2017

Assessment and Attitudes: Biodiversity in Urban Landscapes of North Central Texas

Gray Harrison Kerry A.

Assessment and Attitudes:

Biodiversity in Urban Landscapes of North Central Texas

By

Kerry A. Gray-Harrison

The University of Texas at Arlington

December 2017

Supervising Professor: David Hopman

ACKNOWLEDGEMENTS

Many thanks to my thesis chair, Professor David Hopman, for the free rein to pursue a topic I found interesting. Thank you, also, to my committee, Dr. Amy Archambeau and Dr. Diane Jones Allen, for your reviews and comments throughout this endeavor.

Special thanks to other landscape architecture faculty for their support over the last few years: Dr. Taner Özdil, and John Fain, and also to my classmates in the landscape architecture program.

I am deeply grateful to my aunt and uncle for their hospitality during these years of grueling commutes to Arlington, and to my husband’s grandmother, Norma Blue, for her encouragement and financial assistance.

Thank you to Andy Reinmann and Kate Miller for your field instruction years ago at the University of Maine.

Deepest gratitude to my editor, field assistant, best friend and husband, Conrad Harrison.

Abstract

North Central Texas is expected to undergo increased population growth and density inside and outside of current municipal boundaries. As development increases to meet the needs of the growing population, the landscape is transformed, which results in the loss or homogenization of species (McKinney, 2006; Vitousek, Mooney, Lubchenco, & Melillo, 1997). This study examined how landscape architects can quickly assess biodiversity on a project site before and after construction without specialized knowledge or skills. Three methods were used to collect data for this study: interviews, a DNA assessment of soil fungi, and a rapid biological assessment (BioBlitz).

Two groups were interviewed: a group containing biologists, ecologists, and naturalists, and a group comprised of registered landscape architects and designers. The biologist group expressed, in general, dismay at the clearing of land before construction and the lack of ecologically viable vegetation replacements afterwards. The designer group expressed frustration with restrictive codes in some cities and the lack of knowledgeable installers on some projects. Few designers expressed interest in exploring biodiversity in depth.

For this research study, it was determined to use a simple BioBlitz with hand collection as a model for biodiversity evaluation. The trial was conducted on a 1500 square foot plot with a polyculture of intermingled plantings native to the area. About 35 distinct species of organisms were found by ten students over a 120 minute period.

Soil fungal analysis showed a gradient in the plant root-associated fungus present in the soil, which indicated the most biologically active soil community occurring in a mixed native polyculture planting located on the University of Texas at Arlington campus.

There is a need for landscape architects to lead the conversation with clients and policy makers about incorporating habitat for biological diversity. If landscape architects do not fulfill this role in the development process, there is a real possibility that no other professionals will. By simply observing and documenting existing flora and fauna, they can illustrate the need to design for and preserve biological diversity and gradually become more knowledgeable about this vital design parameter.

TABLE OF CONTENTS

Acknowledgements i
Abstract ii
List of Figures vi
Chapter 1 Introduction 1
1.1 Introduction 1
1.2 Research Objectives 2
1.3 Research Questions 2
1.4 Definition of Terms 2
1.5 Research Methods 4
1.6 Significance of the Study 5
1.7 Delimitations and Limitations of the Study 5
1.8 Conclusion 6
Chapter 2 Literature Review 7
2.1 Introduction 7
2.2 Biological Diversity 7
2.3 Ecosystem Services and Ecological Roles 9
2.4 Global Loss of Habitat and Biodiversity 15
2.5 Regional Loss of Habitat and Biodiversity 16
2.6 Urban Ecology Studies 17
2.7 Urban Ecology and Landscape Architecture 20
2.8 Biodiversity Resources for North Central Texas 22
2.9 Hands-On Biodiversity Assessment for Landscape Architects 23
2.10 Conclusion 24
Chapter 3 Methodology 27
3.1 Introduction 27
3.2 Research Strategy and Design 27
3.3 Subject Recruitment Methods 30
3.4 Soil Sampling Methods 31
3.5 Mini BioBlitz Methods 34

3.6 Qualitative Data Analysis....35
3.7 Conclusion....35
Chapter 4 Analysis and Findings....37
4.1 Introduction....37
4.2 Summary of Findings from Interviews....37
4.3 Responses from Biologist group....38
4.4 Responses from Designer Group....43
4.5 Soil Analysis Results....45
4.6 Trial BioBlitz Findings....46
4.7 Analysis of Findings from all Sources....47
4.8 Conclusion....48
Chapter 5 Conclusion....50
5.1 Introduction....50
5.2 Responses to Research Questions....50
5.3 Discussion of Findings....51
5.4 Significance to Landscape Architecture....53
5.5 Future Research....54
5.6 Conclusion....56
References....58

List of figures

Figure 1 Types of biodiversity. 8

Figure 2 Atmospheric carbon dioxide. 11

Figure 3 Healthy and stunted trees. 14

Figure 4 Soil food web. 14

Figure 5 Dallas Fort Worth region. 11

Figure 6 Removal of vegetation at a park construction site in Dallas. 18

Figure 7 Soil sampling. 32

Figure 8 Sample C after homogenization. 33

Figure 9 Soil sample depth. 33

Figure 10 Introduction to mini BioBlitz. 34

Figure 11 Students participating in the mini-BioBlitz on October 12, 2017. 35

Figure 12 Interview Subjects by Interest or Profession 38

Figure 13 Sweep net. 42

Figure 14 Pitfall traps. 42

Figure 15 Malaise traps. 42

Figure 16 Experience of Subjects in Design Group. 43

Figure 17 Soil samples. 11

Figure 18 Results of Fungal DNA Analysis. 46

Figure 19 BioBlitz Findings. 11

Chapter One

Introduction

1.1 Introduction

Many landscape architects have embraced the concept of biodiversity, but this professed support does not usually translate into observable results in North Texas. Biodiversity is an important part of landscape performance, which is itself an important topic in the practice of landscape architecture research (Landscape Architecture Foundation, n.d.). As our cities expand, land cover changes and agricultural or undeveloped areas are converted to housing or commercial developments. This change leads directly to loss of biodiversity (Vitousek, Mooney, Lubchenco, & Melillo, 1997).

Although many landscape professionals may have an interest in designing for biodiversity, information available in the scientific literature is not targeted towards design solutions (Franklin, 2012). In addition, the ecology of cities is an emerging field (Vitousek, Mooney, Lubchenco, & Melillo, 1997). Ecosystem studies of cities were first published in the early 1970s, but how cities function in the ecosystem as a whole is not yet known, and there is no mature body of information for scientists or landscape architects to draw upon (Marzluff, et al, 2008).

However, species richness, the number of species in a given location, is one concept that landscape architects can embrace superficially without statistical analysis. It is important for local practitioners to have techniques for recognizing this important indicator of ecological health.

This study explores techniques landscape architects in North Central Texas can use to assess biodiversity on project sites. Assessment techniques were determined through a literature review and interviews with experts in biological and ecological fields. The rapid biological assessment technique (BioBlitz) was chosen, simplified and used in a landscape architecture class activity to test the concept.

1.2 Research Objectives

- To determine field techniques landscape architects can use to better assess biodiversity in built environments in North Central Texas.
- To test the techniques by assessing attitudes of landscape architects towards them and field testing on the University of Texas at Arlington campus.

1.3 Research Questions

- Which techniques, used by biologists and ecologists, can best be adapted for use in a landscape architecture practice to measure biodiversity on project sites?
- Have landscape architects in North Central Texas committed to promoting an understanding of biodiversity within their firms?

1.4 Definition of Terms

Anthroposphere: The socio-economic world of people (Marzluff, et al, 2008).

Biodiversity: "The total of variation in organisms, in past times and present, in locations up to and including the entire planet, and organized at three levels: ecosystems, species comprising the ecosystems, and genes prescribing the traits of the species" (Wilson, 2016). "…The variety of life…" (Gaston & Spicer, 2004, p. 3).

BioBlitz: a short duration intense survey "designed to rapidly quantify species richness." (Foster, Muller, Dykes, Wyatt & Gray, 2013, p.57). Also called a rapid biodiversity assessment.

Citizen science: the process of using non-scientists to collect data usable in a scientific inquiry.

Ecology: The study of the natural environment and of the relationships of organisms to each other and to their surroundings (Ricklefs, 2000). A major interacting system that includes organisms and their nonliving environment (Raven, Johnson, Losos, Mason, & Singer, 2008).

Ecosystem services: "… the goods and services humanity extracts from the ecosystem." (Matlock & Morgan, 2011, p.1) "Societally important consequences of ecosystem processes (e.g., water purification, mitigation of floods, pollination of crops)" (Wall, Bardgett, Covich, & Snellgrove, 2004, p. 9).

North Central Texas: The geopolitical region comprised of sixteen member counties in the North Central Texas Council of Governments.

Snowball sampling: also called purposive or referral sampling. Seeking "data expected to be most helpful in addressing the research question" (Deming and Swaffield, 2011, p. 131).

Species: "A genetically distinct population or cluster of populations whose members freely interbreed with one another in nature" (Wilson, 2016). This term is more difficult to define for soil-dwelling organisms. "Species as we once knew them, no longer really exist" They are called operational taxonomic units. (Wall, Fitter, & Paul, 2005, p. 15).

Species richness: the number of species in a given area (Gaston and Spicer, 2004).

Urban ecology: "The study of ecosystems that include humans living in cities and urbanizing landscapes" (Marzluff, et al., 2008 p. vii).

1.5 Research Methods

Three sets of data were collected for this study. In the first set, the researcher interviewed two groups of professionals. The first group was comprised of biologists, ecologists, and naturalists with field experience in the 16-county North Central Texas study area (biologist group). Subjects were selected through literature review and referral, or snowball, sampling to provide a range of techniques for organisms at several scales

The second group of interview subjects was comprised of landscape architects and landscape designers with work experience in the North Central Texas area (designer group). These subjects were selected by online website searches and snowball sampling. Interviews were conducted to gather professionals' research methods and techniques, if any, for documenting or researching biodiversity on a project site.

The conversations for both groups were recorded, if permission was given, transcribed, and analyzed using the domain analysis technique.

For the second set of data, the researcher designed handouts for and led a trial mini-BioBlitz on campus as part of a landscape architecture class activity. Data was also collected by a paper questionnaire administered to students.

Finally, the researcher collected soil samples for fungal diversity analysis for the third set of data. The fungal analysis examined the presence of a small subset of all possible soil organisms, arbuscular mycorrhizal fungi, which serves as an indicator for the soil's biological activity.

1.6 Significance of the Study

In the North Central Texas region, as in other fast-growing large cities in the United States, habitat is often severely degraded where development occurs. Learning about and sharing knowledge of habitat creation is a great way for the profession to distinguish itself from competing disciplines and professions. Participation in a BioBlitz is also a way to build community support for the living things within the built environment.

1.5 Delimitations and Limitations of this Study

This study is delimited to techniques appropriate for landscape architects' assessment of species richness as one part of the biodiversity of North Central Texas. The physical boundaries of study subjects' experience were defined as the sixteen county North central Texas region to keep the topic narrow.

Limitations of the study include the small number of scientists interviewed, the limited number of soil samples taken, and the lack of replication of the BioBlitz on campus. The amount of time available for this study was a factor in the limitations. More interviews would have contributed to a better understanding of types of habitat present in the study area. More soil samples would provide more data about the different types of soil biota and the soil's chemical composition, which can suggest what food sources are available to those organisms. A rapid biological assessment of a planted area could have been repeated in another area of campus with a different type of vegetation and maintenance plan, and the results from the two assessments could have been compared.

1.8 Conclusion

This study is located in the North Texas region and uses interviews, soil testing, and a trial assessment to investigate how landscape architects in this area can assess biodiversity on a particular site. A literature review discusses global extinction, loss of habitat that contributes to extinction, and the importance of a single species in complex ecologies. The literature review also discusses existing assessment techniques and information available, and how they may or may not be suitable for incorporation into a design firm's practice.

The interviews from the biologist group yielded concerns about the built environment without an understanding for the restrictions faced by designers. The designers group discussed methods used to design for or research biodiversity without an understanding of how complex that biodiversity is. The BioBlitz technique has potential to be integrated into a design practice as a way to educate and interest designers and clients about the role of small organisms in the larger ecology of an area.

Landscape architects in this region have a great opportunity to increase usage of a more diverse array of vegetation which will support the insects and other invertebrates so important to a healthy ecology. Landscape architects can play a leadership role as advocates for a robust local ecology. This research reinforces the important potential of landscape architects to act as a bridge between ecological scientists and project clients.

Chapter Two

Literature Review

2.1 Introduction

In the summer of 2016, a convention of landscape architects and other concerned individuals met to produce a revised version of the profession's 1966 *Declaration of Concern*. The "New Landscape Declaration," as it is called, includes this passage:

> As landscape architects we vow to create places that serve the higher purpose of social and ecological justice for all peoples and all species. We vow to create places that nourish our deepest needs for communion with the natural world and with one another. (Landscape Architecture Foundation, 2016)

In making this declaration, landscape architects have joined their voices to those of many others in biological and ecological fields, and, by doing so, have indirectly voiced their support for research into how to support a biologically diverse built environment. In order for landscape architects to fulfill this vow, they must understand the larger picture of global and local extinction, how their day-to-day professional decisions, on all sizes of projects, might affect biodiversity outcomes, and how to assess existing biodiversity at project sites.

2.2 Biological Diversity

Although biology, conservation, and ecology researchers have different definitions for the term (Tzoulas & James, 2010), biodiversity in the field of landscape architecture is defined by Ahern, Leduc, and York (2006) as "…the totality—over time—of genes, species, and ecosystems, including the ecosystem structure and function that support and sustain life" (p. 6).

In biology literature, Lovejoy (1997) describes biodiversity by explaining, “Natural communities each have their own characteristic biodiversity, both in terms of numbers and composition of species” (p. 7). **Figure 1** illustrates some of the complexity of biological diversity and ecological roles. The Convention on Biodiversity, a landmark international treaty produced in 1992, states that

> ‘Biological diversity’ means the variability among living organisms from all sources including [among other things] terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems (Gaston & Spicer, 2004, p.4).

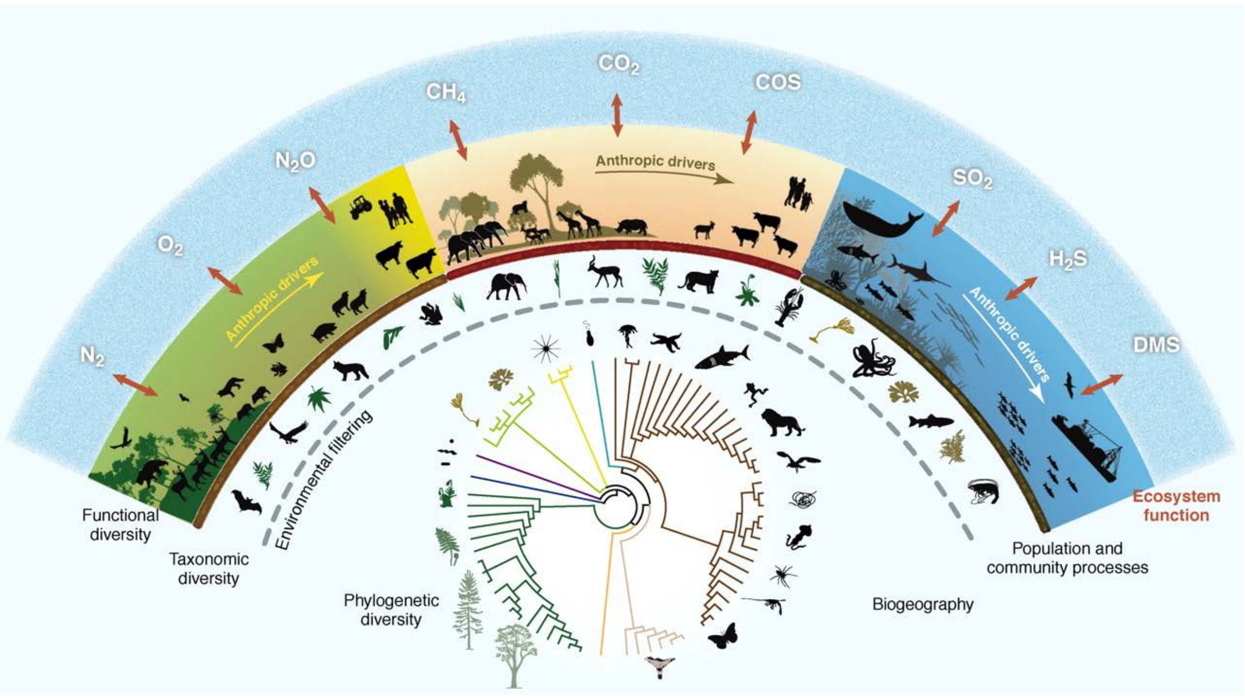

Figure 1 Types of biodiversity (Naeem, Duffy, & Zavaleta, 2010).

2.3 Ecosystem Services and Ecological Roles

The term “ecosystem services” is defined by Matlock and Morgan as the goods and services humans derive from the ecosystem (2011). Humans depend upon other organisms for producing all of our food, much of our clothing, the gases that we breathe, and many of the chemicals taken as drugs that help us to fight off disease (Raven, Johnson, Losos, Mason, & Singer, 2008). We also depend upon the services of other organisms for breaking down our trash, purifying our water, sequestering carbon, and pollinating many of our food crops (Wall, Bardgett, Covich, & Snelgrove, 2004). In short, we depend upon other organisms for the support systems that keep us alive and functioning. If, for no other reason, our own self-interest should compel us to conserve as many of those organisms as possible for the ecosystem services that they provide to us. These services are intertwined with the roles of different groups of organisms that make vital global processes, such as the carbon and nitrogen cycles possible.

Humans benefit from many of those processes that occur “behind the scenes,” yet many of them are not known to science. Biologists estimate 7.4 to 10 million species currently on earth, and about 86 percent of those are not yet known to science (Mora, Tittensor, Adl, Simpson, & Worm, 2011). These species may go extinct before their roles in the ecology of their area is determined (Wilson, 2016). A species may play a small role in the ecosystem but the effects of those roles can be large. In discussing soil and sediment biodiversity, Covich (2004) states “…the loss of a single species could alter these ecosystem services” (p. 13).

An example of this is illustrated by the interactions of a certain ant species living inside a pepper plant in the rainforest. One group of scientists, studying complex rainforest interactions, found that the seedlings of dominant canopy tree species were eaten by caterpillars kept in check by a species of pepper-dwelling ant, which were themselves kept in check by a species of beetle. When the scientists added beetles to a patch of forest that did not previously have them, they found that the ant numbers were reduced so that they were unable to keep caterpillars in check, and several caterpillar species ate so many plants that the seedlings of the dominant trees were destroyed (Metzner, 2017).

Another example involving an invasive ant in North America looked at the germination rates of seeds held in invasive ant and native ant nests. The study showed that seeds gathered and held in the native ant nests germinated slightly sooner than those held in the invasive ant nests. Although no research is available showing that the plants used in this study would benefit by slightly earlier germination, the authors discuss that, in general, early germination can lead to greater overall success of plants in the wild (Prior, Saxena, & Frederickson, 2014).

These specific examples illustrate some of the details of competition occurring in ecosystems; all of these competitions influence the greater picture of ecological processes. Multiplied by thousands of ant colonies, the changes in these species can have large effects on plant communities and on an entire region. Just as important, but not as entertaining, is the cycling of elements within the environment. Two of the most important processes are the carbon and nitrogen cycles, which depend upon living things for recycling.

“Carbon sequestration” is a term frequently used in descriptions of low-impact design, or LID projects. In those projects and in other landscapes, vegetation and soil are important for locking away, or sequestering, carbon, as is visible in **Figure 2** below. The red line indicates the seasonal cycle of atmospheric carbon dioxide, or the Keeling curve, which peaks in the Northern Hemisphere in May as frozen forests thaw, bud, and begin photosynthesis (Ricklefs, 2000).

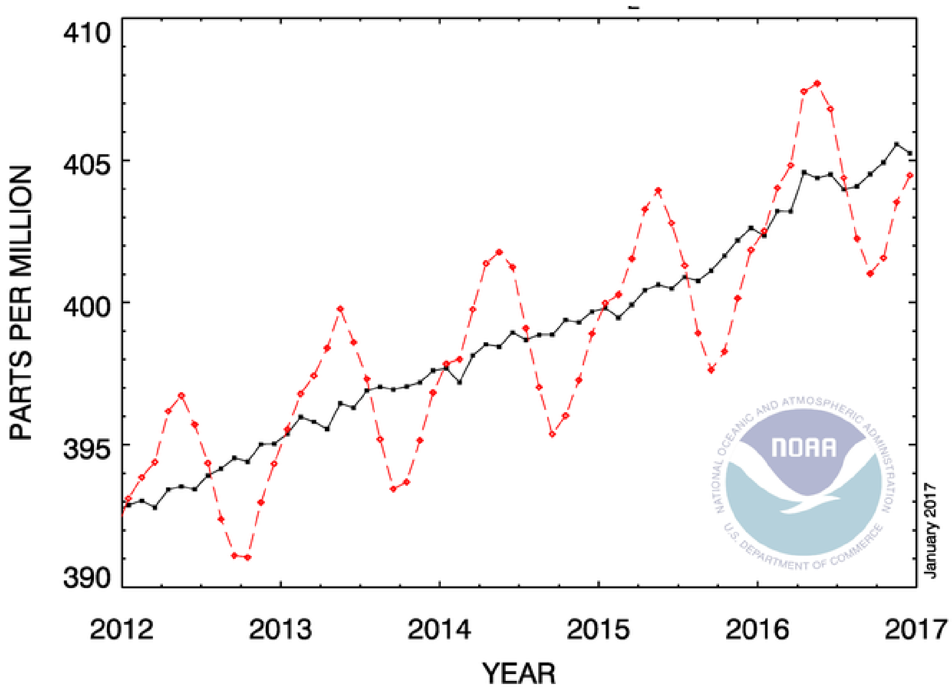

Figure 2 Atmospheric carbon dioxide. Saw tooth-shaped Keeling curve shown in red. Source: National Oceanic & Atmospheric Administration, Earth System Research Laboratory

Although the general overall rise of the graph is largely due to human production of carbon dioxide, the small peaks on the red Keeling curve are due to decomposition of organic matter and the resulting respiration of microorganisms in soils (Ricklefs, 2000). The living things in soil, the soil biota, are important not only in the decomposition that recycles carbon, but in the second important cycle: the nitrogen cycle.

Nitrogen is vital to plant growth, and is often the limiting factor keeping growth in check (Raven, Evert, & Eichhorn, 1997). Because atmospheric nitrogen is not a form that plants use, chemical fertilizers, usually including nitrogen, are often applied to agricultural and horticultural plantings. When not managed by humans, plants depend on symbiotic and some non-symbiotic bacteria in soils or sediments to convert atmospheric nitrogen to a form available to plant roots

(Wall, Bardgett, Covich, & Snelgrove, 2004). Trees and other plants in confined areas, such as parking lot islands, often show stunted growth. High soil temperatures, low soil volume, limited water availability, and pollution are the main causes of this (Dumitrascu, Stanica, Gala, & Manescu, 2012). However, larger tree wells are shown in one study to do better than their counterparts with smaller tree wells. This exposure to atmospheric nitrogen may be an important factor (Day & Amateis, 2011). Difference in tree growth rates is illustrated in **Figure 3** below. All trees were planted at the same time, but A and B have been removed. C was planted with a large amount of soil, but D had restricted roots. Differences in growth rates between C and D are visible.

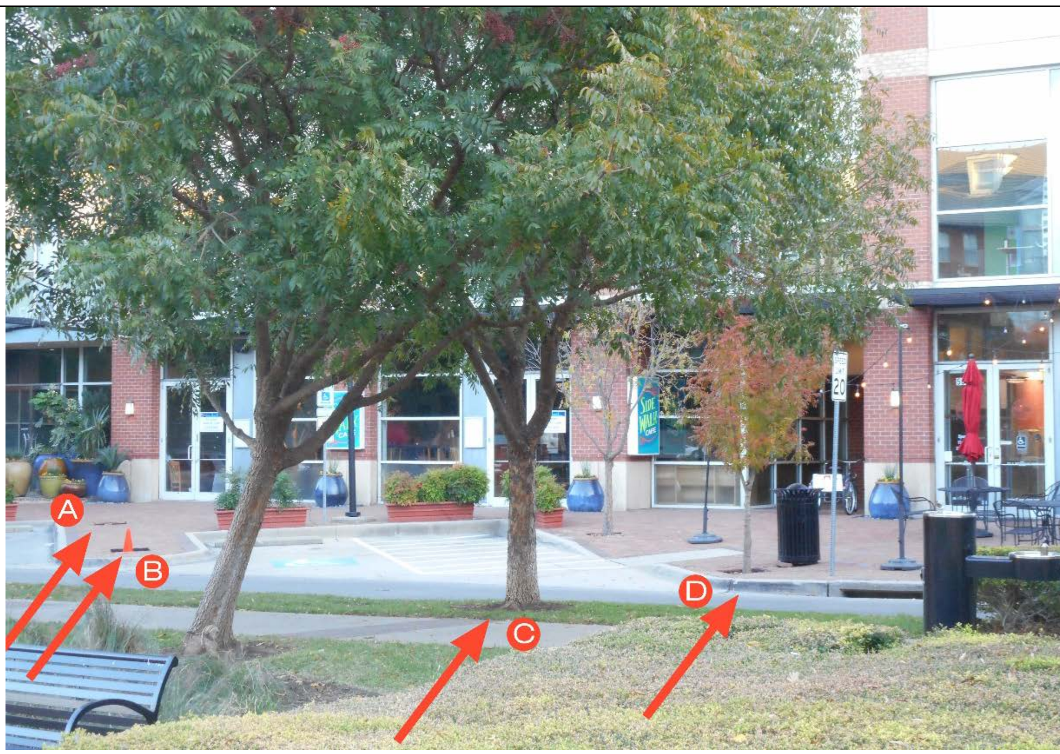

Figure 3 Healthy and stunted trees. A and B have been removed. C has grown more than D.

Nitrogen is not the only important factor for plant growth; fungi often form associations with plant roots and are important components of soil health and the diverse biota of soils. Fungi help plants to take up more nutrients than they would be able to do on their own (Raven, Evert, & Eichhorn, 1997). Mycorrhizae are fungi that form associations with plant roots and are especially important in helping plants take up phosphorus from the soil. These fungi associate with roots in two ways: inside the root cell and outside the root cell. The fungi which form outside of roots, “ectomycorrhizae,” are less common and usually closely associated with specific families of plants (Raven, Evert, & Eichhorn, 1997). The fungi which form structures inside the root cell, “endomycorrhizae,” are not specialized and occur in about 80 percent of all plant species (Raven, Evert, & Eichhorn, 1997). A type of endomycorrhizae forms recognizable vesicles or structures inside root cells. Diversity of these arbuscular mycorrhizal (AM) fungi are known to be lost as a result of disturbance caused by humans (Leake, Johnson, Donnelly, Boddy, & Read, 2005). Some studies in agricultural fields have used types and abundance of AMF as indicators of soil quality (Mahecha-Vásquez, Sierra, & Posada, 2017; Säle et al., 2015). A DNA assessment of AM fungi abundance is included in this study.

Some fungi form an association with photosynthetic partners in little-studied partnerships called lichens. Lichens may be important in temperate rainforests and subarctic ecosystems for nitrogen cycling (Nash, 1996a) but are very susceptible to pollution and not often seen in abundance in urban environments (Gries, 1996). When they are present, lichens provide food and habitat for tiny insects, mites, and the unusual small creatures known for surviving extreme conditions: tardigrades, or “water bears.” Tardigrades can withstand desiccation for decades (Beatley, 2011). Some lichens live on rocks and break down their substrate into small particles which is one of the early stages of soil formation (Nash, 1996b).

The rough bark of a tree or the leaf litter underneath it is a complex landscape full of vantage points and hiding places if one takes a bug's point of view. The base of some terrestrial food webs depends on very small creatures like tardigrades, detritus-shredding arthropods, or even smaller organisms, such as fungus and bacteria, which consume the leaf litter shed by plants as shown in **Figure 4** (Ricklefs, 2000).

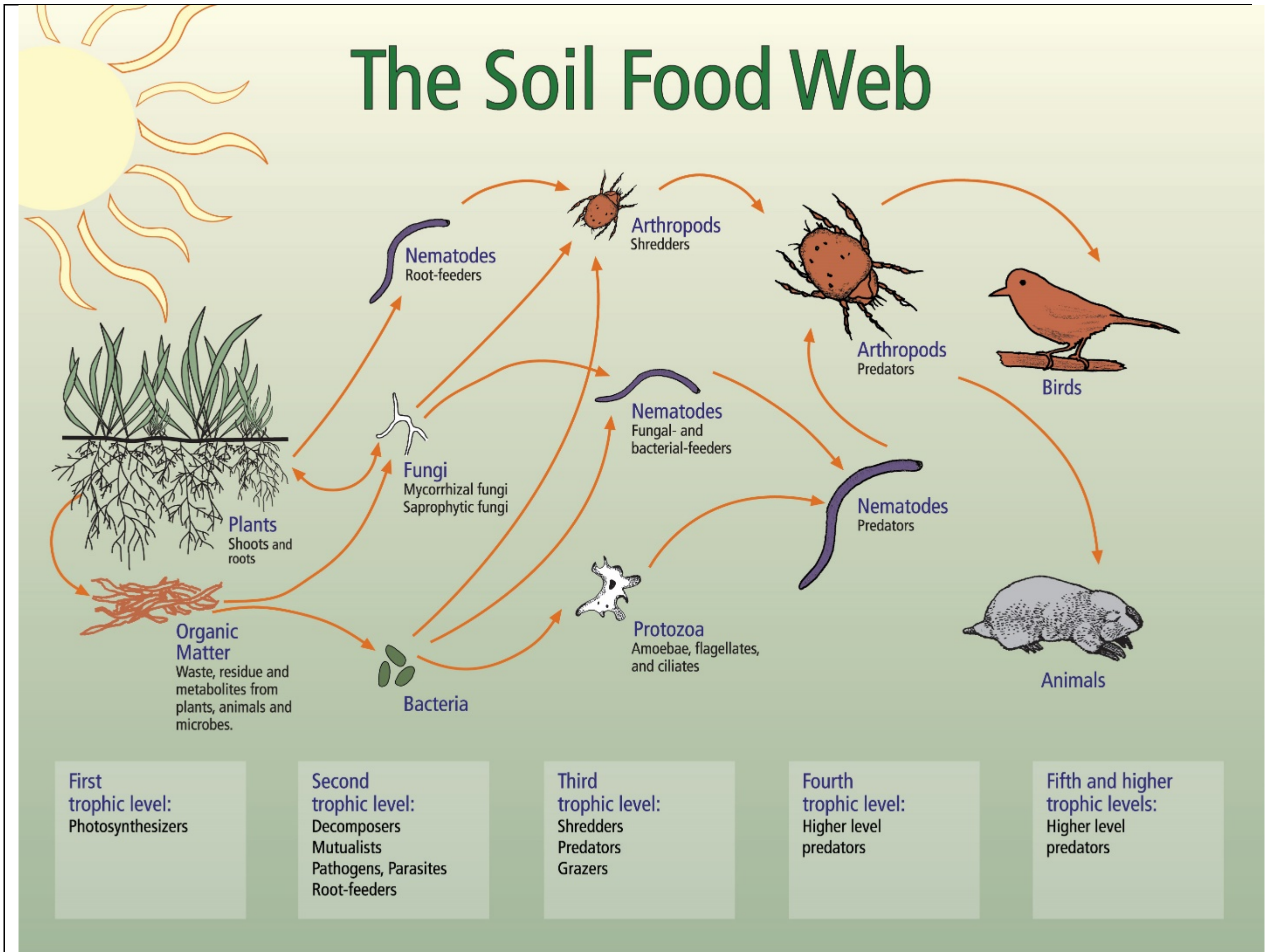

Figure 4 Soil food web. Image: USDA Natural Resources Conservation

Wall, Fitter, and Paul (2005) point out in their soil biodiversity book that "The world seems primarily microscopic" and that "We do not know their names or what they do" when referring to life in the soil (p. 11). Soils are vitally important for sequestering carbon and vegetation depends on soil, but much research remains to be done. (Wall, Fitter, & Paul, 2005).

Pollination is another important service that organisms provide and from which humans benefit. Although many plants depend on water or wind for pollination, several types of vertebrate and invertebrate animals visit and deliver pollen to flowers. At least 130,000 species of animals, including bees, flies, beetles, butterflies, moths, birds, and bats frequently visit flowers and are potential pollinators (Willmer, 2011).

Many honeybees, which are an introduced species, are facing declines because of colony collapse disorder. Beck (2013) points out that native bees can fill their crop pollination role if given proper nesting areas and consistent flower forage. Although some native bees are specialists, many are generalists and need only a patch of bare ground, an abandoned rodent burrow, or a tree cavity to nest in.

"Charismatic megafauna" the large, furry animals popular in media, are relatively few in number. The real work of ecosystems is done by plants and animals out of the spotlight: ants, microbes, fungus and other small organisms. The biologist E. O. Wilson summed it up nicely: "If all mankind were to disappear, the world would regenerate back to the rich state of equilibrium that existed ten thousand years ago. If insects were to vanish, the environment would collapse into chaos" (MacNeal, 2017).

2.4 Global Loss of Habitat and Biodiversity

Human actions are often responsible for species loss worldwide, as listed in an often-quoted review article in the journal *Nature*: "…humans are co-opting resources, fragmenting habitats, introducing non-native species, spreading pathogens, killing species directly, and changing global climate" (Barnosky, et al., 2011, p. 51). Insects, especially, are in decline, and may be worse off than plants or animals (Thomas, et al., 2004) A quarter of all known bird species are thought to have gone extinct in the past two millennia (Vitousek, Mooney, Lubchenco, & Melillo, 1997).

Tropical rainforests are important regions for biodiversity, but the conversion of rainforest to pasture changes the soil life as well as the vegetation above ground. Wardle et al. (2004) describe an area in the Amazonian rainforest where conversion to pasture resulted in the earthworm dominating the soil. As a result, the soil became almost as compacted as by heavy machinery, anaerobic, and with increased release of methane.

2.5 Regional Loss of Habitat and Biodiversity

At the southern end of the tallgrass prairie of North America, where the urban areas of Dallas and Fort Worth are located (Griffith, Bryce, Omernik & Rogers, 2007), agricultural practices in range and crop management have changed the historic habitat. Because of its suitability for agricultural use, a very small percentage of the tallgrass prairie remains in the United States (Samson & Knopf, 1994), and less than 1 percent of Texas blackland prairie remains uncultivated (Eidson & Smeins, 1999). In the towns and cities surrounding Dallas and Fort Worth, agricultural use of land is becoming less common as towns grow to meet increasing populations. Most of these communities will see increasing urbanization in the next several decades (North Central Texas Council of Governments, 2014). Development between the years of 1974 and 2016 is shown in the satellite images in **Figure 5**.

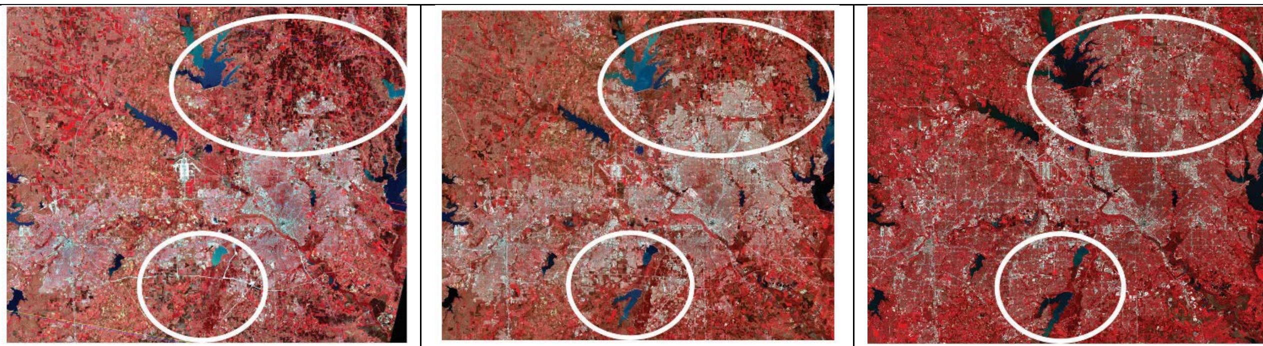

Figure 5. Dallas Fort Worth Region 1974, 1989, and 2016. (United States Geological Survey, 2016)

Some species are able to adapt to these changes, but others are not (Campbell, 1995). Of those in decline, a few, such as the Bald Eagle or Whooping Crane, were well publicized in popular media when added to the federal endangered species list. However, some of the species on Texas and federal watch lists are not well known to the public because their range is so small, they are not "charismatic megafauna," and they inhabit sparsely populated areas. In order to educate the public, The Endangered Resources Branch of Texas Parks and Wildlife Department maintains an online interactive map with data compiled from all counties in Texas. The sixteen counties in the North Central Texas region (Collin, Denton, Dallas, Ellis, Erath, Hood, Hunt, Johnson, Navarro, Palo Pinto Parker, Tarrant, Somervell, Kaufman, Rockwall, and Wise) provide data for 63 species of fish, mollusks, plants, insects, and animals threatened at the state level (Texas Parks and Wildlife, 2016). As urbanization increases, they will likely suffer from homogenization seen in other urban areas (McKinney, 2002).

2.6 Urban Ecology Studies

Vitousek et al. (1997) state, "Overall, land transformation represents the primary driving force in the loss of biological diversity worldwide" (p. 5). In general, as land use changes from agricultural to urban use, species diversity drops (Alberti et al., 2008; McKinney, 2006).

McKinney (2006) lists the reasons for this as the dramatic modification of land cover, illustrated in **Figure 6**, the long-timeline of urban cover, and its intensification over time. Because these changes are well known, many studies have been conducted on the ecology of urban areas. Some examples of these studies examine green roofs (Braaker, Obrist, Ghazoul, & Moretti, 2017; Oberndorfer et al. 2007; Tonietto, Fant, Ellis & Lenkin, 2011; and Williams, Lundholm, MacIvor, & Fuller, 2014), the types of arthropods in urban patches (Gibb & Hochuli, 2002), the presence or absence of urban pollinators (Hall, et al., 2016), and the species of ants found in Manhattan (Savage, Hackett, Guenard, Youngsteadt, & Dunn, 2015).

Figure 6. Removal of vegetation. Park construction site in Dallas, Texas.

While urban cores are shown to have low levels of biodiversity, the suburban fringes are sometimes shown to have more biodiversity than the less developed outer edges. Researchers hypothesize that the variety of habitats occurring in close proximity, along with the planting of exotic species, cause this bump in diversity. This irregular gradient from urban to rural is often not linear, and has been demonstrated in mammals, birds, butterflies, bumblebees, ants, lizards, and plants (McKinney, 2002; Kowarik, 2011). However, McKinney (2006) argues that while local urban biodiversity might be high, global biodiversity drops due to homogenization of species in urban areas. Other studies find similar results (Muratet, 2008). But not all researchers have found this to be true. Hall et al. (2016) examine urban pollinators and find that bee diversity- even the specialty bees with a preference for a narrow range of flowers- is greater within some cities than in the surrounding areas. They argue that resources should be used to conserve for urban pollinators, since they have "relatively small functional requirements" compared to mammals (p. 26). This paper does not discuss the intensity of the urban development studied in the many cites listed, but does support the proposition that urban conservation, at least for bees, is a worthwhile pursuit because of the strong support of people interested in them.

Biodiversity is studied across other gradients, not just urban to rural. While many researchers have deduced a differing level of biodiversity across a rural to urban gradient, Fattorini (2011), examined insect diversity over time, and found that in Rome, insect diversity has declined and local extinctions have occurred. Other researchers have examined bees in cities across income gradients, and found that lower income neighborhoods tend to have higher bee diversity (Lowenstein, Matteson, Xiao, Silva, & Minor, 2014). This may be due to less intensive landscape maintenance which allows more forage for the bees or lower pesticide use in these neighborhoods.

In the North Central Texas region, little documentation may be available to show changes over time. Beckham, Warriner, Atkinson, and Kennedy (2016) found little documentation available for the presence of native bumblebee populations in rural areas where grasslands are the major landcover. In this region, many species may not be well documented (A. Nelson, personal communication, September 15, 2017).

2.7 Urban Ecology and Landscape Architecture

Humans are dependent upon other organisms for basic needs such as oxygen and food, as well as the psychological needs of relaxation and mental health (Beatley, 2011). Landscape architects are familiar with incorporating green spaces, trees, and "nature" into their projects. However, ecologists have only recently shown interest in examining anthropogenic ecology in recent years. This emerging area of study is "Urban Ecology."

The field of urban ecology studies both human and non-human interaction in the urban environment. For a long while, ecologists preferred not to study urban ecology, thinking that "urban ecosystems were regarded as highly disturbed and supporting relatively common species" (Kuhn & Klotz, 2006, Muratet et al., 2008). But recent publications show great interest in the fields where landscape architecture, urban planning, and ecology converge.

Frederick Steiner, dean of the University of Pennsylvania School of Design, proposed a new term, "landscape ecological urbanism", as a response to emerging ideas regarding the planning and design of cities in the 1990s (Steiner, 2011). In 2010, Dumbarton Oaks, a research library and museum, held a symposium titled "Designing Wildlife Habitats." The speakers, from many different disciplines, approached the topic from differing viewpoints. Nina-Marie Lister, an associate professor in urban and regional planning, spoke about ecological infrastructure and the need for nodes, edges, and corridors to allow species the ability to move about. Steven Handel, a professor of ecology, talked about the term "ecosystem services" as a selling point that piques the interest of government officials. He employed birds (and ants) as seeding contractors to spread fleshy fruits on Fresh Kills, the 2,000 acre landfill near New York City. He also said that diverse habitats offer value by “supporting complex life histories, feeding sites through time, protecting species from predators/storms and enabling change through the years” (Green, 2010).

At the American Society of Landscape Architects convention in New Orleans in 2016, Frederick Steiner led a panel discussion composed of the authors of the follow-up book to *Ecological Design and Planning*, which he co-edited with George Thompson in 1997. This new book, titled *Nature and Cities: the Ecological Imperative*, has been available in print only since the spring of 2017. The panelists discussed his or her chapter in the book, which often mentioned a way for the profession to best incorporate ecology into the urban environment: to stitch spaces throughout the city. City biodiversity plans are becoming a reality for cities in Europe, and landscape architects on that continent are able to incorporate biodiversity goals as complements to aesthetic goals in the landscape. The Convention on Biodiversity, although adopted by several European cities, has not been adopted by the United States, however, as of 2017 (Nilon et al., 2017).

One potential method of increasing biodiversity is through careful use of native and adapted plantings. David Hopman discusses how he determined a mixture of plants that would look well-kept and fulfill ecological roles in his series of web postings on the Field, the ASLA professional practice blog. Because these plantings do not need to be mowed regularly, they could provide a rich source of seeds and insects for birds. These “aesthetically qualified native urban polycultures” as he calls them, are potentially scalable to retrofit small areas such as parking lot islands as well as larger areas of new construction (Hopman, 2016a).

Polycultures offer an alternative to turf in planted areas with the potential to harbor invertebrates, birds, and lizards. Grass-free lawns have been studied in the United Kingdom for their potential to harbor insect diversity. Researchers replaced turf with low-growing mow-tolerant perennial forbs which appear turf-like, a visual concern important to some landowners (Smith, Broyles, Larzleer, & Fellowes, 2015). Polycultures have an advantage over mowable forbs, however, by needing little maintenance, and they provide enhanced habitat with a small carbon footprint.

Examples of this interconnection of species are found in the North Central Texas area, too. Other non-insect arthropods, and even other phyla, are vital players in the complicated ecological puzzle. The Golden Cheeked Warbler, endemic to the Ashe Juniper stands of Central Texas, uses spider webs to interweave strips of juniper bark into its nests (Campbell, 1995). Another threatened bird, Henslow's Sparrow, is so light in weight that "…they can perch on and eat the seeds of the tall swaying grasses without bending them to the ground" (Kline, 2005, p. 12).

2.8 Biodiversity Resources for North Central Texas

Landscape architects in North Central Texas can draw on the resources of the Landscape Architecture Foundation and, especially, the Landscape Performance website for recent research. Many of the tools posted on the site focus on storm water management, pollution mitigation, and urban heat island effects, although some research studies listed on the landscape architecture foundation website do mention biodiversity. The InVest (Integrated Valuation of Ecosystem Services and Tradeoffs) tool looks at "goods and services from nature that sustain and fulfill human life." However, the role of biological organisms in the InVest tool and listed studies are limited and do not address the full scope of the richness in ecological systems. Case studies and other publications on the Landscape Performance Series site list methods used to determine biodiversity on finished projects. These methods include the Plant Stewardship Index, the Floristic Quality Assessment, and the Reciprocal Simpson Index.

The Texas Nongame and Rare Species Program of the Texas Parks and Wildlife Department maintains a website containing sections on native pollinators, species with greatest conservation needs that are not legally protected, and the state conservation plan (Texas Parks and Wildlife Department, 2017). The Endangered Resources Branch of the Texas Parks and Wildlife Department maintains a useful interactive map for providing data about rare, threatened, or endangered species by county (Texas Parks and Wildlife Department, 2016).

Many cities in the region offer nature walks and talks open to the public. The City of Richardson sponsors an Urban Naturalist program targeted towards educating the public. Cities throughout the region sponsor some types of biodiversity education for the public. The website http://www.nhnct.org/urban/biod2.html#ecology shows links to many resources.

2.9 Hands-On Biodiversity Assessment for Landscape Architects

Where data will not be needed for analysis, no particular method is needed for assessment. However, if data is needed for a study, assessment techniques will have already been developed based on the target organisms. For nonmoving organisms such as plants, sampling is often based on identifying plants within a transect, or straight line, at predetermined intervals. A wire or plastic frame, called a quadrat, is often used to mark the sample area along the transect (Wheater, Bell, & Cook, 2011).

Moving organisms such as insects or amphibians require a different approach. Insects can be sampled through observation, such as for butterflies or dragonflies, but soil-dwelling and ground-active insects can be sampled by hand searches or pitfall traps. The exact design depends upon the target organism, but the general design of a pitfall trap requires a container such as a plastic cup sunk into the ground with a small amount of preservative in the bottom. Antifreeze or a combination of methyl or ethyl alcohol with a small amount of added glycerol are common (Wheater, Bell, & Cook, 2011).

Plant-feeding organisms can be collected via an aspiration device, sweep nets, or beating vegetation to disturb organisms onto a collection tray. Flying insects can be intercepted with clear glass “windows” or nets set to intercept flight. A Malaise trap is set up like a three-sided tent with an angled roof to direct flying insects into a trap at the top (Wheater, Bell, & Cook, 2011).

Larger animals such as reptiles or mammals can be recorded through direct observation or motion-activated cameras. Amphibians can be observed directly, but care must be used when handing them. Salamanders drop their tails when disturbed, and all amphibians are susceptible to fungal diseases which can be transmitted through handling. Vinyl gloves are best (Wheater, Bell, & Cook, 2011).

2.10 Conclusion

Beck (2013) describes how landscape architects must find the best balance between many elements in a landscape design:

> Designers are attuned to the importance of context and to the relationship between form and function. We understand how the patterns of a landscape affect the ways it is used. We are accustomed to scaling and shaping spaces for their human occupants, to locating various elements in an efficient relationship to one another, and to creating useful

> connections between them…We can extend this same thinking to the needs of other organisms and to ecological processes in general. (p. 209)

Dramstad, Olson, and Forman describe patches, edges, corridors, and mosaics as elements of the structural pattern of a landscape or region (1996). Humans help to create new types of those four elements as we cultivate or build on land. In order to support the living things on which we draw goods and services, we must design those patches, edges, corridors, and mosaics to be quality habitat. Because we still know so little about the processes upon which we depend, we must work to make our built environments as inclusive to biota as possible. Working to design or preserve soil health is vitally important as so little is still known about soil life. For example, estimates place less than 5 percent of species and less than one percent of operational taxonomic units as described in the scientific literature (OTUs are used where the label of species does not apply, as they cannot be separated into discrete species) (Wall, Fitter, & Paul, 2005).

The Sustainable Sites Initiative and SITES certification is another positive step in the direction of biodiversity education and promotion for landscape architects and related professionals. The educational materials discuss biodiversity and the importance of native plants. Points towards SITES certification are awarded to projects for the use of native plant materials, but the details of pollinator needs, such as variety in flower size, are not discussed. Other organisms are not mentioned at all (Calkins, 2011).

At the 2017 ASLA convention in Los Angeles, discussion in one professional practice network involved using plants from similar climates as a source of new resilient vegetative material. One panel member at the 2016 ASLA convention also described research on plants from similar biomes when designing the planting plan for Grand Park in Los Angeles. What we now call the biome concept is not new. Beck describes its first publication in 1805, and lists a decision chart to use when a designer is considering bringing in a new exotic species. It is important first to look at one's own region as a source for vegetative materials (Beck, 2013).

Preserving biodiversity is seen by some scientists as one of the most pressing problems currently known (Rockström et al., 2009). Although biological diversity is a multi-scalar and wide-ranging topic, landscape architects often oversimplify it to mean simply the inclusion of nectar-producing plants for pollinators. However, many landscape architects have made a public commitment to preserve ecosystems, and even include a statement about supporting biodiversity in their project descriptions or marketing materials. To design with human and non-human habitat in mind, planners and designers must combine human needs with needs of plants, non-human animals, fungi, and bacteria. Although conservation and restoration are not appropriate for many project sites, landscape architects can better design for biodiversity if they are aware of it. The methodology presented in the next chapter outlines a way to make that happen.

Chapter Three

METHODOLOGY

3.1 Introduction

Landscape architecture is a broad discipline sharing boundaries with the allied professions of architecture, planning, and civil and environmental engineering. Research strategies and methods vary throughout and between these disciplines. Van den Brink, Bruns, Bell, and Tobi (2017) describe the research approach of landscape architecture by stating, "…much landscape architecture academic, doctoral, or commissioned research tends to look broadly at a problem from many angles but cannot (and often does not need to) dig so deeply into them" (p. 2). This chapter focuses on the research strategy, design, methods, and techniques employed to collect and analyze data for this study.

3.2 Research Strategy and Design

Because of the interdisciplinary nature of landscape architecture inquiry, mixed method studies are often used. Deming and Swaffield (2011) discuss research strategy and the importance of "multiple forms of knowing [which] are valuable and necessary in contributing to new knowledge in the field" (p. 13). This study incorporates mostly qualitative and some quantitative data to explore how landscape architects can better approach the assessment of biodiversity in the Dallas-Fort Worth area.

Qualitative data collected through in-depth interviews helps researchers to examine an issue in depth, and is established method of interdisciplinary research (Tobi & van den Brink, 2017). The qualitative data collection for this study are divided into two phases. In the first phase, interview data was collected from five biologists, ecologists, and naturalists with interests and research in plants of the Cross Timbers region, insects, mammals, and soil biology. Conversations were open-ended, but each subject was asked four main questions.

- What are your recommendations to landscape architects or others in the construction industry to promote a habitat which supports maximum biodiversity?

Because biologists and ecologists publish work in journals, many of their findings are not readily available to the public. This questions was meant to give the subject a chance to summarize his or her work and how it might apply to designers' work.

- Could you describe any involvement you have had in leading or participating in a BioBlitz {a 24-hour citizen-science event where species are observed and recorded}?

A review of literature showed that rapid assessment, or BioBlitz might be a good method for involving non-scientists in exploring diversity. Subjects were asked this question to determine if they could provide additional information for applying those methods to a group of non-scientists.

- Could you describe any research you have done in suburban or urban areas?

Because landscape architects often work in cities or suburbs, learning about research from local experts was important to determine what was studied, why, and how it might apply to habitat creation in a landscape architect's design.

- Could you recommend sources for a landscape designer or architect who is interested in promoting biodiversity?

Although scientists often publish in journals, they would be a good filter for designers to use to determine what information available to the public was good quality.

In the second phase, phone and in-person interview data from landscape architects involved in habitat restoration, preservation, or the use of native plants was collected. Subjects' projects included corporate headquarters, parks and natural areas, an Army Corps of Engineers floodway restoration, and rural residential projects. These conversations were also open-ended, but each subject was asked three main questions:

- Please describe any tools or techniques used for documenting any type of biodiversity in your firm's projects.

This question was meant to determine if any documentation of biodiversity occurred during the design process, and if so, what species designers were interested in, and how designers were determining species richness on site.

- What methods do you or colleagues use to research local biodiversity?

The answers designers gave to this question could be evaluated for rigor.

- How do local development or building codes help or hinder your choice of planting materials on projects?

The researcher's own experience in a non-profit design office affiliated with city planning department showed that codes could be a barrier to using native plant materials in a planting design.

Before each interview, the subject was emailed or read the Informed Consent documentation required by the Institutional Review Board (IRB) of the Regulatory Services Department of the University of Texas at Arlington. All subjects gave consent to be interviewed by signing the consent form or by verbally agreeing to participate in the study, as outlined in the IRB materials submitted and approved before contacted for interviews.

In addition to qualitative data, a limited set of quantitative data was collected from soil samples in three locations on and near campus. The top six inches of soil were taken from a “Polyculture” planting, St. Augustine turf, and a park with relatively undisturbed soil near an eroded stream. All three plots were sampled under Cedar Elm trees. These soils were sampled to assess one type of indicator fungus, arbuscular mycorrhizal fungi or AMF. AMF form associations with plant roots and are considered important to plant health and robustness (Prescott, Harley, & Klein, 2005). Agricultural studies have used AMF as indicators for biological activity in the soil (Mahecha-Vásquez, Sierra, & Posada, 2017; Säle et al., 2015).

Finally, the researcher led a mini BioBlitz biodiversity assessment with student subjects enrolled in a graduate Landscape Architecture Plant Identification course. The introduction, assessment of plants and animals, and a student opinion survey were conducted on the west side of the CAPPA building in the “Polyculture” mixed planting bed and took about two hours of class time. Each student brought a camera or smartphone to take photos, a pen or pencil, and was given a plastic petri dish and a plastic bag to serve as a one-size-fits-all glove to dig through the leaf litter and soil. Students also documented plant species and distribution as part of the regularly scheduled class.

3.3 Subject Recruitment Methods

Subjects for both sets of interviews were recruited through purposive, also called snowball or referral technique. Deming and Swaffield (2011) describe purposive sampling as seeking “data expected to be most helpful in addressing the research question” (p. 131). The initial subjects for both sets of interviews were selected based on word of mouth or internet searches. At the end of each interview, subjects were asked for referrals to other individuals who had an interest in biodiversity or quality habitat.

Interview subjects for the first group of this study were selected to represent a range of biological and ecological disciplines and experience in field biology collection techniques.

Interview subjects for the second stage of the study were chosen to represent landscape architects with an existing interest in biodiversity or habitat design.

3.4 Soil Sampling Methods

Sample locations were determined prior to the sampling date through discussion with a soil scientist and the committee chair. Materials needed for the sample collection were purchased ahead of the collection date. Cold packs were kept overnight in a residential freezer at approximately five degrees Fahrenheit. **Figures 7 and 10** show the Dutch auger and ice chest used.

Figure 7. Equipment used to dig soil sample. Polyculture visible in background

On the day of sample collection, standard Nalgene brand sample bottles were labeled with plot numbers. At each sample site, latitude and longitude were recorded, photos were taken of the surrounding vegetation, and soil texture was noted. A garden spade and a Dutch auger were used to dig a sample core approximately four inches in diameter. A ruler was used to verify each core was at least six inches deep. The soil was collected into a marked zip-top plastic bag and mixed thoroughly to create homogeneity in the sample. See **Figures 8 and 9,** below. The sample bottle was used to scoop up a sample, the threads were wiped clean with a paper towel, the cap was replaced, and the bottle was placed in a zip-top plastic bag, sealed, and placed in a cooler filled with frozen gel packs. This procedure was repeated at each site.

After all samples were collected, the filled cooler was sealed closed with packing tape and sent to the research lab for delivery the next morning.

Figure 8. Soil Sample C after homogenization.

Figure 9 showing depth of sample and labeled bottle

3.5 Mini BioBlitz Methods

The researcher led a mini BioBlitz during a regularly scheduled Plant Identification and Ecology class in the UTA landscape architecture program. Ten students participated, and students completed a paper survey after the mini BioBlitz to provide their opinions on the techniques used. Students used collection materials proved by the researcher, but plastic quadrats were provided by the professor, who was also the committee chair for this research. See **Figures 10 and 11** below.

Figure 10. Introduction to mini BioBlitz sampling methods. Photo by N. Dasa Gangadhar.

Figure 11. UTA students participating in mini-BioBlitz, October 12, 2017

3.6 Qualitative Data Analysis

Qualitative data analysis was used to draw conclusions from the interview transcripts. Key phrases within the conversations were marked and grouped according to relevance. Common themes within each group were identified and ranked. Keywords were determined by the researcher, and repetitions of those words noted.

3.7 Conclusion

Many methods exist for generating new knowledge in the field of landscape architecture research. Mixed-method research is commonly used in landscape architecture. This study uses qualitative data from interviews and quantitative data to study and propose solutions for the problem of determining the quality of habitat for plants and other biota in the region of North Texas. By identifying an easy-to-use assessment procedure for documenting biodiversity, this study helps give landscape architects tools to use when assessing habitat for both humans and nonhumans.

Chapter Four

Findings and Analysis

4.1 Introduction

This study examines techniques landscape architects may use to better assess biodiversity on a project site before and after completion of construction. The researcher collected qualitative data through interviews of two groups of subjects: a biologist group composed of biologists, ecologists, and naturalists, and a designer group composed of registered landscape architects and landscape designers. The researcher also collected data with a soil microbial analysis and a mini BioBlitz. Qualitative data was analyzed using both hand coding and software coding techniques. A small number of themes were identified from the interview transcripts and passages from the transcripts were assigned to a coding frame using qualitative content analysis described by Schreiner (2013). Findings from those interviews, soil samples, and the BioBlitz are described in this chapter.

4.2 Summary of Findings from interviews

The two sets of interviews were similar in that they covered a wide range of topics. In general, the biologist group gave recommendations to landscape architects with reasons for those actions and why they would be good for biodiversity. The designer group showed interest in designing for biodiversity but lacked knowledge about it. They often mentioned how they embraced biodiversity but were unable to list how they did that beyond a varied planting plan. During interviews, the designer group expressed little interest in using an assessment technique in their firms. The total number and interests of the subjects are shown in **Figure 12** below. Fifteen interviews were conducted from September 15 to October 20, 2017. Six of these were biologists or naturalists, and nine were landscape architects or designers

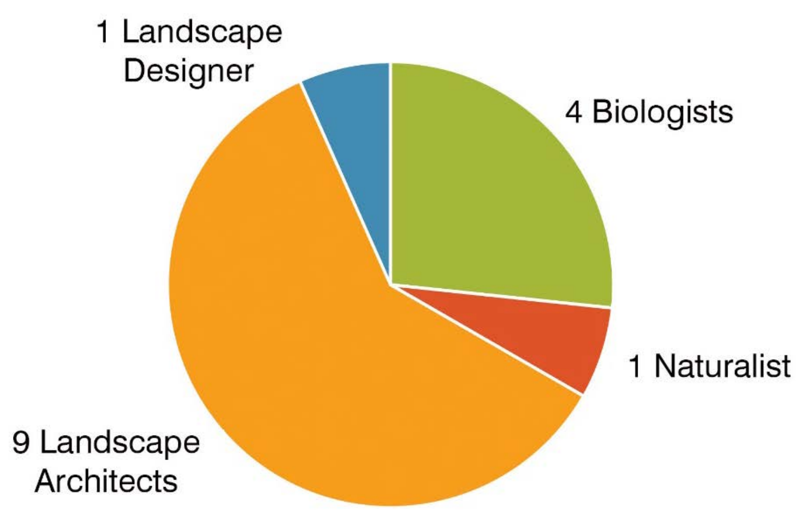

Figure 12 Interview Subjects by Interest or Profession

4.3 Responses from Biologist Group

Most respondents of the biologist group had strong opinions on what they saw as grave mistakes occurring in the built environment. Their responses are recorded below with the corresponding interview question.

1. ***What are your recommendations to landscape architects or others in the construction industry to promote a habitat which supports maximum biodiversity?***

Three major themes or domains emerged from the interviews in the biologist group. Subjects expressed the importance of keeping as much existing vegetation as possible on site unless it was considered an invasive pest, and using native alternatives to exotic plants, especially the local ecotypes wherever possible. This group also encouraged designers to consider the long-term effects of their design, not just how it looked in the short term.

While trees and other understory vegetation were considered important as a group because they provide cover for many ground-foraging birds, and protect soil from erosion, not all of the trees and shrubs were considered good to keep. Invasive woody plants such as ligustrum or privet species were best removed to allow the seeds from native plants already in the soil to germinate. Trees were also mentioned for their importance for harboring soil microorganisms.

Native plants were considered a basic requirement by all subjects in the biologist group because of their adaptations to the temperature fluctuations, day length, soil type, and animal life in the area. Many of the native plants in our area were food for some type of insect because of the chemistry of the vegetation or the timing of the flower production. Because Texas is important for butterfly migrations, having nectar from fall-blooming flowers was considered very important to the overall diversity of the area. The same thing was important for bird migrations. Nectar is important for hummingbirds, and other birds needed different types of food such as seeds, fruit, or insects.

Finally, subjects in the biologist group stressed the importance of long-term effects of design choices. Impermeable cover was considered as detrimental to the overall health of the region as exotic plant material. They stressed the importance of finding a way to make permeable paving work and one biologist suggested finding a way to subsidize the cost of installation until the price became lower.

2. ***Could you describe any involvement you have had in leading or participating in a BioBlitz {a 24-hour citizen-science event where species are observed and recorded}?***

Two of the subjects in the biologist group had led BioBlitzes, and another biologist had led college-level classes or groups of research students outdoors. One naturalist, subject 'E,' had participated in a BioBlitz at an area of land donated to a city for use as a park. Subject 'E' identified the dragonflies, damselflies, and some moths and butterflies for the group. This particular event was meant to identify species so that the city could make good decisions about where features, such as walking paths and picnic tables, would be located.

3. Could you describe any research you have done in suburban or urban areas?

- "…Looked at small mammals and associated plants…"
- "I identify dragonflies and damselflies in the order Odonata."
- "…Soil biology, specifically with how carbon sequestration is affected by agricultural methods. I am also involved in methane production in soils due to land use, really more of agricultural, but it affects air quality everywhere."
- "I have looked at just about everything but am most interested in riparian habitats. They are disappearing fast."

4. Could you recommend resources for a landscape designer or architect who is interested in promoting biodiversity?

Subjects offered many resources for further investigation into biodiversity. Journals such as the *Texas Journal of Science* and publications by the Botanical Research Institute of Texas were mentioned as valuable sources. One biologist recommended the many herbaria in Texas as sources to investigate local ecotypes. State biological surveys were also recommended for other states, because many species overlap political boundaries and most areas within Texas have not been formally surveyed. While valuable to scientists, some of these resources are not available to the public and others are not self-explanatory. For a herbarium to be useful, one must spend time researching a species before the information contained on a single plant might be useful. Some specimens of the herbaria are available online, but others require special permission to visit. The *Texas Journal of Science* is not available without a subscription or database access for online articles.

Sources more easily accessible by the public included the USDA plants database, Master Naturalist meetings, and publications by river authorities such as the Nueces River Authority. The river authority publications were targeted to land owners, and information contained in them was relevant to the needs of a landscape architect or designer when designing a landscape in a riparian area.

When asked about assessment methods, most biologists referred to their own published work regarding assessment and capture techniques. They used standard documented techniques aimed at collecting their target range of species, so some of the collection techniques were very narrow. Some involved specialized equipment such as very fine large nets, lights, or required overnight installation. Insect collection involved sweep nets, pitfall traps, and Malaise traps, shown in **Figures 13 through 15**, below, but insect observation and documentation was also used in some studies. Randomizing locations were considered important for determining plant species. Overall, repeatability was most important to the biologists so that the sets of data from year to year could be compared.

Figure 13. Sweep Net. Image: Amateur Entomologists' Society

Figure 14. Pitfall traps. Left image: Wikimedia Commons. Right image: Fieldmaster®

Figure 15. Malaise trap. Image: National Parks Service

4.4 Responses from the Designer Group

Information about the size of firms, the years of experience, and the types of work each subject is shown in **Figure 16** below:

Subject code	Years as registered LA/ years in landscape design	Size of firm
D	37	1
F	0/6	1
G	38	3
H	37	30
J	10/14	2
K	37	9
L	10/12	30
N	3/6	9
O	10/12	30

Figure 16 Experience of subjects in designer group.

Many of the respondents in this group discussed how they considered biodiversity in the design of projects in the area. Only one landscape architect showed interest in using assessment techniques at the firm

1. ***Please describe any tools or techniques used for documenting any type of biodiversity in your firm's projects.***

Many respondents replied that a good site analysis documents soil types, drainage, and vegetation. Two projects outside of the North Central Texas region were mentioned as examples of sensitive habitat where migratory birds nested. In those projects, the landscape architects involved deferred to wildlife biologist consultants.

2. What methods do you or colleagues use to research local biodiversity?

Every landscape architect office had a different approach to researching habitat or plant data. One office relied heavily on online catalogue information published by an out-of-region nursery, Mountain States Wholesale Nursery. Some practitioners no longer looked for new resources, but relied upon an established plant palette. Other designers looked to colleagues for information. Large scale habitat or restoration projects usually included wildlife biologists and habitat specialists on the team, and those people served as a resource for the landscape architects. Subject K listed several sources: "websites of growers that we know – Native American Seed, tree growers, native plant growers. Also for info - Lady Bird Johnson Wildflower, Texas Parks and Wildlife for invasive plant list, USDA website, BRIT and others." The complete list is as follows:

- Master naturalist classes
- Wildflower Center Native Plants Database
- Colleagues
- Past experience only
- Nursery supplier information
- Wildlife biologists on project team

3. How do local development or building codes help or hinder your choice of planting materials on projects?

Responses varied by location of projects and jurisdiction of governmental entities. Some cities required twenty-four inch high evergreens to screen parking around commercial parking lots. Other municipalities as one subject put it "…way out in the boonies... " had little restriction on plant materials and the designer could use what he or she wished.

4.5 Soil Analysis results

DNA analysis showed that the number of base pairs corresponding to arbuscular mycorrhizal (AM) fungus varied along a gradient with the most abundance found in the polyculture and the least abundance found in the control. The researcher had originally surmised that the undisturbed area would have the highest fungal abundance, but when the soil sample was taken, the soil was dry, sandy, and did not harbor much organic matter. This sample was shown to have the least abundance of AM fungi, most likely due to its quick drainage. See **Figure 17**.

Figure 17 Soil samples. Left to right: A Polyculture, B St. Augustine turf, and C, Sandy soil typical for Arlington, Texas.

The number of AM fungus DNA copies per gram of soil for the three samples are shown below in **Figure 18**:

Sample A	121,797,816	Located in "Polyculture"
Sample B	118,074,203	Located in "weedy" St. Augustine turf
Sample C	58,120,966	Located in nearby non-irrigated park

Figure 18 showing numbers of DNA copies of AM fungus per gram of soil

4.6 Trial BioBlitz Findings

Students found about 35 species of plants and animals from 8 taxonomic groups during the two hours of class activity, as shown in **Figure 19.**

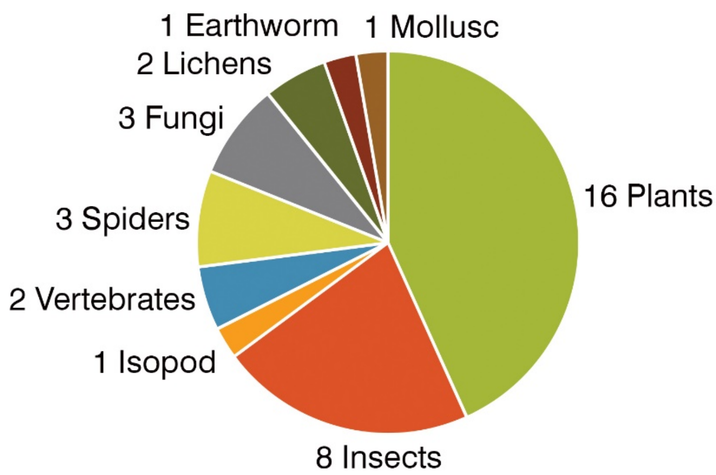

Figure 19 Distinct species of organisms found during class mini BioBlitz. Grouped by type.

Almost every student found mature isopods and earwigs in various stages of life. The two vertebrates observed were humans and an anole lizard, which had perched near the blooming Dicliptera to feed on flying insects attracted to the nectar of the flowers. Students also photographed two types of wasps and three types of spiders. Most students captured and photographed earthworms, but only one group of students photographed an orange beetle and a white spider. The paper surveys filled out by students indicated that about half of the students enjoyed observing the crawling or wiggling organisms most and about half enjoyed finding plants the most.

4.7 Analysis of Findings from all Sources

4.7.1 Use of terms

Biologists and landscape architects used the term “biodiversity” to mean different things. One landscape architect asked for a definition of the term, but most others used the term biodiversity as meaning “not a monoculture” or sometimes referred to a variety of planting materials to provide pollinator food sources. No landscape architect referred to a more in-depth meaning or mentioned different types of small life other than pollinators. Biologists rarely used the term “biodiversity” but when they did, they referred to its type, such as “ecological biodiversity” “functional biodiversity” or “genetic biodiversity.”

4.7.2 Concerns of Landscape Architects and Designers

Landscape architects’ responses varied in approaches to their design, the type of projects they worked on, and to barriers to the use of native plants. Few practitioners were interested in biodiversity beyond the use of native plant material, although some did mention the desire to incorporate plants specifically for pollinators. No landscape architect mentioned diversity of birds or types of invertebrates, even when prompted by the researcher.

4.7.3 Suitability of Specific Assessment Techniques

For plants and small, slow-moving creatures such as snails and isopods (woodlice) a quadrat method of sampling was sufficient because these are easily picked up by hand. For small areas such as parking lot islands, a square meter quadrat, or even a hula hoop, suffices to define the count boundary.

“BioBlitzes” require a few easily available tools: plastic dishes to collect ground-dwelling invertebrates, a good camera for photos, a device for recording latitude and longitude, and a clipboard for note taking. The iNaturalist smartphone application is particularly well suited as a tool for BioBlitzes. The iNaturalist organization began as the Master's final project of students at UC Berkeley's School of Information in 2008. The iNaturalist smartphone application verifies species through crowdsourcing experts and tallies information by area automatically. Because a BioBlitz can be held for any length of time, it is adaptable to the needs of a professional office.

4.7.4 Awareness of Restrictions

The biologist group was not aware of municipal building and construction codes or the restrictions imposed by codes, nor aware of which projects might be designed and which projects were installed by contractors according to minimums required by code. This is important when regarding how biologists might share their knowledge. If they are not aware of the construction process, they will not know where to direct their concerns and may inadvertently assign blame to the wrong party.

4.8 Conclusion

This study approached the question of how to quickly and simply assess biodiversity in a way usable by landscape architecture firms.

The interviews showed that biologists, ecologists, and naturalists want to see as many wild places and weedy areas remain as possible because they see the value of those areas to provide food and habitat to the small flowers and prey which support larger insects and birds. Most of the professionals interviewed were abstractly aware of habitat, but were not aware of how development adversely affects that habitat. Most were not engaged enough with natural cycles to *want* to know more about the actual measurable impact of development upon habitat.

A simplified BioBlitz, or rapid biological assessment, is shown to be suitable as an assessment technique because it requires little specialized knowledge or equipment, can be conducted over a long lunch break, and takes advantage of expert crowdsourcing to identify small organisms. This technique was demonstrated to provide quantifiable results; even in the highly developed campus area, many types of small life were easily found. Although most landscape architects reacted negatively to the idea of including biological assessment in their firms, they did express interest in incorporating biodiversity into their designs.

Chapter Five

Conclusions

5.1 Introduction

This study approached the question of how to quickly and simply assess biodiversity in a way usable by landscape architecture firms. The research focused on obtaining qualitative data from interviews with two groups of people experienced in the North Central Texas region as defined by the North Central Texas Council of Governments. Data was collected in three areas. Qualitative data was collected from in-depth interviews conducted with biologists, ecologist, naturalists, landscape architects, and designers. A trial BioBlitz was conducted using hand collection techniques, and soil fungus data was collected from three sites. This chapter discusses the findings from those three sets of data, presents the significance of this study to the field of landscape architecture, and concludes with suggested areas for future research into this topic.

5.2 Responses to Research Questions

The research questions were addressed by looking at the range of answers provided by the two groups of surveys and by the BioBlitz trial.

- Which techniques, used by biologists and ecologists, can best be adapted for use in a landscape architecture practice to measure biodiversity on project sites?

Many techniques are used in ecological or biological research; the specific technique depends upon the species studied. Some researchers used a specific technique for collecting only one species. Others used general techniques to collect a narrow type of organisms, such as only high flying, low flying or ground dwelling insects.

A landscape architecture firm interested in assessing biodiversity could invest a small amount of time and a few tools to conduct a mini-BioBlitz using hand collection or even a sweep net technique. The exercise could be held any time of day and would need only a container for holding organisms, a good camera and a phone application to crowdsource species identification. Although this technique would assess only a small range of species present, it would be a useful way for non-scientists to become interested in and to continuously learn about the larger role of those visible organisms in other types of diversity.

- Have landscape architects in North Central Texas committed to promoting an understanding of biodiversity within their firms?

In general, biodiversity is not a high priority for the landscape architects interviewed in this region. Although most of the landscape architects interviewed responded positively when asked to describe how they included biodiversity considerations in a project's design, they simply listed how they avoided monoculture planting materials, or tried to use native plants where possible. One office expressed interest in using a biodiversity assessment technique in their firm, but most did not consider biodiversity something that was not already assessed and addressed.

5.3 Discussion of Findings

There is a clear lack of understanding about the breadth of biodiversity among the landscape architects interviewed, although there is a general positive attitude towards supporting biodiversity. Education certainly plays a role in this lack of understanding; designers with architecture backgrounds may not ever have had exposure to important ecological concepts such as food webs or the life cycles and migrations of birds and insects. Three landscape architects were interviewed in the firm that expressed interest in a biodiversity assessment technique. Of those three, the two with the least number of years in practice had more interest in and knowledge of biodiversity than the principal in the firm, who had acquired thirty-seven years as a registered landscape architect. If the profession considers education important, it may be more beneficial to target the older generation of designers who hold influence as decision-makers in their firms.

Some aspects of living things are more appealing to people than others. Monarch butterflies are often a popular topic in Texas, but spiders are not. Many organisms are not do not have good connotations, and are avoided. It is important for non-biologists to learn that stinging, biting, and hunting organisms, although unpleasant to some people, are important for ecological cycles and need consideration in designs if those designs are to support biodiversity.

Biologists, ecologists, and naturalists in general answered that the less disturbance made on a construction site, the better for providing habitat. Allowing existing trees to remain was important not only for their shade, but for the soil biota held around their roots. Keeping the native understory wherever possible was also important, and native plants in general were important to keep established cycles of feeding intact. However, the biologist group did not consider the degraded state of, and the invasive plants present at, many construction sites. Landscape architects must often address sites with no suitable vegetation remaining. While it is useful for a designer to keep the biologists' suggestions in mind, they must often address the rebuilding of habitat for diverse species from the ground up and mimicking what was on site in the past is often not possible.

Where vegetation must be replaced, biologists suggested planning for almost year-round supplies of nectar on various types and sizes of flowers, various types of seeds and berries for non-pollinators, and a variety of native plants for herbivores. One interview subject suggested finding ways to incorporate even the ugly native plants into a cohesive and attractive design.

The results of the soil AM fungus quantities demonstrate how humans can alter the biota of an area. Because the relatively undisturbed soils in the area are sandy, they dry out quickly and harbor a different population of AM fungus than the soils containing more humus. More fungal species are likely available to plants where the soil has been amended and seeded with fungal species present in the transplants and compost applied to the area (A. Somenahally, personal communication, Nov. 9, 2017). Even though this particular site has had no soil amendments since its initial installation two years ago, a rich fungal flora is present.

The results of the mini-BioBlitz demonstrated that this simple technique worked to rapidly assess vertebrates and invertebrates on the site. Even though it does not address many types of biodiversity, it is still a good way to encourage individuals to go outside and get involved in observations. Physical involvement can lead to better appreciation and desire to learn about local ecology.

5.4 Significance to Landscape Architecture

Landscape architects can use this research as another way to set their profession apart from allied fields such as architecture, environmental engineering, and planning. Because landscape architecture involves many scales of landscape and human experience, the profession could be well suited to bridging the divide between what is known to ecology and how to build a landscape that incorporates the many needs of nonhumans and humans.

The tallgrass prairie present in our area before European settlement cannot be restored to areas of urban and suburban development for many reasons. Most significant of these is the unsuitability of wide areas of large shrubs, grasses, and forbs to outdoor human activities such as sports or dog walking. Also significant is the number of prairie annuals which require large areas to reproduce by seed each year (Hopman, 2016b). landscape architecture can bring in a better understanding of the important link between plants native to this area of Texas and the species who have evolved to feed on or nest in that vegetation. A current trend in landscape architecture is to plan for resiliency, which in landscape architecture means designing for floods, tough plant materials, and unpredictable weather patterns. Understanding and designing for many species rather than only a few species or monocultures is another vitally important way to plan for resiliency.

5.5 Future research

A. Study of microclimates and microhabitat in urban environments: How does global warming and the urban heat island effect impact the urban food web? Brown and Gillespie (2017) discuss the need for the examination of habitats as part of microclimate and suggest that “Research is required to understand the microclimatic needs of both flora and fauna in urban areas so that future designs can provide appropriate habitat” (p. 254).

B. How do building and development codes of the North Central Texas counties limit or encourage plant diversity by using native plants? Several interview subjects mentioned that the plant lists for smaller cities within the study area were restrictive or outdated, but that the Fort Worth and Dallas codes were changing for the better. It would be informative to study these codes, find out the reasoning behind them, and look at the municipal support for or against change. Whether school districts or municipalities, there were plant restrictions mentioned in the interviews. It is clear that these are not based on ecological concepts, but what are they based on and how could they be changed?

C. What are the goals of landscape architects involved in writing code or landscape design guidelines for public or permitting agencies? Were they written based on availability of plants, appearance, water use, or value as habitat and food sources, and how were each of these factors weighed in making decisions?

D. How much has been written on urban nature? A literature review of urban ecology and urban design fields is needed. (Spirn, p. 66)

E. It would be useful to study a wide range of the site analysis documents mentioned in the landscape architect-group interviews and see what types of analysis are documented. It makes sense that an ecologically sensitive area, such as a nature center, would have an assessment of living things, but the argument of this researcher is that we must incorporate an ecologically sensitive mentality and apply it to all development. Commercial parking lots cover much of our land, and can be a welcoming haven to a few species of life. Small changes can lead to larger changes, and parking lots might become an important stopover habitat for migratory animals.

F. How can landscape architects advocate for and assist with completion of a biological survey of our area? Ian McHarg suggested completing an entire listing of the biological survey of the United States. In our region, that does not yet exist, although parts of it have been started (Rosiere, Nelson, & Cowley, 2013). The Biota of North America Program is active in this area.

G. How could familiarity with the construction process help biodiversity advocates in the biologist group target their efforts in a fruitful direction?

H. In this country, how important do landscape architects hold biodiversity overall? What are the regional differences in attitudes?

I. How adaptable is the BioBlitz to the needs of a professional office?

5.6 Conclusion

Although research shows that biodiversity in urban areas declines towards the city center, the skills and knowledge of landscape architects can help to shift that gradient. Urban centers can host trees, native understory, associated invertebrates, birds, lizards, and other animals. Larger patches in less dense areas outside the city center can harbor a wider array of plants and animals. This research has discussed how many of these very small organisms, which are often unnoticed, can be important to the overall ecological health of a region. Findings from this study indicate that information about the interconnections of complex food webs are not readily available to landscape architects and designers in the North Texas region. Although the ecologists interviewed are concerned about habitat loss to development, they have not shared information about habitat mitigation with professionals in the landscape design fields interviewed for this study.

Findings from this study also indicate that an assessment of the variety of visible organisms on a site can be done in a short amount of time. Decision-makers in landscape architecture firms could incorporate a short biological assessment into their standard site analysis to engage both clients and staff with the needs of non-humans in the design development process. Landscape architects should take the leadership role to assess biodiversity and disseminate ecological research to their clients and to the general public.

References

Ahern, J., Leduc, E., and York, M. L. (2006). *Biodiversity planning and design*. Washington, DC: Island Press.

Alberti, M., Marzluff, J. M., Shulenberger, E., Bradley, G., Ryan, C., & ZumBrunnen, C. (2008). Integrating humans into ecology: Opportunities and challenges for studying urban ecosystems. In Marzluff, J. M., Shulenberger, E., Endlicher, W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., Simon, U. (Eds.) *Urban ecology: An international perspective on the interaction between humans and nature* (pp.143-158). New York: Springer.

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O. U., Swartz, B., Quental, T. B., . . . Ferrer, E. A., (2011). Has the earth's sixth mass extinction already arrived? *Nature*, 471(7336), 51. doi:10.1038/nature09678

Beatley, T. (2011). *Biophilic cities: Integrating nature into urban design and planning*. Washington, DC: Island Press.

Beck, T., (2013). *Principles of ecological landscape design*. Washington, DC: Island Press.

Beckham, J. L., Warriner, M. D., Atkinson, S. F., Kennedy, J. H. (2016). The persistence of bumble bees (Hymenoptera: Apidae) in northeastern Texas. *Proceedings of the Entomological Society of Washington*. 118(4):481-497. https://doi.org/10.4289/0013-8797.118.4.481

Braaker, S., Obrist, M. K., Ghazoul, J. and Moretti, M. (2017), Habitat connectivity and local conditions shape taxonomic and functional diversity of arthropods on green roofs. Journal of Animal Ecology, 86: 521–531. doi:10.1111/1365-2656.12648

Brown, R. D., & Gillespie, T. J. (2017). Thermally comfortable urban environments. In A. van den Brink, D. Bruns, H. Tobi & S. Bell (Eds.), *Research in landscape architecture: Methods and methodology* (pp.263-284). New York: Routledge.

Calkins, M. (2011). *The sustainable sites handbook*. Hoboken, NJ: John Wiley & Sons, Inc.

Campbell, L. (1995). *Endangered and threatened animals of Texas: Their life history and management*. Austin, TX: Texas Parks & Wildlife, Resource Protection Division, Endangered Resources Branch.

Covich, A. P. (2004). Ecosystem processes and the sustainable delivery of goods and services. In Wall, D. H. (Ed.). *Sustaining biodiversity and ecosystem services in soils and sediments*. (pp.13-14). Washington, DC: Island Press.

Day, S. D., & Amateis, R. L. (2011). Predicting canopy and trunk cross-sectional area of silver linden (Tilia tomentosa) in confined planting cutouts. Urban Forestry & Urban Greening, 10(4), 317-322.

Deming, M. E., & Swaffield, S. (2011). *Landscape architecture research: Inquiry, strategy, design*. Hoboken, NJ: John Wiley & Sons, Inc.

Dramstad, W. E., Olson, J. D., & Forman, R. T. T. (1996). *Landscape ecology: Principles in landscape architecture and land-use planning*. Washington, DC: Island Press.

Dumitrascu, M., Stanica, F., Gala, R., & Manescu, C. (2012). Studies regarding the behavior of some ornamental plants in large parking lots [electronic resource]. Accessed November 26, 2017. *Acta Horticulturae*, (9372), 1089-1092.

Eidson, J. & Smeins, F. E. (1999). Texas blackland prairies. In T. Ricketts, E. Dinerstein, D. Olson, C. Loucks, W. Eichbaum, D. DellaSalla,...S. Walters (Eds.). *Terrestrial ecoregions of North America: A conservation assessment*. Washington, DC: Island Press.

Fattorini, S. (2011). Insect extinction by urbanization: A long term study in Rome. *Biological Conservation, 144*(1), 370-375. doi:10.1016/j.biocon.2010.09.014

Foster, M. A., Muller, L. I., Dykes, S. A., Pete Wyatt, R. L., & Gray, M. J. (2013). Efficacy of BioBlitz Surveys with Implications for Sampling Nongame Species. *Journal of the Tennessee Academy of Science*, 88(3/4), 57-63.

Gaston, K. J., & Spicer, J. I. (2004). *Biodiversity: An introduction.* Malden, MA: Blackwell Publishing Company.

Gibb, H., & Hochuli, D. F. (2002). Habitat fragmentation in an urban environment: Large and small fragments support different arthropod assemblages. *Biological Conservation*, 106(1), 91-100. doi:10.1016/S0006-3207(01)00232-4

Green, J. (2010). Restoring the balance between people and nature through wildlife habitat design. [Weblog]. Retrieved from https://dirt.asla.org.2015/05/20/restoring-balance-between-people-and-nature-through-wildlife-habitats

Gries, C. (1996). Lichens as indicators of air pollution. In Nash III, T. H. (Ed.). *Lichen biology*. (pp. 240-254). New York: Cambridge University Press.

Griffith, G., Bryce, B., Omernik, J., & Rogers, A. (2007). *Ecoregions of Texas*. Austin, Texas: Texas Commission on Environmental Quality.

Hall, D. M., Camilo, G. R., Tonietto, R. K., Ollerton, J., Ahrné, K., Arduser, M., . . . Threlfall, C. G. (2017). The city as a refuge for insect pollinators. *Conservation Biology,* 31(1), 24-29. doi:10.1111/cobi.12840

Hopman, D., (2016). *Future viable plant palettes for metropolitan areas, part 10*. [Weblog]. Retrieved November 2 2016 from: https://thefield.asla.org/tag/david-hopman/

Hopman, D., (2016b). *Future viable plant palettes for metropolitan areas, part 5*. [Weblog]. Retrieved December 4 2017 from: https://thefield.asla.org/tag/david-hopman/

Hunter, M.C., & Hunter, M.D. (2008). Designing for conservation of insects in the built environment. *Insect Conservation and Diversity*, 1(4): 189-196.

Kline, V. M. (2005). Orchards of oak and a sea of grass. In S. Packard & C. F. Mutel (Eds.), *The tallgrass restoration handbook: For prairies, savannas, and woodlands*. (pp. 3-21). Washington, DC: Island Press.

Kowarik, I. (2011). Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution*, 159(8), 1974-1983. doi:10.1016/j.envpol.2011.02.022

Kühn, I., & Klotz, S. (2006). Urbanization and homogenization – Comparing the floras of urban and rural areas in Germany. *Biological Conservation*, 127(3), 292-300. doi:10.1016/j.biocon.2005.06.033

Landscape Architecture Foundation. (2016). *New Landscape Declaration*. Retrieved November 5, 2016 from: http:// lafoundation.org/news-events/2016-summit/new-landscape-declaration

Landscape Architecture Foundation. (n.d.) About landscape performance. Retrieved November 2, 2017 from https://landscapeperformance.org/about-landscape-performance

Leake, J. R., Johnson, D., Donnelly, D. P., Boddy, L., & Read, D. J. (2005). Is diversity of mycorrhizal fungi important for ecosystem functioning? In R. D. Bard, M. B. Usher, & D. W. Hopkins (Eds.). *Biological diversity and function in soils*. (pp. 216-235). New York: Cambridge University Press.

Lovejoy, T. E. (1997) Biodiversity: What is it? In Reaka-Kudla, M. L., Wilson, D. E., & Wilson, E. O. (Eds.) *Biodiversity II: Understanding and protecting our biological resources*. Washington, DC: Joseph Henry Press.

Lovell, S. T., & Johnston, D. M. (2009). Designing Landscapes for Performance Based on Emerging Principles in Landscape Ecology. *Ecology & Society*, 14(1), 1-24.

Lowenstein, D. M., Matteson, K. C., Xiao, I., Silva, A. M., & Minor, E. S. (2014). Humans, bees, and pollination services in the city: the case of Chicago, IL (USA). *Biodiversity and Conservation*. 23(11). 2857-2874.

MacNeal, D. (2017). *Bugged: The insects who rule the world and the people obsessed with them*. New York: St. Martin's Press.

Mahecha-Vásquez, G., Sierra, S., & Posada, R. (2017). Diversity indices using arbuscular mycorrhizal fungi to evaluate the soil state in banana crops in Colombia. Applied Soil Ecology, 10932-39. doi:10.1016/j.apsoil.2016.09.017)

Marzluff, J. M., Shulenberger, E., Endlicher, W., Alberti, M., Bradley, G., Ryan, C., ZumBrunnen, C., & Simon, U. (Eds.) (2008). *Urban ecology: An international perspective on the interaction between humans and nature*. New York: Springer.

Matlock, M. D., & Morgan, R. A. (2011). *Ecological engineering design : Restoring and conserving ecosystem services.* Retrieved from http://ebookcentral.proquest.com

McKinney, M. L. (2002). Urbanization, biodiversity, and conservation. *BioScience.* 52(10): 883-890. doi:10.1641/0006-3568(2002)052[0883:ubac]2.0.co;2

McKinney, M. L. (2006). Urbanization as a major cause of biotic homogenization. *Biological Conservation*. 127(3), 247-260. doi://doi.org/10.1016/j.biocon.2005.09.005

Metzner, J., (2017, September 22). Invisible web of the rainforest. Pulse of the planet podcast. Retrieved October 19, 2017 from: https://www.pulseplanet.com/dailyprogram/dailies.php?POP=6670

Mooney, H. A. (2004) Foreword. In D. H. Wall (Ed.), Sustaining biodiversity and ecosystem services in soils and sediments (pp. xv-xvi).Washington, DC: Island Press.

Mora, C., Tittensor, D. P., Adl, S., Simpson, A. G. B., & Worm, B. (2011). How many species are there on Earth and in the ocean? *PLoS Biology*. 9 (8): e1001127 DOI: 10.1371/journal.pbio.1001127

Muratet, A., Porcher, E., Devictor, V., Arnal, G., Moret, J., Wright, S., & Machon, N. (2008). Evaluation of floristic diversity in urban areas as a basis for habitat management. *Applied Vegetation Science*, 11(4), 451-460. doi:10.3170/2008-7-18530

Naeem, S., Duffy, J. E., Zavaleta, E. (2010). The functions of biological diversity in an age of extinction. Science 336 (6087), pp. 1401-1406. DOI: 10.1126/science.1215855

Nash, T. H., III. (1996a) Nitrogen, its metabolism and potential contributions to ecosytems. In T. H. Nash III, (Ed.). *Lichen biology*. (pp. 121-135). New York: Cambridge University Press.

Nash, T. H., III. (1996b) Nutrients, elemental accumulation, and mineral cycling. In T. H. Nash III (Ed.). *Lichen biology*. (pp. 136-153). New York: Cambridge University Press.

Nilon, C. H., Aronson, M. F. J., Cilliers, S. S., Dobbs, C., Frazee, L. J., Goddard, M. A., . . . Yocom, K. P. (2017). Planning for the future of urban biodiversity: A global review of city-scale initiatives. *Bioscience*, 67(4), 332-342. doi:10.1093/biosci/bix012

North Central Texas Council of Governments. (2014). Regional Ecosystem Framework Update. Accessed 13 September, 2017 at: http://www.nctcog.org/traces/ref/REF-Update-Doc-Appendix-12.4.15.pdf

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., …& Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. *Bioscience, 57*(10), 823-833. doi:10.1641/B571005

Oehl, F, Laczko, E., Bogenrieder, A., Stahr, K., Bosch, R., van der Heijden, M, & Sieverding, E. (2010). Soil type and land use intensity determine the composition of arbuscular mycorrhizal fungal communities. Soil biology & biochemistry. 42 (5). 724. doi: 10.1016/j.soilbio.2010.01.006

Prescott, L. M., Harley, J. P., & Klein, D. A. (2005). *Microbiology*. (6th ed.) New York: McGraw-Hill.

Prior, K. M., Saxena, K., Frederickson, M. E., (2014) Seed handling behaviors of native and invasive seed-dispersing ants differentially influence seedling emergence in an introduced plant. *Ecological Entomology* 39(1): 66–74. doi: 10.1111/een.12068

Raven, P. H., Evert, R. F., Eichhorn, S. E. (1997). *Biology of Plants*. (5th ed.) New York: Worth Publishers.

Raven, P. H., Johnson, G. B., Losos, J. B., Mason, K. A., & Singer, S. R. (2008). Biology. New York: McGraw-Hill.

Ricklefs, R. E. (2000). *The economy of nature (5th ed.).* New York: Freeman.

Rockström, J., Steffen, W., Noone, K., Persson, A.,Chapin, F. S. III, Lambin, E., …Foley, J. (2009) Planetary boundaries: Exploring the safe operating space for humanity. *Ecology & Society*, 14(2).

Rosiere, R. E., Nelson, A. D., & Cowley, L. P. (2013). Composition and structure of a mixed-hardwood bottomland forest in the West Cross Timbers of North-Central Texas. *The Southwestern Naturalist*. 58(1), 81–90.

Säle, V., Aguilera, P., Laczko, E., Mäder, P., Berner, A., Zihlmann, U., & ... Oehl, F. (2015). Impact of conservation tillage and organic farming on the diversity of arbuscular mycorrhizal fungi. *Soil Biology & Biochemistry*, 38-52. doi:10.1016/j.soilbio.2015.02.005

Samson, F., & Knopf, F. (1994). Prairie conservation in North America. *BioScience*,44 (6): 418-421. doi: 10.2307/1312365

Savage, A. M., Hackett, B., Gunard, B., Youngsteadt, E. K., & Dunn, R. R. (2015). Fine-scale heterogeneity across manhattan's urban habitat mosaic is associated with variation in ant composition and richness. Insect Conservation & Diversity, 8(3), 216-228. doi:10.1111/icad.12098

Seastedt, T., & Crossley, D. (1984). The influence of arthropods on ecosystems. BioScience, 34(3), 157-161. doi:10.2307/1309750

Smith, L., Broyles, M., Larzleer, H., & Fellowes, M. (2015). Adding ecological value to the urban lawnscape: Insect abundance and diversity in grass-free lawns. Biodiversity and Conservation, 24(1), 47-62. doi:10.1007/s10531-014-0788-1

Spirn, A. W. (2016). The granite garden: Where do we stand today? In F. R. Steiner, G. F. Thompson, & A. Carbondell (Eds.), Nature and cities: *The ecological imperative in urban design and planning*. pp. 50-67). Cambridge, MA: Lincoln Institute of Land Policy.

Steiner, F., (2011). Landscape ecological urbanism: Origins and trajectories. Landscape and Urban Planning. 100(4), 333-337. doi:10.1016/j.landurbplan.2011.01.020

Texas Parks and Wildlife Department. (2016). [Interactive map with reports and lists of species for all counties in Texas July, 2017] *Rare, Threatened, and Endangered Species of Texas by County*. Retrieved from: http://tpwd.texas.gov/gis/rtest/

Texas Parks and Wildlife Department. (2017). [website listing resources on Texas conservation for the public] *Texas Nongame and Rare Species Program*. Retrieved from: https://tpwd.texas.gov/huntwild/wild/wildlife_diversity/nongame/

Thompson, George F. and Frederick R. Steiner, eds. *Ecological Design and Planning*. New York: John Wiley and Sons, Inc.1997.

Tobi, H., & van den Brink, A. (2017). A process approach to research in landscape architecture. In A. van den Brink, D. Bruns, H. Tobi & S. Bell (Eds.), *Research in landscape architecture: Methods and methodology*. (pp.24-34). New York: Routledge.

Tonietto, R., Fant, J., Ellis, J., & Lenkin, K. (2011). A comparison of bee communities of Chicago green roofs, parks and prairies. *Landscape and urban planning*. 103(1). 102-108.

Tzoulas, K., & James, P. (2010). Making biodiversity measures accessible to non-specialists: An innovative method for rapid assessment of urban biodiversity. *Urban Ecosystems, 13*(1), 113-127. doi:10.1007/s11252-009-0107-x

United States Geological Survey. (2016) Earthshots: Satellite images of environmental change. Retrieved November 16, 2017 from https://earthshots.usgs.gov/earthshots/Dallas-Texas#ad-image-2

USDA Natural Resources Conservation Service. Retrieved November 1, 2016 from: https://www.nrcs.usda.gov/Internet/FSE_MEDIA/nrcs142p2_049822.jpg van den Brink, A., Bruns, D., Bell, S., & Tobi, H. (2017). Introduction. In A. van den Brink, D. Bruns, H. Tobi & S. Bell (Eds.), *Research in landscape architecture: Methods and methodology* (pp.1-8). New York: Routledge.

Vitousek, P. M., Mooney, H. A., Libchenco, J., Melillo, J. M. (1997). Human Domination of Earth's Ecosystems. In Marzluff, et al. (Eds.) *Urban Ecology: An international perspective on the interaction between humans and nature* (pp. 3-13). New York: Springer.

Wall, D. H., Bardgett, R. D., Covich, A. P., & Snelgrove, P. V. R. (2004). The need for understanding how biodiversity and ecosystem functioning affect ecosystem services in soils and sediments. In D. H. Wall (Ed.) *Sustaining biodiversity and ecosystem services in soils and sediments*. (pp. 1-12). Washington, DC: Island Press.

Wall, D. H., Fitter, A. H., & Paul, E. A. (2005). Developing new perspectives from advances in soil biodiversity research. In Bard, R. D., Usher, M. B., & Hopkins, D. W. (Eds.). *Biological diversity and function in soils*. New York: Cambridge University Press.

Wardle, D. A., Brown, V. K., Behan-Pelletier, V., St. John, M., Wojtowicz, T., Badgett, R. D.,….Wall, D. H. (2004). Vulnerability to global change of ecosystem goods and services driven by soil biota. In Wall, D. H. (Ed.). *Sustaining biodiversity and ecosystem services in soils and sediments*. (pp. 101-120). Washington, DC: Island Press.

Wheater, C. P., Bell, J. R., & Cook, P. A. (2011). *Practical Field Ecology: A project guide*. Hoboken, NJ: Wiley-Blackwell.

Williams, N. S. G., Lundholm, J., Scott MacIvor, J., & Fuller, R. (2014). Do green roofs help urban biodiversity conservation? *Journal of Applied Ecology*, *51*(6), 1643-1649. doi:10.1111/1365-2664.12333

Willmer, P. (2011) *Pollination and Floral Ecology*. Princeton, NJ: Princeton University Press.

Wilson, E. O. (2016). *Half-Earth: Our planet's fight for life*. New York: Liveright Publishing Corporation.