may help explain the difference in percent canopy cover as related to the narrower trail footprint width along the first ten sampling points. First, it seems possible that the investigator could have inadvertently used the fence line as the vegetation boundary, which would potentially account for the narrower trail footprint width. If greenway management did not mow consistently behind the fence, and the investigator was sampling during the latter part of the mowing cycle, it might appear that the vegetation boundary was on the fence line, when in fact it was farther back from the fence line and only evident shortly after mowing had occurred. In addition, it may be that fence construction required increased width in which trees were removed, resulting in a situation where perhaps the vegetation line was measured correctly; however trees and canopy had not recovered since fence installation. It then stands to reason, if the 10 ft (3.0 m) trail footprint widths are not correct due to the sampling error, the percent canopy cover data for the 10 ft (3.0 m) trail may be correct. This provides for the possibility that vegetation clearing and management around the fence line are leading to conditions, such as increased mowing/footprint width, that negatively effect percent canopy cover.

Based on the literature (Akbari et al. 1995; Aseada et al. 1996; Marsh, 2005), it seems reasonable to conclude that the wider asphalt trails would have higher raw surface temperatures; however, this was not the case with the data. On the contrary, as trail width increased, mean surface temperatures decreased. Ambient air temperatures may explain the raw mean surface temperature differences. Mean ambient air temperatures were higher for the 8 ft (2.4 m) trail (*M = 86° F [30°C]*) when surface temperatures were taken and lower when the 10 (*M = 81° F [27.2°C]*) and 12 (*M = 83° F [28.3°C]*) ft (3.0 and 3.6 m) trail surface temperatures were collected. The mean trail surface temperature data appear inconclusive and are generally in conflict with the literature.

Trail Age (Hypothesis Four)

Hypothesis Four stated that there was no significant difference in percent canopy cover among the different trail ages. Trail age was in three categories that corresponded directly to trail footprint width of 8 (2.4m), 10 (3.0m) and 12 (3.6m) ft. There was no significant difference among the three trail ages on percent canopy. In order to adequately assess the effect of trail age on percent canopy cover, treatment groups would need to include trails with the same widths, but different ages. Trail ages ranged from 4 to 16 years old, and no clear trend existed in the canopy cover data as related to trail age. While the oldest trail (8 ft [2.4 m]) does have the highest percent canopy cover at 74%, it is followed by the youngest trail (12 ft [3.6 m]) at 71%, and then the 10 ft (3.0 m) trail with the lowest percent canopy cover at 64%. These data lack a clear trend and are inconclusive.

Percent Canopy Cover and Surface Temperature Correlation (Hypothesis Five)

Hypothesis Five stated that there would be a positive relationship between percent canopy cover and surface temperature. The findings were mixed. For example, percent canopy cover and surface temperature were weakly correlated in the forest interior control sites but were not correlated on the trail sites. The correlation between percent canopy cover and surface temperature in the forest interior sites seem consistent with the suggestions of Leonard and Whitney (1977), Chen et al. (1993, 1995), Jo et al. (2001) and Cunningham, et al. (2008). Cunningham et al. (2008) found the presence of canopy cover and leaf cover (duff) positively related to cooler ground surface temperatures. Forest canopy cover and duff reflect solar radiation, there by limiting absorption by the soil surface (Cunningham et al. 2008; Marsh, 2005). Forest interior on-site control sampling points included canopy cover and duff while trail sites did not include duff. In the current study, duff was removed prior to surface temperature measurement similar to methods used by Brosofske et al. (1997) in collecting soil surface temperature. Based on the data in the current study and existing literature, it seems reasonable to suggest that the solar radiation reflectivity and shading of the canopy and duff explain the cooler temperature correlations to higher levels of percent canopy cover in forest interior control sites. Removal of the duff allowed the investigator to get actual soil surface temperature measurements, as opposed to the temperature of the leaf surface. On the trail there tended to be no duff, but some canopy, perhaps indicating that the duff effects surface temperature and canopy cover relationships as much if not more than canopy cover.

Trail percent canopy cover and trail surface temperature were not correlated. It seems the only plausible explanation for this is that the asphalt trail's presence and management (removal of leaf litter) are having some effect on the relationship of the two variables. In example, asphalt's albedo is 5 to 10%, indicating that large amounts of solar radiation or heat energy are being absorbed by the asphalt trail, thereby increasing the trail's surface temperature (Marsh, 2005). This may explain the lack of correlation between the trails' percent canopy cover and surface temperature. For example, the trail's solar gain would be expected to exceed the soil's solar gain, as solar gain is a function of incoming solar radiation and a surface's albedo (Marsh, 2005). Soil albedo is in the range of 25 to 30%, while forest vegetation's albedo ranges from 10 to 20% (Marsh, 2005). Based on substance (pavement, duff, vegetation etc.) albedo it seems reasonable to expect that the wider trail would have a greater surface temperature than a narrower trail and that both would be related to canopy cover. The current study data was in contrast to the literature. The 12 (3.6 m) ft trail had a mean surface temperature of 79°F; the 10 (3.0 m) ft trail had a mean surface temperature of 82°F, and the 8 (2.4 m) ft trail had a mean surface temperature of 84°F, the opposite of what is suggested by the literature. It seems reasonable to conclude that solar radiation resulting from reduced canopy cover over the trail and primarily lower albedo of the asphalt may have skewed this relationship.

Concrete Versus Asphalt Surface Temperature (Hypothesis Six)

Hypothesis Six affirmed that there was no significant difference in surface temperature between the two trail surface types, asphalt and concrete. The data were collected on two separate days in December with mean ambient air temperatures of 67°F for the asphalt trail and 69°F for the concrete trail. Both concrete and asphalt surface temperature measurements were collected in the shade. There were no significant differences in surface temperature between the asphalt and concrete trails. Both the concrete and asphalt trail had temperatures close to subsurface temperature. The asphalt trail did have a lower average surface temperature (*M = 58°F [14°C]*) as compared to the concrete trail (*M = 61°F [16°C]*).

These findings are contradictory with the literature. For example, Aseada et al. (1996) found surface temperatures significantly greater for asphalt as compared to concrete; however, these measurements were collected during the warmer months of the year. It has also been suggested that darker surfaces, such as asphalt, absorb more solar radiation, which impacts surface and air temperatures. There are several possible explanations for the contrast between the current study's data and the literature. It seems plausible that the cooler ambient air temperature, sun angle, approximately 16° at this time of year, and seasonal variability may explain the lower asphalt temperature. The sun angle of 16° would provide reduced radiation intensity and thus less solar radiation striking both the asphalt and concrete trail surface (Marsh, 2005). Sun angle during the winter solstice is low, which results in diffuse solar radiation striking the earth's surface and thus less solar heat gain. In contrast, during summer solstice, the sun angle is greater, resulting in concentrated solar radiation striking the earth's surface and greater solar heat gain (Marsh, 2005). Importantly, Cunningham et al. (2008) found that the majority of variability in surface temperature was accounted for by seasonal variability, which may in part be accounted for by sun angle (Marsh, 2005).

Secondly, both asphalt and concrete surface temperatures were close to subsurface ground temperature. Because surface temperature measurements were collected on cloudy days and ambient temperatures were low, sub surface temperatures or the thermal mass effect of the earth may have had an increased effect on trail surface temperatures (Marsh, 2005). Based on the current study data and the literature, it seems reasonable to conclude that seasonality, sun angle, cooler ambient air temperatures, and the subsurface ground temperature were controlling factors for the similar and low concrete and asphalt surface temperatures.

Tree Species Diversity

The second purpose of the study was to examine a measure of biodiversity, tree species diversity, in the greenway as compared to a pristine reference site. Tree species diversity was lower in the greenway as compared to Radnor Lake State Natural Area, and the types of species present varied between the two sites. This is likely explained by differences in historic land use between the two sites. Radnor Lake State Natural Area has not had timber harvested since the 1950s (Schibig, 1996), and the tree harvesting was based on selective harvest methods. In contrast, there was some evidence, such as remnant fencerows, that the greenway site had been formerly used for agricultural purposes. Thus, it would appear that lower tree species diversity on the greenway is not necessarily related to greenway development or management, but more likely an artifact of historic land use and land use change. This does present an interesting opportunity for researchers and greenway managers. Researchers should continue to assess tree species diversity and other forms of biodiversity on the greenway, as long as biodiversity is included as a goal for greenways as has been suggested by Ahern (1995). Secondly, it is important to develop a baseline for tree species diversity and other types of biodiversity within greenways. Regarding tree species diversity, the current study findings represent the baseline and present greenway managers an opportunity to focus vegetation restoration projects on increasing tree species diversity.

Limitations

Study limitations included the lack of an offsite surface temperature control, lack of continuous surface temperature measurement, and not controlling for mowed width or vertical height of vegetation management around trails. In addition, the primary study purpose was assessed using one middle Tennessee greenway, and only 89 sample points along 1.3 miles of 5.9 total miles of trail were sampled. The study did not have an off-site control for surface temperature. An off-site control could be located with the percent canopy site in the ecoregional reference areas, and individual sampling points should be selected based on location of percent canopy cover measurement points. An off-site surface temperature control would allow investigators to potentially assess the effect of the trail on greenway forest interior surface temperatures. For example, the off-site control surface temperature could be compared to the on site control to see if differences existed. If differences did exist, one might conclude that the on-site forest interior is impaired, elaborating on Cole's (1993) conclusion that the greenway trail footprint was a high impact zone.

Secondly, temperature data collection occurred over a three-day period, with each of the three treatment groups being observed on different days and only one instance of data collection for each location. Many of the temperature studies referenced utilized surface temperature probes and data loggers to collect temperatures at multiple times on multiple days. The temperature data collection tools used in the current study could not continuously collect surface temperatures as the data loggers and continuous surface temperature probes did in other studies. Because of this there was no way to control for ambient air temperature, other than to sample on days with similar weather conditions, including air temperatures.

The current study did not control for vegetation management around the trail. In the current study, trail footprint width was categorized as trail width plus mowed area and did not control for mowed widths around the trail. Controlling for mowed width around trails might have helped determine the relationship between the trail footprint width and percent canopy cover. Initially, the current study sought to assess the effects of mowed width on canopy cover; however the researcher was unable to find greenway trails without mowing. In addition, given the 25-point grid used for sampling percent canopy cover and the distance (25 ft [7.6m]) it represented along the trail, it would have been difficult to find mowed areas, consistent enough in width to assess the effect of trail footprint mowed area on percent canopy cover. It may be that future research should focus on percent-managed area based on Mason et al. (2007) as opposed to trail width plus mowed area.

For the majority of the data collection, the study only assessed one greenway and 89 sample points along approximately 1.3 miles (1.6 km) of greenway trail. While sampling in one greenway had advantages, assessing additional greenway trails would increase the generalizability of the study. In addition, sampling matched pairs of similar greenways and more data points along greenways would increase data reliability and sensitivity. Moreover, sampling along wider than 12 ft (3.6 m) and narrower than 8 ft (2.4

m) trails and associated managed areas would give a broader range of potential effects for assessment.

General Conclusions and Future Research Directions

A primary conclusion from this study was that percent canopy cover was affected by trail width when compared to adjacent on-site and off-site controls. A statistically significant difference in percent canopy cover existed for wider trails and their respective control sites. However, no statistically significant difference existed for the narrower trail as compared to its adjacent on-site control. Based on this data, it seems reasonable to conclude that wider trails may have a greater impact on percent canopy cover; however, as suggested by Baschak and Brown (1995) and documented by Mason et al. (2007), it is likely also related to mowed vegetation management. The latter is contrary to the 10 ft (3.0 m) trail data, which had the lowest percent canopy cover (*M = 64%*), and a 19 ft (5.7 m) footprint width as compared to the 12 ft trail footprint width of 19 ft (4.8 m) and a percent canopy cover of 71%. The difference in the 10 ft (2.4 m) trail's percent canopy cover may be related to the presence of the fence and associated low percent canopy cover in the first ten sampling points along the trail. Therefore, greenway managers should consider how vegetation management along trail and fence lines effects habitat in the greenway trail footprint.

Greenway surface temperature data indicate that the trail surface temperatures are generally higher than forest edge and forest interior surface temperatures. In contrast to Chen et al. (1993, 1995), it appears that forest edge temperatures are intermediate to trail center and forest interior sites. Thus, it seems reasonable to conclude that the combination of canopy openings and the presence of the asphalt trail are primarily responsible for differences in surface temperature. Finally, it appears from this study's data that asphalt trails in greenways may have an effect most likely from the asphalt's albedo on the relationship between percent canopy and surface temperature.

Generally, greenway research is needed that identifies and categorizes natural resource problems in existing greenways. This type of baseline data would add significantly to the recreational greenway literature and be very helpful in directing future research efforts. An inventory of this nature might include assessment of numbers, type, and extent of recreation related environmental problems such as soil erosion, vegetation condition such as damage to trees, vegetative richness and composition, exotic vegetation, and presence or absence of social trails, and location of recreational features relative to environmental features. The inventory and categorization of recreation related problems would help researchers develop more specific research problems that could then be used to better understand the problems and thus direct greenway management decisions.

Based on the current study's findings, future research should include larger samples across a range of different greenways in an effort to better characterize the ecology of existing recreational greenways. These studies are needed to help minimize recreation and environmental conflict in the planning, development, and management of recreational greenways. Furthermore, the research is needed on a local, regional, and national scale. For example, developing a baseline of research on greenways nationally would help identify greenway management practices utilized to minimize recreation and environmental conflicts, as well as help researchers focus on environmental problems and solutions. This research should initially focus on testing and refining the greenway theory and three hypotheses proposed by Ahern (2004).

Although percent canopy cover and surface temperature did not vary significantly among the three treatment groups, these variables deserve additional study. For example, if research included larger (than 12 ft [3.6 m]) and smaller (than 8 ft [2.4 m]) trail widths while controlling for trail and mowed width while assessing percent canopy cover, it may help researchers better understand the impact of footprint width on habitat. In addition, studying the mowed width's relationship to surface temperature may help illuminate issues related to surface albedo and how it may or may not effect percent canopy cover.

To address greenway trail footprint impacts on percent canopy cover, future research should include an assessment of the mowed or manicured area around the trail. This might provide insight as to why there were no significant differences associated with percent canopy cover and surface temperature change scores among the three treatment groups. Furthermore, potential greenway corridors and adjacent control sites should be assessed prior to and following greenway trail construction. This type of study would allow researchers to assess the direct effect of trail construction on a host of variables, including percent canopy cover, surface temperature, soil moisture, and vegetation amount, while controlling for mowed and managed widths as suggested previously.

While surface temperatures varied significantly across the three greenway locations, research is needed to better understand these differences. For example, including an off-site temperature control may help investigators understand the extent of the trail's impact zone. Additionally, surface temperatures should be collected at more locations in the forested zone to establish and assess the extent of trail impact into the forested zone.

Because the surface temperature data for the concrete and asphalt trail were collected during a cooler month, future research should be conducted during warmer months to assess the effect of trail surface type on surface temperature in addition to including temperature probes and continuous data loggers to assess temperature at multiple locations simultaneously and closer to the summer solstice. In addition data should be collected on the trail surface thickness as different thickness would represent different levels of thermal mass and thus heat storage.

Finally, a more detailed assessment of trail impacts on tree species diversity would be instructive. Baseline data could be collected within a greenway corridor's proposed trail location and control sites prior to and after trail construction to better examine trail construction effects. Moreover, time series analysis could be conducted to examine impacts to vegetation richness and composition over an extended period. Research is needed to determine trail effects on vegetation diversity, so that greenway planners and managers might have information about how existing trails effect diversity and thus have some guidance as to how to minimize effects as was suggested by Ahern's (2004) hypothesis of use compatibility.

References

Ahern, J. (1991). *Greenways and ecology.* Paper presented at the 1991 meeting of the Landscape/Landuse Planning Committee of the American Society of Landscape Architecture's 1991 meeting, Washington DC.

Ahern, J. (1995). Greenways as a planning strategy. *Landscape and Urban Planning, 33*, 131-155.

Ahern, J. (2004). Greenways in the U.S.A.: Theory, trends and prospects. In R. Jongman and G. Pungetti (Eds.), *Ecological networks and greenways concept, design implementation* (pp. 34-55). Cambridge, UK: Cambridge University Press.

Akbari, H., Pomerantz, M., & Taha, H. (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy, 70*(3), 295-310.

Akbari, H., Resenfeld, A., & Taha, H. (1995). Cool construction materials offer energy savings and help reduce smog. *ASTM Standardization News, 23*(11), 32-37.

Arendt, R. (2004). Linked landscapes: Creating greenway corridors through conservation subdivision design strategies in the northeastern and central United States. *Landscape and Urban Planning, 68,* 241-269.

Arwine, D., Broach, J., Cartwright, L., & Denton, G. (2000). *Tennessee ecoregion project.* Nashville, TN: Tennessee Department of Environment and Conservation.

Asaeda, T., Thanh, C., & Wake, A. (1996). Heat storage of pavement and its effect on lower atmosphere. *Atmospheric Environment, 30*(3), 413-427.

Baschak, L., & Brown, R. (1995). An ecological framework for the planning, design and management of urban greenways. *Landscape and Urban Planning, 33*, 211-225.

Bauer, S. (1980). *A case study analysis of Oregon's Willamette River greenway program.* Unpublished doctoral dissertation, Oregon State University, Corvallis.

Benedict, M., & McMahon, E. (2002). Green infrastructure: Smart conservation for the 21st century. *Renewable Resources Journal, 20*, 12-17.

Bennett, K. A., & Zuelke, E. (1999). *The effects of recreation on birds: A literature review.* Retrieved September 28, 2008, from http://www.dnrec.state.de.us/nhp/

Bodie, J. R. (2001). Stream and riparian management for freshwater turtles. *Journal of Environmental Management, 62*, 443-455.

Boyle, S. A., & Samson, F. B. (1985). Effects of non-consumptive recreation on wildlife: A review. *Wildlife Society Bulletin, 13*, 110-116.

Broadmeadow, S., & Nisbet, T. R. (2004). The effects of riparian forest management on the freshwater environment: A literature review of best management practice. *Hydrology and Earth System Sciences, 8*(3), 286-305.

Brokaw, N. & Thompson, J. (2000). The H for DBH. *Forest Ecology and Management (129)*, 89-91.

Brashears, M. B., Fajvan, M. A., & Schuler, T. M. (2004). An assessment of canopy stratification and tree species diversity following clearcutting in central Appalachian hardwoods. *Forest Science, 50*(1), 54-64.

Brosofske, K., Chen, J., Naiman, R., & Franklin, J. (1997). Harvesting effects on microclimate gradients from small streams to uplands in western Washington. *Ecological Applications, 7*(4), 1188-1200.

Brower, J., & Zar, J. (1984). *Field and laboratory methods for general ecology.* Dubuque, IO: William C. Brown Publishers.

Carlson, D., & Groot, A. (1997). Microclimate of clear-cut, forest interior and small openings in trembling aspen forest. *Agriculture and Forest Meteorology, 87*(4), 313-329.

Cassierer, E. F., Freddy, D. J., & Ables, E. D. (1992). Elk responses to disturbance by cross-country skiers in Yellowstone National Park. *Wildlife Society Bulletin, 20*, 375-381.

Chen, J. T. (1991). *Edge effects: Microclimate pattern and biological response in old-growth Douglas Fir forests.* Unpublished doctoral dissertation, University of Washington, Seattle.

Chen, J., Franklin, J., & Spies, T. (1993). Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas fir forest. *Agriculture and Meteorology, 63*(3/4), 219-237.

Chen, J., Franklin, J. F., & Spies, T. A. (1995). Growing season microclimatic gradients from clearcut edges into old-growth Douglas fir forests. *Ecological Applications, 5*(1), 74-86.

Chen, J., Saunders, S., Crow, R., Naiman, R., Brosofske, K., Mroz, G., et al. (1999). Microclimate in forest ecosystem and landscape ecology. *BioScience, 40*(4), 207-288.

Cockle, K. L., & Richardson, J. S. (2003). Do riparian buffer strips mitigate the impacts of clearcutting on small mammals? *Biological Conservation, 113*, 133-140.

Coley, R. L., Kuo, F. E., & Sullivan, W. C. (1997). Where does community grow? The social context created by nature in urban public housing. *Environment and Behavior, 29*(4), 468-495.

Cole, D. N. (1989a). *Area of vegetation loss: A new index of campsite impact* (Research Note Report No. INT-389). Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Cole, D. N. (1989b). *Wilderness campsite monitoring methods: A sourcebook* (General Tech. Rep. INT-259). Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Cole, D. N. (1993). Minimizing conflict between recreation and nature. In D. S. Smith & P. C. Hellmund (Eds.), *Ecology of greenways: Design and function of linear conservation areas,* (pp. 43-68). Minneapolis, MN: University of Minnesota Press.

Cole, D. N. (1995). Experimental trampling of vegetation. II. Predictors of resistance and resilience. *Journal of Applied Ecology, 32*, 215-224.

Cole, D. N. (2004). Impacts of hiking and camping on soils and vegetation: A review. In R. Buckley (Ed.), *Environmental impacts of ecotourism* (pp. 41-60). Wallingford, UK: CABI Publishing.

Cole, D. N., & Bayfield, N. G. (1993). Recreational trampling of vegetation: Standard experimental procedures. *Biological Conservation 63*, 209-215.

Cole, D., & Spildie, D. R. (2007). *Vegetation and soil restoration on highly impacted campsites in the Eagle Cap Wilderness, Oregon* (General Technical Report RMRS-GTR-185). United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Coley, R. L., Kuo, F. E., & Sullivan, W. C. (1997). Where does community grow? The social context created by nature in urban public housing. *Environment and Behavior, 29*(4), 468-495.

Cotham, G., & Curtis, J. T. (1956). The use of distance measures in phytosociological sampling. *Ecology, 37*(3), 451-460.

Crompton, J. (2000). *The impacts of parks and open space on property values and the property tax base.* [Monograph]. Washington, DC: National Parks and Recreation Association.

Cunningham, G., Schaefer, J., Cebek, J., & Murry, D. (2008). Correlations of biotic and abiotic variable with ground surface temperature: An ectothermic perspective. Ecoscience 15(4), 472-477.

Dale, D., & Weaver, T. (1974). Trampling effects on vegetation of the trail corridors of north Rocky Mountain forests. *Journal of Applied Ecology, 11*, 767-772.

Daubenmire, R. (1959). A canopy-coverage method of vegetation analysis. *Northwest Science, 33*, 43-64.

Dawson, J. O., Hinz, P. N., & Gordon, J. C. (1974). Hiking trail impact on Iowa stream valley forest preserves. *Iowa State Journal of Research, 48*, 329-337.

Driver, B. (1990). The North American experience in measuring the benefits of leisure. In E. Hamilton-Smith (Ed.), *Proceedings of national workshop on measuring recreation benefits* (pp. 1-57). Bandora, Australia: Phillip Institute of Technology.

Driver, B. (1999). The benefits approach to leisure. In E. L. Jackson & T. L. Burton (Eds.), *Understanding leisure and recreation: Mapping the past, charting the future* (pp. 349-369). State College, PA: Venture Publishing.

Dwyer, J. F., Nowak, D. J., Noble, M. H., & Sisinni, S. M. (2000). *Connecting people with ecosystems in the 21st century: An assessment of our nation's urban forests* (General Technical Report PNW-GTR-490). Portland, OR: United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Espey, M., & Owusu-Edusei, K. (2001). Neighborhood parks and residential property values in Greenville, South Carolina. *Journal of Agricultural and Applied Economics, 33*(3), 487-492.

Ettema, C., Lowrance, R., & Coleman, D. (1999). Riparian soil response to surface nitrogen input: Temporal changes in denitrification, labile and microbial C and N pools, and bacterial and fugal respiration. *Soil Biology and Biochemistry, 31*, 1609-1624.

Fabos, J. (2004). Greenway planning in the United States: Its origins and recent case studies. *Landscape and Urban Planning, 68*, 321-342.

Fabos, J. G. (1995). Introduction and overview: The greenway movement and uses of potential greenways. *Landscape and Urban Planning, 33*, 1-14.

Fabos, J., Milde, G., & Weinmayr, M. (1968). *Fredrick founder of landscape architecture in America.* Amherst, MA: University of Massachusetts.

Fischer, R. A., & Fischenich, J. C. (2000). *Design recommendations for riparian corridors and vegetated buffer strips.* Vicksburg, MS: U.S. Army, Engineer Research and Development Center, Environmental Laboratory.

Flink, C., & Searns, R. (1993). *Greenways: A guide to planning, design, and development.* Washington, DC: Island Press.

Fluke Corporation (2004). *Infrared thermometers, users manual.* Everett, WA: Fluke Corporation.

Fogg, G. E. (2005). *Park, recreation and leisure facilities site planning guidelines.* Washington, DC: National Recreation and Park Association.

Forman, R. (1983). An ecology of the landscape. *Bioscience 33,* 535.

Forman, R. (2000). Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology, 14*(1), 31-35.

Forsey, E., & Baggs, E. (2001). Winter activity of mammals in riparian zones and adjacent forests prior to and following clear-cutting at Copper Lake, Newfoundland, Canada. *Forest Ecology and Management, 145*, 163-171.

Frauman, E., & Cunningham, P. (2001). Using a means-end approach to understand the factors that influence greenway use. *Journal of Park and Recreation Administration, 19*, 93-113.

Ganey, J. L., & Block, W. M. (1994). A comparison of two techniques for measuring canopy closure. *Western Journal of Applied Forestry, 9*, 21-23.

Geographic Resource Solutions. (2008). *User manual.* Retrieved July 13, 2008, from http://www.grgis.com

Giles-Corti, S. J., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Lange, A., et al. (2005). Increasing walking: How important is distance to attractiveness, and size of public open space? *American Journal of Preventive Medicine, 28*, 169-176.

Globe. (2005). Surface temperature and percent canopy protocol. Retrieved July 4, 2008, from www.globe.gov

Gobster, P. H. (1995). Perception and use of a metropolitan greenway system for recreation. *Landscape and Urban Planning, 33*, 401-413.

Godbey, G., Caldwell, L., Floyd, M., & Payne, L. (2005). Contributions of leisure studies and recreation park management research to the active living agenda. *American Journal of Preventive Medicine, 28*, 150-158.

Google Earth. (n.d). *User's guide.* Retrieved July 3, 2007, from http://earth.google.com/intl/en/userguide/

Governor's Council on Greenways and Trails. (2001). *Tennessee greenways and trails plan.* Nashville, TN: Tennessee Department of Environment and Conservation.

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An ecosystem perspective of riparian zones: Focus on links between land and water. *Bioscience, 41*, 540-551.

Hall, C. N., & Kuss, F. R. (1989). Vegetation alteration along trails in Shenandoah National Park, Virginia. *Biological Conservation, 48*, 211-227.

Hammit, W. E., & Cole, D. N. (1998). *Wildland recreation: Ecology and management* (2nd ed.) New York: John Wiley & Sons.

Hartig, T., Mang, M., & Evans, G. (1991). Restorative effects of natural environment experiences. *Environment and Behavior, 21*(1), 3-26.

Hawes, E., & Smith, M. (2005). *Riparian buffer zones: Functions and recommended widths.* New Haven, CT: Yale School of Forestry and Environmental Studies.

Hay, K. G. (1991). Greenways and biodiversity. In W. E. Hudson (Ed.), *Landscape linkages and biodiversity* (pp. 162-175). Washington, DC: Island Press.

Heat Island Group. (2005). *Working to cool urban heat islands.* [Brochure]. Berkeley, CA: Lawrence Berkeley National Laboratory.

Hedman, C. W., & Van Lear, D. H. (1995). Vegetative structure and composition of Southern Appalachian riparian forests. *Bulletin Torrey Botanical Club, 122,* 134-144.

Henderson, K. (2005, August). Parks and physical activity. *Parks and Recreation*, 20-26.

Hoctor, T., Carr, M., Zwick, P., & Maehr, D. (2004). The Florida state greenways project: Its realization and political context. In R. Jongman & G. Pungetti (Eds.), *Ecological networks and greenways concept, design implementation,* (pp. 222-248). Cambridge, UK: Cambridge University Press.

Hopper, G., Applegate, H., Dale, G., & Winslow, R. (1995). *Forest practice guidelines for Tennessee.* Retrieved February 5, 2009, from http://www.utextension.Utk.edu/ publications/pbfiles/pb1523.pdf

International Society of Arboriculture. (n.d.). *Tree ordinance guidelines.* Retrieved January 15, 2009, from http://www.isa-arbor.com/publications/tree-ord/heritage.aspx

Jackson, E. L., & Burton, T. L. (1999). *Leisure studies: Prospects for the twenty-first century.* State College, PA: Venture Publishing.

Jo, M., Lee, K. J., Jun, B. W., Kwan, B. K., & Jo., Y. W. (2001, November). *The spatial topographic analysis of urban surface temperature using remotely sensed data and GIS.* Paper Presented at the 22nd Asian Conference on Remote Sensing. Singapore, China.

Jongman R., & Pungetti G. (2004). *Ecological networks and greenways concept, design implementation.* Cambridge, UK: Cambridge University Press.

Kaplan, S. (1995). Restorative benefits of nature: Toward an integrative framework. *Journal of Environmental Psychology, 15*(3), 169-182.

King, W. C., Brach, J. S., Belle, S., Killingworth, R., Fenton, M., & Kriska, A. M. (2005). The relationship between convenience of destinations and walking levels in older women. *American Journal of Health Promotion, 18*, 74-82.

Knight, R. L., & Cole, D. N. (1991). Effects of recreational activity on wildlife in wildlands. *Transactions of the North American Wildlife and Natural Resource Conference, 56*, 238-247.

Kuo, F., & Sullivan W. (2001). Aggression and violence in the inner city: Impacts of environment via mental fatigue. *Environment & Behavior, 33*(4), 543-571.

Kuss, F., & Hall, C. (1991). Ground flora trampling studies: Five years after closure. *Environmental Management, 15*(5), 715-727.

Labaree, J. (1992). *How greenways work: A handbook on ecology.* Ipswich, MA: National Park Service and Atlantic Center for the Environment.

Lanarc Consultants Limited. (1995). *Community greenways: Linking communities to country, and people to nature.* Victoria, British Columbia, Canada: Department of Fisheries and Oceans.

Leblanc, J. (n.d.). *Working in the woods: Making and using a tree measuring stick.* Retrieved September 2, 2008, from http://www.cnr.berkeley.edu/departments/ espm/extension/TREESTK.htm

Ledwith, T. (1996, Summer). *The effects of buffer strip width on air temperature and relative humidity in a stream riparian zone.* Retrieved February 13, 2009, from http://watershed.org/news/sum_96/buffer.html

Lee, P., Smyth, C., & Boutin, S. (2004). Quantitative review of riparian buffer width guidelines from Canada and the United States. *Journal of Environmental Management, 70,* 165-180.

Leonard, R. E., & Whitney, A. M. (1977). *Trail transect: A method for documenting trail changes* (Research Paper NE-389). Upper Darby, PA: U.S. Department of Agriculture-Forest Service, Northeastern Forest Experiment Station.

Leung, Y. F., & Marion, J. L. (1999). The influence of sampling interval on the accuracy of trail impact assessment. *Landscape and Urban Planning, 43*, 167-179.

Leung, Y. F., & Marion, J. L. (2000). Recreation impacts and management in wilderness: A state-of-knowledge review. In D. N. Cole, S. McCool, W. Boorie, & J. O'Loughlin (Eds.), *Proceedings: Wilderness science in a time of change; Vol 5: Wilderness ecosystems, threats, and management,* (pp. 23-48). Ogden, UT: U.S. Department of Agriculture, Forest Service.

Lewis, P. (1964, January). Quality corridors for Wisconsin. *Landscape Architecture Quarterly,* 100-107.

Liddle, M. (1997). *Recreation ecology: The ecological impact of outdoor recreation and ecotourism.* Cambridge, UK: Cambridge University Press.

Lindsey, G. (2003). Sustainability and urban greenways: Indicators in Indianapolis. *Journal of the American Planning Association, 69*(2), 165-180.

Linehan, J., Gross, M., & Finn, J. (1995). Greenway planning: Developing a landscape ecological network approach. *Landscape and Urban Planning, 33,* 179-193.

Little, C. (1990). *Greenways for America.* Baltimore: The Johns Hopkins University Press.

Lutzenhiser, M., & Netusil, N. (2001). The effect of open space on a home's sale price. *Contemporary Economic Policy, 19*(3), 291-298.

MacKaye, B. (1921). An Appalachian trail: A project in regional planning. *Journal of the American Institute of Architecture, 9*, 325-330.

Maco, S., & McPherson, G. (2002). Assessing canopy cover over streets and sidewalks in street tree populations. *Journal of Arboriculture, 28*(6), 270-276.

Marion, J. L. (1991). *Developing a natural resource inventory and monitoring program for visitor impacts on recreation sites: A procedural manual.* Denver, CO. National Park Service.

Marion, J. L., & Cole, D. N. (1996). Spatial and temporal variation in soil and vegetation impacts on campsites. *Ecological Applications, 6*(2), 520-530.

Marion, J. L., & Leung, Y. F. (2001). Trail resource impacts and an examination of alternative assessment techniques. *Journal of Parks and Recreation Administration, 19*(3), 17-37.

Marion, J. L., & Olive, N. (2006). *Assessing and understanding trail degradation: Results from Big South Fork National River and Recreational Area.* Blacksburg, VA: U.S. Department of Interior, Geologic Survey, Patuxent Wildlife Research Center.

Marion, J. L., Leung, Y. F., & Nepal, S. K. (2006). Monitoring trail conditions: New methodological considerations. *The George Wright Forum, 23*(2), 36-49.

Marsh, W. M. (2005). *Landscape planning: Environmental applications* (4th ed). New York: John Wiley & Sons.

Marshall, C., & Rossman, G. (1999). *Designing qualitative research* (3rd ed). Thousand Oaks, CA: Sage Publishing.

Mason, J., Moorman, C., Hess, G., & Sinclair, K. (2007). Designing urban greenways to provide habitat for forest breeding birds. *Landscape and Urban planning, 80,* 153-164.

McCullough, D. A. (1999). *A review and synthesis of effects of alterations to the water temperature regime of freshwater life stages of salminids, with special reference to Chinook salmon* (Water Resources Assessment EPA 910-R-99-010). Portland OR: Columbia River Inter-Tribal Fish Commission.

McGuckin, C., & Brown, R. (1995). A landscape ecological model for wildlife enhancement of stormwater management practices in urban greenways. *Landscape and Urban Planning, 33,* 237-246.

McHarg, I. (1969). *Design with nature.* New York: The Natural History Press.

McPherson, E. G. (1994). Cooling urban heat islands with sustainable landscapes. In H. P. Rutherford, R. A. Rowntree & P. C. Muick (Eds.), *The ecological city: Preserving and restoring urban biodiversity* (pp. 151-171). Amherst, MA: University of Massachusetts Press.

McPherson, E. G., & Rowntree, R. A. (1993). Energy conservation potential of urban tree planting. *Journal of Arboriculture, 19*(6), 321-331.

Meleason, M. A., & Quinn, J. M. (2004). Influence of riparian buffer width on air temperature at Whangapoua Forest, Coromandel Peninsula, New Zealand. *Forest and Ecology Management, 191*(1-3), 365-371.

Mertes, J., & Hall, J. (1995). *Park, recreation, open space and greenway guidelines.* Washington, DC: National Recreation and Parks Association

Metropolitan Board of Parks & Recreation. (2002). *Metropolitan parks and greenways master plan.* Nashville, TN: Author.

Meyer, J., Kaplan, L., Newbold, D., Strayer, D., Woltmade, C., Zedler, J., et al. (2003). *Where rivers are born: The scientific imperative for defending small streams and wetlands.* Washington, DC: American Rivers.

Miller, J., & Hobbs. T. (2000). Recreational trails, human activity, and nest predation in lowland riparian areas. *Landscape and Urban Planning, 50,* 227-236.

Miller, S. G., Knight R. L., & Miller C. K. (1998). Influence of recreational trails on breeding bird communities. *Ecological Applications, 8*(1), 162-169.

Moore, R., & Shafer, S. (2001). Introduction to the special issue trails and greenways: Opportunities for planners, managers and scholars. *Journal of Parks and Recreation, 19*(3), 1-16.

Murfreesboro, Tennessee (1993). *Final master plan Stones River Greenway.* Murfreesboro, TN: Author.

Nadkarni, N., Merwin, M., & Neider, J. (2001). Forest canopies, plant diversity. In S. Levin (Ed.), *Encyclopedia of biodiversity: Vol. 3.* (pp. 27-40). Princeton University, New Jersey: Academic Free Press.

Naeem, S., Chapin, F., Constanza, R., Ehrlich, P., Golley, F., Hooper, D., et al. (1999). *Biodiversity and ecosystem functioning: Maintaining natural life support processes.* Retrieved June 27, 2005, from: http://www.esa.org/science/issues/textissues/issue4.php

National Arbor Day Foundation. (n.d.). *Tree diversity activity.* Retrieved February 5, 2009, from http://www.arborday.org/programs/TreeDiversityActv.pdf

National Park Service. (1993). *Greenway management.* Retrieved August, 29, 2006, from http://www.nps.gov/phso/rtca/grnmgnt.html

National Park Service. (2006). *The National Park Service: A brief history.* Retrieved March 6, 2007, from http://www.cr.nps.gov/history/hisnps/NPSHistory /briefhistory.htm

National Research Council. (2002). *Riparian areas: Functions and strategies for management.* Washington, DC: National Academy Press.

Nelson, T., Macedo, R., & Valentine, B. (2007). *A preliminary study of streamside air temperatures within the coast redwood zone 2001 to 2003* (General Technical Report. PSW-GTR-194). Albany, CA: U.S. Department of Agriculture.

Nicholls, S., & Crompton, J. (2005). The impact of greenways on property values: Evidence from Atin Texas. *Journal of Leisure Research, 37*(3), 321-341.

Nowak, D. J., Rowntree, R. A., McPherson, G. E., Sisinni, S. M., Kerkman, E. R., & Stevens, J. C. (1996). Measuring and analyzing urban tree cover. *Landscape and Urban Planning, 36.* 49-57.

Orsega-Smith, E., Mowen, A., Payne, L., & Godbey, G. (2004). The interaction of stress and park use on psycho-physiological health. *Journal of Leisure Research, 36*(2), 232-257.

Pauchard, A., Ugarte, E., & Millan, J. (2000). A multiscale method for assessing vegetation baseline of environmental impact assessment (EIA) in protected areas of Chile. In S. F. McCool, D. N. Cole, W. T. Boorie, & J. O'Loughlin (Eds.), *Wilderness Science in a Time of Change: Wilderness as a place for scientific inquiry* (pp. 111-116). Missoula, MT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Peet, R., Wentworth, T., Duncan, R., & White, P. (1997). *The North Carolina vegetation survey protocol: A flexible, multipurpose method for recording vegetation composition and structure.* Retrieved July 4, 2006, from: http://www.bio.unc.edu/faculty/peet/lab/CVS/

Peterjohn, W., & Correll, D. (1984). Nutrient dynamics in an agricultural watershed: Observations on the role of the riparian forest. *Ecology, 65*(5), 1466-1475.

President's Commission on Americans and outdoors. (1987). *Americans outdoors: The legacy, the challenge.* Washington, DC: Island Press.

Purcell, A. T., & Lamb, R. J. (1998). Preference and naturalness: An ecological approach. *Landscape and Urban Planning, 42*, 57-66.

REM Design Group. (2002). Parks, trails, and recreation, master plan. Retrieved January 3, 2009, from http://www.brentwood-tn.org/

Ribeiro, L., & Barao, T. (2006). Greenways for recreation and maintenance of landscape quality: Five case studies in Portugal. *Landscape and Urban Planning, 76,* 79-97.

Rodewald, A. D., & Bakermans, M. (2006). What is the appropriate paradigm for riparian forest conservation? *Biological Conservation, 128*(2), 193-200.

Rottenborn, S. (1999). Predicting the impacts of urbanization on riparian bird communities. *Biological Conservation, 88*(3), 289-299.

Ryan, K. (Ed.). (1993). *Trails for the 21st century: Planning, design and management manual for multi-use trails.* Washington, DC: Rails to Trails Conservancy.

Ryan, R. L., Fabos, J. G., & Allan, J. J. (2006). Understanding opportunities and challenges for collaborative greenway planning in New England. *Landscape and Urban Planning, 76*, 172-191.

Ryder, B. (1995). Greenway planning and growth management: Partners in conservation? *Landscape and Urban Planning, 33*, 417-432.

Salazar, M. (2005). *Promises and challenges of urban community oriented conservation: The case of greenways in Detroit.* Unpublished doctoral dissertation, Michigan State University, Lansing.

Schibig, J. (1996). Twenty years of forest change at Radnor Lake Natural Area, Davidson County, Middle Tennessee. *Journal of the Tennessee Academy of Sciences 71*(3), 1-16

Schiller, A., & Horn, S. (1997). Wildlife conservation in urban greenways of the mid-southeastern United States. *Urban Ecosystems, 1*(2), 103-116.

Searns, R. M. (1995). The evolution of greenways as an adaptive urban landscape form. *Landscape and Urban Planning, 33*, 65-80.

Shafer, S., Scott, D., & Mixon, J. (2000). A greenway classification system: Defining the function and character of greenways in urban areas. *Journal of Parks and Recreation Administration, 18*, 88-106.

Shavelson, R. (1996). *Statistical reasoning for the behavioral sciences.* Needham Heights, MA: Allyn & Bacon.

Sinclair, K., Hess, G., Moorman, C., & Mason, J. (2005). Mammalian nest predators respond to greenway width, landscape context and habitat structure. *Landscape and Urban Planning, 71*, 277-293.

Smith, D., & Hellmund, P. (1993). *Ecology of greenways: Design and function of linear conservation areas.* Minneapolis, MN: University of Minnesota Press.

Speight, M. C. D. (1973). *Outdoor recreation and its ecological effects: A bibliography and review.* London, England: University College.

Stankey, G. H., Cole, D. N., Lucas, R. C., Petersen, M. E., & Frissell, S. S. (1985). *The limits of acceptable change (LAC) system for wilderness planning* (Res. Pap. INT-176). Ogden, UT: U.S. Department of Agriculture, Forest Service.

Stauffer, D., & Best, L. (1980). Habitat selection by birds of riparian communities: Evaluating the effects of habitat alteration. *Journal of Wildlife Management, 44*(1), 1-13.

Sullivan, W., Kuo, F. E., & de Pooter, S. F. (2004). The fruit of urban nature: Vital neighborhood spaces. *Environment and Behavior, 36*, 678-700.

Swinnerton, G. (1989). Recreation & Conservation. In E. L. Jackson & T. L. Burton (Eds.), *Understanding leisure and recreation: Mapping the past, charting the future* (pp. 517-565). State College, PA: Venture Publishing.

Tennessee Department of Environment and Conservation. (2006). *The status of water quality in Tennessee, 305(b) report.* Nashville, TN: Division of Water Pollution Control.

Tennessee Department of Environment and Conservation. (2007). *Greenways and trails database.* Retrieved March 11, 2007, from http://www.state.tn.us/environment/ recreation/ greentrails.shtml

Thorne, J. F. (1993). Landscape ecology: A foundation for greenway design. In D. S. Smith & P. C. Hellmund (Eds.), *Ecology of greenways: Design and function of linear conservation areas* (pp. 23-42). Minneapolis, MN: University of Minnesota Press.

Toccolini, A., Fumagalli, N., & Senes, G. (2006). Greenways planning in Italy: The Lambro River valley system. *Landscape and Urban Planning, 76*, 98-111.

Tonnesen, S. A., & Ebersole, J. J. (1997). Human trampling effects on regeneration of age structure of Pinus edulis and Juniperus monosperma. *Great Basin Naturalist, 57*(1), 50-56.

Tyser, R. W., & Christopher, C. A. (1992). Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). *Conservation Biology, 6*(2), 253-262.

United States Department of Transportation, Federal Highway Administration. (n.d.). *Fact sheet on highway provisions.* Retrieved December 17, 2008, from http:// www.fhwa.dot.gov/safetealu/index.htm

University of Tennessee. (n.d.). *Trees for wildlife.* Retrieved February 5, 2009, from http://www.utextension.utk.edu/publications/pbfiles/pb1446.pdf

University of New Mexico. (n.d.). *Federal wildlife and related laws handbook.* Retrieved February 5, 2009, from University of New Mexico website http://wildlifelaw.unm. edu/fedbook/index.html

Urban Forestry (n.d.). *Tree diversity.* Retrieved February 4, 2009, from http://environ. binghamton.edu/urban/diversity.html

Urban Forestry South Expo. (2006). *Urban forestry manual.* Retrieved January 18, 2009, from http://www.urbanforestrysouth.org/pubs/ufmanual/soils/index.htm

Walmsley, A. (1995). Greenways and the making of urban form. *Landscape and Urban Planning, 33*, 81-127.

Walsh, C. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., & Morgan, R. P. (2005). The urban stream syndrome: Current knowledge and the search for a cure. *The North American Benthological Society, 24*(3), 706-723.

Wenger, S. (1999). *A review of the scientific literature on riparian buffer width, extent and vegetation.* Retrieved June 21, 2006, from http://www.rivercenter.uga.edu/ publication.htm

Whitford, V., Ennos, A., & Handley, J. F. (2001). "City form and natural process" - indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape and Urban Planning, 57*, 91-103.

World Commission on Environment and Development. (1987). *Our common future.* London: Oxford University Press.

Wornell, H. (1994). *Laying down routes: An evaluation of the Greater Vancouver regional district's recreation greenway program.* Unpublished master's thesis, Simon Fraser University, Vancouver, BC.

Yahner, T., Korostoff, N., Johnson, T., Battaglia, M., & Jones, D. (1995). Cultural landscapes and landscape ecology in contemporary greenway planning, design and management: A case study. *Landscape and Urban Planning, 33*, 295-316.

Yu, K., Li, D., & Li, N. (2006). The evolution of greenways in China. *Landscape and Urban Planning, 76*, 223-239.

APPENDIX

August 28, 2008

John McFadden & Dr. Tara Perry
Department of Health and Human Performance
john@tectn.org, tperry@mtsu.edu

Re: Protocol Title: "The Effects of Trail Footprint, Trail Surface Type, Trail Age..."
Protocol Number: 09-023 **Expedited Research**

Dear Investigator(s):

I have reviewed the research proposal identified above and determined that the study poses minimal risk to participants and qualifies for an expedited review under 45 CFR 46.110 Category 7. Approval is for one (1) year from the date of this letter for **10** participants.

According to MTSU Policy, **a researcher is defined as anyone who works with data or has contact with participants**. Anyone meeting this definition needs to be listed on the protocol and needs to provide a certificate of training to the Office of Compliance. If you add researchers to an approved project, please forward an updated list of researchers and their certificates of training to the Office of Compliance before they begin to work on the project. **Any changes to the protocol must be submitted to the IRB before implementing this change**.

Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 as soon as possible.

You will need to submit an end-of-project report to the Office of Compliance upon completion of your research. Complete research means that you have finished collecting and analyzing data. Should you not finish your research within the one (1) year period, you must submit a Progress Report and request a continuation prior to the expiration date. Please allow time for review and requested revisions. **Your study expires August 28, 2009.**

Please note, all research materials must be retained by the PI or **faculty advisor (if the PI is a student)** for at least three (3) years after study completion. Should you have any questions or need additional information, please do not hesitate to contact me.

Sincerely,

Tara M. Prairie
Compliance Officer